Acid Sulfate Soil Management Plan Framework – Version 2
Queensland Curtis LNG Project

Project No.: January 2009

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DOCUMENT INFORMATION SHEET	
TITLE: **ACID SULFATE SOIL MANAGEMENT PLAN FRAMEWORK**	
PURPOSE AND SCOPE: The purpose of this document is to provide a Project wide framework for management of acid sulfate soils, including potential acid sulfate soils (PASS) and actual acid sulfate soils (ASS) for the QCLNG Project. This framework will inform development of site specific acid sulfate soils management plans for specific areas and activities for the Project.	
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SECTION 1 - INTRODUCTION

1.1 *Background and Project Description*

This draft Acid Sulfate Soils Management Plan (ASSMP) Framework has been developed to provide a Project wide framework for the management of Actual Acid Sulfate Soils (AASS) and potential Acid Sulfate Soils (PASS) during the construction of the Queensland Curtis Liquified Natural Gas (QCLNG) project (the Project). This Framework will inform development of site specific acid sulfate soils management plans for specific areas and activities for the Project.

The Project comprises five core components encompassing the Coal Seam Gas (CSG) fields in the Surat basin, an Export Pipeline from the CSG field to Curtis Island off the coast from Gladstone, the LNG export terminal at Curtis Island, shipping operations to export the LNG, and dredging activities to support construction of the LNG Facility and ancillary infrastructure. Construction activities have the potential to disturb AASS and PASS during installation of parts of the pipeline, development of the LNG export terminal and dredging activities.

Therefore, of particular interest is the installation of the pipeline through alluvial areas such as creek and river beds and the intertidal zone north of Gladstone (below RL10mAHD), the installation of the pipeline through the sub tidal zone at The Narrows, the construction of the Construction Dock, Materials Offloading Facility (MOF), LNG Jetty, and the excavation of a sediment basin in the intertidal zone on Curtis Island.

For contracting purposes, construction of the QCLNG Project will be broken up into a number of components, with these undertaken by separate Engineer, Procure, Construct (EPC) contractors. At a broad level different EPC contracts will be let for pipeline construction, LNG plant construction and dredging, though these areas may be further broken up into smaller EPC contracts. All EPC contracts will be required to develop site specific ASSMPs (where applicable) in accordance with this ASSMP Framework for applicable areas and activity(ies).

This ASSMP Framework has been prepared in general accordance with Queensland's State Planning Policy 2/02 (SPP2/02), and has taken into consideration previous investigations undertaken for the QCLNG Project.

This ASSMP Framework is not a static document and is expected to evolve over time to reflect continuation of Project detailed design, refinement of proposed construction methodologies, letting of EPC contracts, and to take into account the results of additional ASS investigation and construction control testing as well as feedback received during the development of construction planning and execution.

This ASSMP Framework has been prepared with the assistance of Butler Partners Pty Ltd.

1.2 *Legislation and Policy Requirements*

This ASSMP Framework is designed to satisfy the requirements of:

- Environmental Protection Act and Regulations;
- State Planning Policy 2/02 Policy and Guideline (SPP2/02);
- QLD Acid Sulfate Soil Technical Manual;
- QASSIT Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland 1998; and
- Integrated Planning Act 1997.

At a more general level the ASSMP Framework is designed to address:

- *Coastal Protection and Management Act 1995* (Coastal Act);
- *Fisheries Act 1994* (Fisheries Act);
- *Water Act 2000* (Water Act);
- *Vegetation Management Act 1999* (VM Act);
- *Integrated Planning Act 1997* (IPA);
- *State Development and Public Works Organisation Act 1971* (Station Development Act);
- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); and
- *Environment Protection (Sea Dumping Act) 1981* (Sea Dumping Act).

1.3 ***ASSMP Framework Purpose***

The purpose of the ASSMP Framework is to provide an over-arching framework for the management of ASS and PASS during construction works. This Framework will inform development of site specific acid sulfate soils management plans for specific areas and activities for the Project.

The framework broadly describes the existing environments where Project activities may encounter ASS/PASS which will inform ongoing Project detailed design. It provides a summary of existing ASS/PASS information applicable to the Project. It broadly reviews likely key construction works that may disturb ASS/PASS and finally it provides strategies to assess potential environmental risk from disturbance of ASS/PASS controlling and monitoring of these risks, objectives for key environmental elements and a scope for supervision, validation and auditing.

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1.4 ***Acid Sulfate Soils***

Acid Sulfate Soils are soils or soil horizons containing oxidisable sulfides, principally in the form of iron sulfides (commonly as pyrite). When these soils are exposed to oxygen due to disturbance such as excavation, sufuric acid is generated. ASS are commonly found in coastal areas and in rivers and creeks where marine sediments have been deposited.

Pyrite is the most common form of iron sulfide found in ASS and it forms where sea water or other sulfate rich water mixes with land based sediments containing iron oxides and organic matter in an oxygen deficient environment. Bacteria that help to form pyrite prosper in warm anaerobic conditions.

ASS can be divided into Actual ASS and Potential ASS. Actual ASS are soils containing highly acidic horizons resulting from the aeration of soils rich in iron sulfides. Oxidation leads to the generation of acid in excess of the soil's natural neutralising capacity and results in soils with pH less than 4. These soils are often identified by the presence of yellow mottles and coatings of jarosite. Potential ASS have not oxidised and have a pH in the field of 4 or more. These soils become acidic when exposed to air and oxidised.

In the context of this ASSMP Framework Actual ASS and Potential ASS will be referred to generically as ASS.

SPP2/02 is used as the basis for assessing ASS in Queensland. While ASS occur predominantly in low-lying coastal areas, they can also occur some distance from the existing coastline in-situations where historic low-lying coastal areas have been covered by younger geological material. SPP 2/02 therefore assumes, based upon the precautionary principle that all land to which SPP 2/02 applies may contain ASS unless compelling geological/geomorphic evidence indicates otherwise. Figure 1 summaries the areas to which SPP2/02 applies.

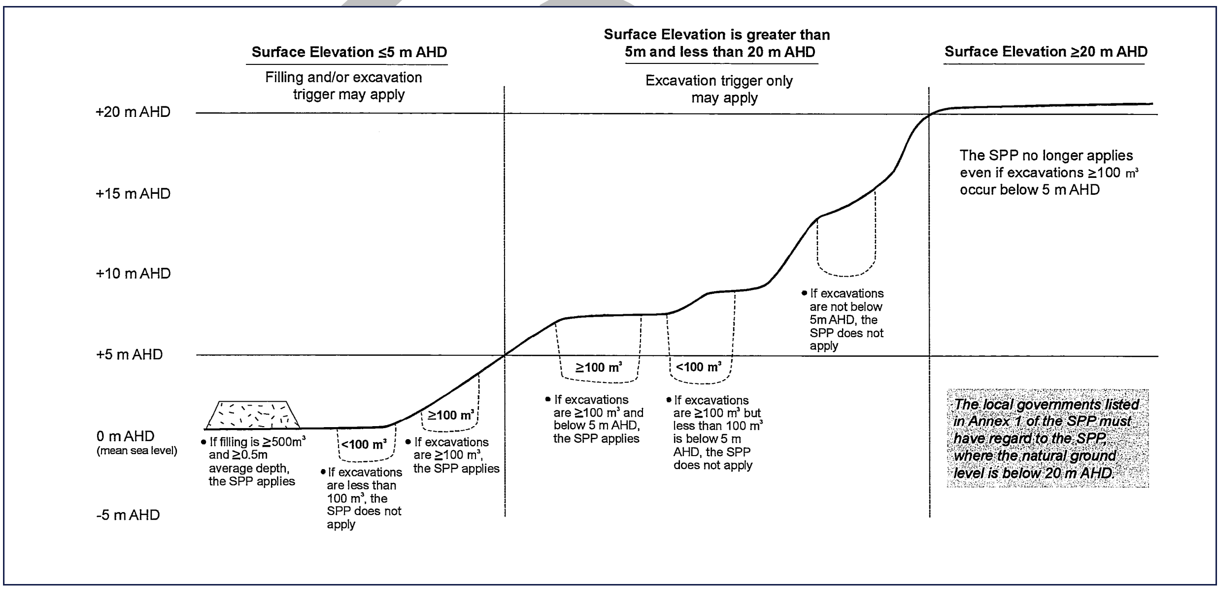


Figure 1: Areas and development to which SPP2/02 applies

SECTION 2 - ENVIRONMENTAL SETTING

2.1 *General Site Description*

The infrastructure works will be undertaken through a variety of environmental settings. In broad terms, these can be divided into three classifications:

- onshore;
- offshore; and
- intertidal zones.

In general terms, the construction activities anticipated to occur in each of these settings where ASS has the potential to occur are:

Onshore:

- Export Pipeline pipeline construction
- clearing of access and working areas associated with the pipeline constructions
- LNG plant construction and associated onshore infrastructure on Curtis Island
- staging areas on the Gladstone mainland at Auckland Point and RG Tanna.

Offshore:

- pipeline construction
- dredging activities.

Intertidal Zones:

- pipeline construction;
- Marine Offload Facility (MOF) on Curtis Island and product loading jetty (piled) and construction dock, and facilities at Auckland Point and RG Tanna; and
- some LNG Facility components, including sediment basins.

2.2 *Acid Sulfate Soil Impacts*

Excavation works in the intertidal zone as well as offshore may encounter ASS. Some onshore works, especially in areas below RL10mAHD will intersect ASS; it is considered that the pipeline in particular will be constructed in high risk areas along the coast and possibly in locations where it crosses creeks and rivers.

Metals such as iron and aluminium can be quickly mobilised out of the soil matrix under acidic conditions and it will become available to the surrounding environment. Concrete components of buildings and metal in construction equipment and other more permanent structures are readily corroded by sulfuric acid generated from ASS. In addition, flora and fauna can be adversely impacted where sulphuric acid generated from ASS enters waterways and lowers the pH.

2.3 *General Approach to Managing of Acid Sulfate Soils*

In general terms, ASS are managed avoidance where possible. Where not possible, by:

1. by accepting that oxidation has the potential to occur and acid will be generated; and/or
2. by preventing or minimising oxidation.

In the first case, the soils are managed by treatment to increase the pH. This is generally done by the addition of lime to the soils to create an acid/base reaction and results in the neutralisation of the soils. Whilst this is a simple and effective means of managing ASS, it is not without risk. Lime is a highly alkaline material and uncontrolled handling and management of it can result in detrimental environmental impacts.

In the second case, the material is handled in a manner that minimises it's exposure to oxygen, thereby preventing the oxidation process. Generally, this is achieved by handling, storing and disposing of the material under water.

2.4 *Potential General Environmental Risks*

Based on the environmental settings described, the nature of the operations and within a frame of reference that relates only to ASS, the following potential risks have been identified:

- water quality in creeks and rivers where the construction of the pipeline disturbs ASS;
- sea water quality where construction works disturb ASS in the intertidal zone and offshore;
- water quality impacts from the mishandling of lime used to treat ASS;
- impacts of degraded water quality or flora and fauna; and
- air/dust impacts from lime becoming airborne from stockpiles and during handling.

In order to mitigate these risks the following elements must be addressed:

- water quality;
- stockpile management;
- erosion and sediment control; and
- dust control/air quality.

Strategies for managing each of these elements will be described in Section 5 of this ASSMP Framework.

2.5 *Regional Geology*

Reference to the Geological Survey of Queensland's 1:100,000 Geological series Gladstone sheet indicates that the geology in the area of the Pipeline crossing of The Narrows and the LNG Facility is generally mapped as underlain by four main different geological units, comprising coastal tidal flats, alluvial plains, residual soils and rock (predominantly, but not only), Doonside Formation (chert, mudstone, minor tuff and arenite) and Wandilla Formation (mudstone, arenite and chert). An excerpt from the geological sheet is given in Figure 2. It will be necessary to carefully consider the geology of all work sites, (downstream, upstream and along pipeline corridors), to provide an indication of the potential presence of ASS.

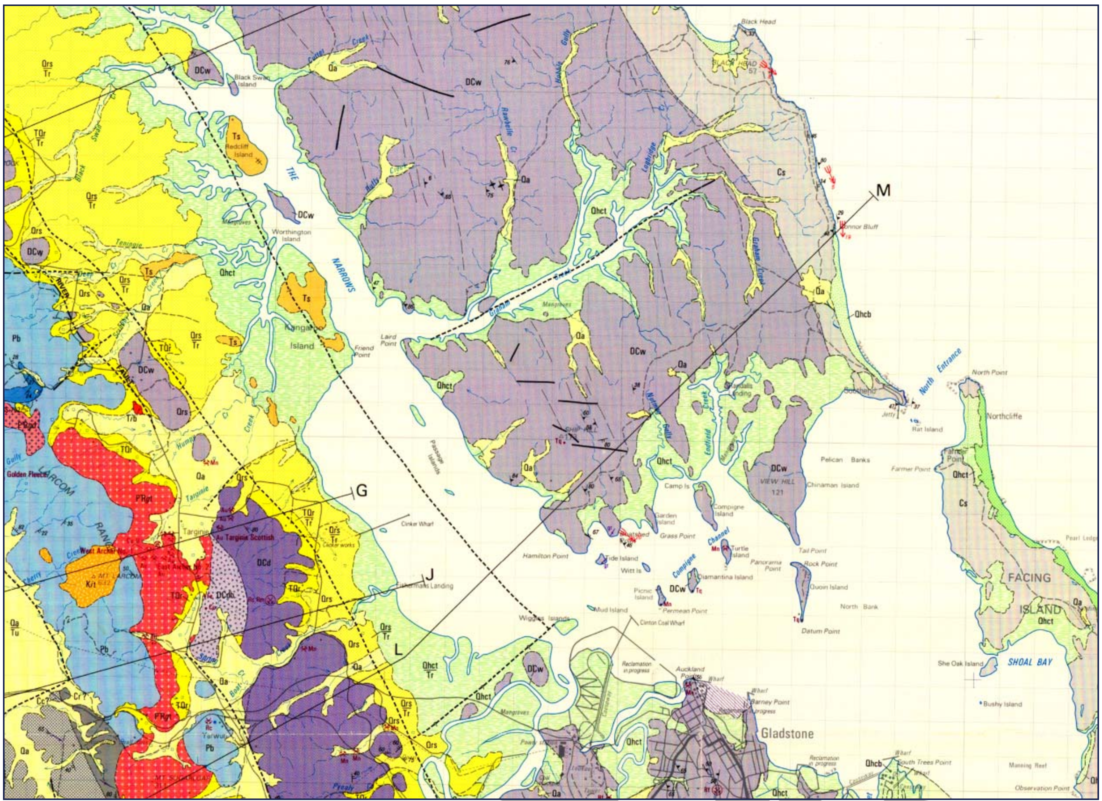


Figure 2: Downstream Area Regional Geology

Table 1: Description of Selected Geological Units Mapped in Figure 2

Map Symbol	Geological Period	Geological Unit	Description
Qa	Holocene	Alluvial Plains	Undifferentiated creek and flood plain alluvium comprising silt, sand and gravel.
Qa_1	Holocene	Alluvial Plains	Lowest flood plain alluvium comprising sand, gravel and minor silt.
Qa_2	Holocene	Alluvial Plains	Intermediate flood plain terraces comprising silt and sand.
Qpa	Holocene	Alluvial Plains	Highest flood plain comprising silt and sand.
Qhcb	Holocene	Coastal Plains and Dunefields	Beach ridge comprising sand.
Qhch	Holocene	Coastal Plains and Dunefields	Chenier, beach barrier comprising shelly sandy mud.
Qhct	Holocene	Coastal Plains and Dunefields	Coastal tidal flats, mangrove flats, supratidal flats and grasslands, comprising sand and mud.
Qhcd	Holocene	Coastal Plains and Dunefields	High blowout dune comprising sand.
Qhmt	Holocene	Marine Deposits	Tidal delta sands and associated sand pits.
Qrs	Holocene/Pleistocene	Residual Soils	Residual soils
T_{QR}	Holocene/Pleistocene/Pliocene	Colluvial Deposits	Colluvial clay, gravel, cobble scree
T_v,T_s	Tertiary	-	Olivine basalt flow, conglomerate and sandstone
K*i*t,Kr	Cretaceous	-	Trachyte plug, Rhyolite flow
Prgt	Triassic/Permian	Targinie Granite	Monzogranite, granite
Pb	Permian	Berserker Beds	Tuff, agglomerate, conglomerate, minor mudstone
DCw	Carboniferous	Wandilla Formation	Mudstone, arenite and chert
DCd	Devonian	Doonside Formation	Chert, mudstone, minor tuff and arenite

2.5.1 Holocene/Pleistocene Deposits

Surficial deposits anticipated to be covering parts of the downstream site can be broadly classified into four main groups; alluvial plains, coastal plains and dunefields, marine deposits and colluvium and a brief description of each is given in the following sections.

2.5.1.1 *Alluvial Plains*

Mud flat/tidal deposits will be encountered underlying 'low lying' areas of the site and are generally expected to comprise a combination of undifferentiated, partially terraced, silts, clays, sands and gravels.

2.5.1.2 *Coastal Plains and Dunefields*

Generally consisting of tidal flats and beach and dune deposits. The deposits are expected to be highly variable and to include sands, gravels, silts and clay. Some variation in the grading of these soils is often noted over relatively short distances, which is consistent with the mode of deposition and reflects varying depositional facies.

In nearby areas, dense/very dense clayey gravels have been encountered, often at depth and overlying residual soils. In some instances recovered samples of gravel from the general area have been found to be subangular to subrounded, rather than the rounded gravel associated with the alluvial plains soils.

2.5.1.3 *Marine Deposits*

Generally comprising tidal delta sands and associated sand spits, with some included shells.

2.5.1.4 *Colluvium*

Slope wash deposits in the general area have previously been found to comprise red-brown clay, with some subangular gravel. Probable cobbles/boulders have previously been encountered in these soils. These deposits are generally encountered in the low lying areas, but above the tidal influence zones.

2.5.2 Residual Soils

Weathering of underlying rock units has resulted in variable residual soil types, but predominately comprising stiff to hard clays. The residual soil deposits are often homogenous and are typically found to lack structure/laminations etc.

2.5.3 Bedrock

In 'elevated' sections of the site and at relatively shallow depths, predominately mudstone (with some chert) rock is anticipated, in various stages of weathering, with areas of basalt, granite, sandstone, conglomerate, rhyolite etc. The mudstones are typically of 'low' strength at shallow depth, with closely spaced defects and the cherts are of higher strength, and can have a gravel like appearance. Laminations within the mudstone are evident, a feature which is used to determine the boundary between residual soil and the upper surface of the weathered Wandilla Formation. The Doonside Formation's lithological characteristics are similar to the Wandilla Formation and it is difficult to reliably distinguish between the two.

SECTION 3 - PROPOSED WORKS

Detailed design of Project component, and in particular refinement of proposed construction methodologies which may impact on ASS, is ongoing. Therefore, this description of the proposed works provides only a general discussion of the proposed works.

3.1 Onshore

3.1.1 Pipeline Construction

The onshore component of the pipeline construction will be located in non-ASS areas along most of its length. However, it will cross numerous creeks and rivers (estimated to be 44km over the entire length of the export pipeline) and may include some areas below RL10mAHD as it approaches the coast.

Where the pipeline is above ground some excavation will be required for the footings for pipe supports. Where construction is below ground, there are a number of potential construction techniques including open trenching or directional drilling. These techniques will generate spoil and where construction works disturb ASS, this will require management.

Regardless of construction techniques, earthworks will be required to provide access and working areas for the pipeline construction. Excavation will be required for entry and exit points, and mud pits for directional drilling and tunnelling.

3.1.2 LNG Plant Construction

The LNG Facility is to be constructed on Curtis Island, with much of the Plant at an elevation greater than RL10mAHD although some components of LNG Facility will be below RL10m. Bulk earthworks to be undertaken include levelling of areas of the site by cut and fill.

3.1.3 Staging Areas at Auckland Point and RG Tanna

The staging areas will require construction on developed areas of Auckland Point and RG Tanna as well jetty or pontoon structures extending beyond the land and into marine areas. It is envisaged that t minimal onshore excavation will be required. It is likely that any excavation will occur below existing pavement subgrades that will intersect ASS and the jetty structures will be constructed on driven piles which will not generate ASS management requirements.

3.2 Offshore

3.2.1 Pipeline Construction

Offshore pipeline installation is likely to be undertaken either by open trench or directional drilling. These techniques will generate spoil including entry and exit points and/or mud pits. Whilst the entry and exit points and mud pits would be constructed either onshore or in the intertidal zones, ASS will be disturbed as part of the process.

3.2.2 Dredging

Dredging will be required to allow site access to the LNG Facility site, and is proposed specifically as part of construction of the MOF and Construction Dock. Additional dredging for the LNG Jetty swing basin and access channel will be undertaken by the Gladstone Ports Corporation and is not covered by this ASSMP Framework. This work will involve dredging of approximately 2.5 million m^3 of spoil in total (including spoil not considered likely to be ASS). It is likely that this will predominantly comprise soft sediments.

3.3 *Intertidal*

3.3.1 Pipeline Construction

Construction of the pipeline through this area may also be undertaken using open trenching or directional drilling techniques or other appropriate methodologies. Open trenches are likely to be up to 3m deep. Any access and working areas in the intertidal zone will be excavated in alluvial sediments and is likely to disturb ASS. Fill may be imported to these areas to form hard stands working platforms above the HAT level.

3.3.2 Marine Off-Loading Plant (MOF), LNG Jetty and Construction Dock

The MOF and Construction Dock will be used for the off-loading and transport of materials during construction of the LNG Facility. Following construction, the MOF will be used during Facility operation as an access point for both personnel and materials. The LNG Jetty will be used for loading of LNG carriers for export.

3.3.3 Sediment Basin

The current LNG Facility site layout shows a number of sediment basins as part of the construction stormwater management. Due to site area constraints and the size of the facility, it is currently proposed that at least one sediment basin will be constructed in the intertidal zone, in an area that will be built up using site fill material.

SECTION 4 - ACID SULFATE SOILS INVESTIGATION RESULTS

4.1 *Technical Reports*

Information on the nature and extent of ASS at specific locations across the Project area is provided in the reports prepared by GeoCoastal Pty Ltd, Environmental Resources Management Australia and Golder Associates Pty Ltd listed in Section 9 of this ASSMP framework.

4.2 *Results Overview*

Testing for ASS is on-going and will extend throughout the construction phase of the project, both as investigation testing and construction control/verification testing. As a broad guide only, the results of selected investigation testing conducted by both GeoCoastal Pty Ltd and Golder Associates Pty Ltd have been reviewed and the range of reported net acidity and calculated maximum liming rates determined from the review are summarised in Table 2.

The summary of review results given in Table 2 is not an exhaustive summary of all testing results to date and will require updating over time, as the results of current ASS testing results and additional investigation (and construction control) testing become available.

Table 2: Summarised Results of Selected ASS Investigations

Geology	Approximate Range of Reported Net Acidity (%S)	Calculated Maximum Liming Rate (kg/dry tonne)*
Holocene	-7.4 to 6.8	>240
Pre Holocene	-0.3 to 0.3	19

* Determined from Table 3

It should be noted that a substantial amount of shells has been reported in the Holocene sediments, which gives rise to substantial 'self' neutralising capacity (discussed in Section 5.7 in terms of managing ASS). It will be essential to ensure that the shells are sufficiently small (or broken into sufficiently small pieces) if these are to be used for ASS neutralisation, to ensure the soils full self-neutralising capacity is available.

Table 3: Estimating Treatment Levels and Ag-lime Required to Treat the Total Weight of Disturbed Acid Sulfate Soil – Based on Soil Analysis (after Ahern et al. 1998a)

The tonnes (t) of pure fine aglime, $CaCO_3$ required to fully treat the total weight/volume of acid sulfate soils (ASS) can be read from the table at the intersection of the weight of disturbed soil [row] with the existing plus potential acidity [column]. Where the exact weight or soil analysis figure does not appear in the heading of the row or column, use the next highest value.

Disturbed ASS (tonnes) (≈m^3×BD) †	**Soil Analysis# – Existing Acidity plus Potential Acidity (converted to equivalent S% units)**													
	0.03	*0.06*	*0.1*	*0.2*	*0.4*	*0.6*	*0.8*	*1*	*1.5*	*2*	*2.5*	*3*	*4*	*5*
1	0	0	0	0	0	0.03	0.04	0.05	0.1	0.1	0.1	0.1	0.2	0.2
5	0	0	0	0.05	0.1	0.1	0.2	0.2	0.4	0.5	0.6	0.7	0.9	1.2
10	0	0.03	0.05	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.2	1.4	1.9	2.3
50	0.1	0.1	0.2	0.5	0.9	1.4	1.9	2.3	3.5	4.7	5.9	7.0	9.4	12
100	0.1	0.3	0.5	0.9	1.9	2.8	3.7	4.7	7.0	9.4	12	14	19	23
200	0.3	0.6	0.9	1.9	3.7	5.6	7.5	9.4	14	19	23	28	37	47
250	0.4	0.7	1.2	2.3	4.7	7.0	9.4	12	18	23	29	35	47	59
350	0.5	1.0	1.6	3.3	6.6	10	13	16	25	33	41	49	66	82
500	0.7	1.4	2.3	4.7	9.4	14	19	23	35	47	59	70	94	117
600	0.8	1.7	2.8	5.6	11	17	22	28	42	56	70	84	112	140
750	1.1	2.1	3.5	7.0	14	21	28	35	53	70	88	105	140	176
900	1.3	2.5	4.2	8.4	17	25	34	42	63	84	105	126	168	211
1000	1.4	2.8	4.7	9.4	19	28	37	47	70	94	117	140	187	234
2000	2.8	5.6	9.4	19	37	56	75	94	140	187	234	281	374	468
5000	7.0	14	23	47	94	140	187	234	351	468	585	702	936	1170
10000	14	28	47	94	187	281	374	468	702	936	1170	1404	1872	2340

L	**Low treatment:** (≤0.1 tonnes lime)
M	**Medium treatment:** (>0.1 to 1 tonne lime)
H	**High treatment:** (>1 to 5 tonnes lime)
VH	**Very High treatment:** (>5 to 25 tonnes lime)
XH	**Extra High treatment:** (>25 tonnes lime)

Note: Lime rates are for pure fine aglime, $CaCO_3$ assuming an NV of 100% and using a safety factor of 1.5. A factor that accounts for Effective Neutralising Value is needed for commercial grade lime. (See the *Information Sheets* on *Neutralising Agents – Neutralising Considerations*).

† An approximate soil weight (tonnes) can be obtained from the calculated volume by multiplying volume (cubic m) by bulk density (t/m^3). (Use 1.7 if B.D. is not known.) Dense fine sandy soils may have a BD up to 1.7, and hence 100 m^3 of such soil may weigh up to 170 t. In these calculations, it is necessary to convert to dry soil masses, since analyses are reported on a dry weight basis.

Potential acidity can be determined by Chromium Reducible Sulfur (S_{CR}), Peroxide Oxidisable Sulfur (S_{POS}) and Total Oxidisable Sulfur (S_{TOS}). For samples with pH <5.5, the existing acidity must also be determined by appropriate laboratory analysis eg. Titratable Actual Acidity (TAA). Soils with retained acidity eg. jarosite or other similar insoluble compounds have a less available acidity and will require more detailed analysis. The amount of treatment required may be reduced if the self-neutralising capacity of the soil is appropriately measured. Consult the **Queensland Acid Sulfate Soils Technical Manual, Laboratory Methods Guidelines**.

SECTION 5 - GENERAL OVERVIEW OF MANAGEMENT STRATEGIES

5.1 *Introduction*

Management of ASS can be categorised in a hierarchy of preferred strategies. Avoidance of disturbance is the preferred approach. In the case of the QCLNG construction works, this may not be possible in many areas although detailed design and construction planning shall continue to place avoidance at the top of the ASS management hierarchy wherever practicable. Some flexibility may be available in terms of locating non-critical excavations such as sediment basins, access tracks and site amenities and these will be located away from ASS areas where possible. Where avoidance is not possible, a series of risk based management strategies may be adopted in the following order of preference:

- minimisation of disturbance through design and construction methodology
- neutralisation of disturbed ASS;
- hydraulic separation alone or in conjunction with dredging
- strategic reburial of potential ASS below an established groundwater table level.

Each of these is discussed in general terms of potential environmental risk; treatment techniques; technical considerations and performance criteria and verification testing.

Other higher risk strategies are available, some of which will be mentioned in this document, however, additional justification will be required prior to adoption.

Prior to the adoption of any management strategy, the EPC contractor for a particular site must be able to satisfy themselves, QGC Limited and the Queensland Department of Environment and Resource Management (DERM) that the strategy can be implemented in such a manner as to prevent Environmental Harm (as defined in Section 14 of the *Environmental Protection Act, 1994*).

5.2 *Assessment Criteria for Acid Sulfate Soils*

ASS in Queensland are assessed based upon the Queensland Acid Sulfate Soils Investigation Team (QASSIT) *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998* (QASSIT Guidelines) and the SPP2/02. The SPP 2/02 Guideline provides action criteria for assessing the results of laboratory testing quantifying the acid producing effects based on the sum of existing plus potential acidity. These action criteria are presented in Table 4.

Table 4: Action Criteria based on ASS Analysis for Three Broad Texture Categories

Type of Material		Action Criteria (1 – 1000 tonnes disturbed)		Action Criteria (> 1000 tonnes disturbed)	
		Existing + Potential Acidity		Existing + Potential Acidity	
Texture Range	Approx. Clay Content (%)	Equivalent Sulfur %S	Equivalent Acidity Mol H^+/tonne	Equivalent Sulfur %S	Equivalent Acidity Mol H^+/tonne
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, silty clays*	>40	0.1	62	0.03	18

* Likely to be most appropriate for the QCLNG project

5.3 *Minimisation of Disturbance*

Wherever practicable, disturbance of ASS during construction works will be avoided through refinement of design or minimised by selection of construction technique in preference to adopting another management strategy. Where avoidance or minimisation of disturbance is not possible, the presence of ASS will be appropriately characterised whilst planning activities and prior to adopting another management strategy. .

5.4 *Neutralisation of Disturbed ASS*

5.4.1 Potential Environmental Risk

Key risk issues have been identified in the neutralisation of ASS as follows:

Soil Texture:

Different soil textures may present different problems in terms of their handling and propensity to be neutralised. Coarse grained sandy soils may oxidise within hours of exposure to air and a rain event while these materials are stockpiled in an untreated form can result in the mobilisation of acid to the environment. Further advice on the length of time that stockpiles can remain untreated is provided in Section 5.4.3 of this document. Highly plastic marine clays are difficult to treat and difficulties can be experienced in enabling neutralising material to be adequately worked through the soil matrix. Monosulfidic black oozes found to accumulate in waterways are highly reactive and oxidise quickly in contact with oxygen. These may be a particular problem where the pipeline crosses creeks and other waterways.

Neutralising Agents:

The efficiency of the chosen neutralising agent must be taken into account prior to selection of the agent as products such a gypsum and other by-products of sulfidic oxidation (particularly iron and aluminium based compounds) may form coatings on the outside of the individual particles which reduce their ability to neutralise the acid generated by the ASS materials.

More soluble neutralising agents such as hydrated lime and quick lime may result in 'over treating' to the point where the soils become alkaline and with the potential to adversely impact the environment. Soluble neutralising agents may also be more readily flushed from the soil matrix before full oxidation of the ASS occurs resulting in them not being available to neutralise the last of the oxidation product. In addition, the handling and management of these agents can present potential environmental and human health risks.

A comparison of the characteristics of neutralising materials is provided in Table 5 below. The details of two local suppliers of lime are provided in Appendix A, although other appropriate sources of neutralising materials may be utilised at the discretion of the applicable EPC contractor.

Table 5: Summary of the Characteristics of Neutralising Materials

Neutralising material	Composition	Approx pH	Approx NV	Mol. weight	Comments
			LOW SOLUBILITY MATERIALS – 'SAFER OPTIONS'		
Agricultural lime/ AgLime	$CaCO_3$	8.5–9	95–98	100.08	• insoluble in pure water/slight soluble (1 kg/ 4000 L) in water saturated with CO_2 • commonly 95–98% pure • usually cheapest neutralising option for soils • must be finely ground
Dolomite	$CaCO_3$ / $MgCO_3$	8.5–9	60–75		• the proportion of calcium / magnesium carbonate varies depending on the deposit
Magnesite	$MgCO_3$	8.5–9	pure = 119, commercial = 95–105	84.32	• 1 kg soluble in 3330 L water; more soluble in CO_2 saturated water • product of neutralising $MgSO_4$—creates salinity
Magnesite (basic form)	$(MgCO_3)_4.Mg(OH)_2.5H_2O$	8.5–9		486	• limit use if draining to fresh water systems—salinity
Burnt magnesite or magnesia	MgO; forms $Mg(OH)_2$ in water	8.5–9	pure = 250, commercial = 180–220	40.32	• very slightly soluble in water, increased solubility in CO_2 saturated water • takes up CO_2 from the air reverting to carbonate
			MORE SOLUBLE MATERIALS – REQUIRING RISK MANAGEMENT		
Sodium bicarbonate	$NaHCO_3$	8.2		84.0	• 1 kg soluble in 10 L of water • low risk, high cost material • if excess quantities used, gives a higher buffering capacity against flushes of acid water • negative: dispersing effect on soils and water of sodium ions, also salinity
Mixed Limes	$CaCO_3$ / $Ca(OH)_2$ / CaO	11+			• quick action • can be spread with a normal lime spreader • smaller tonnages required so savings on freight and spreading costs • protective clothing and goggles should be worn
Soda Ash	Anhydrous Na_2CO_3	11+		105.99	• 1 kg is soluble in 3.5 L of water • evolves heat on combining with water • negative: sodicity effects on soils, salinity
Washing soda	$Na_2CO_3.10H_2O$	11+		286.15	• 1 kg soluble in 2 L of water • negative: sodicity effects on soils, salinity
Hydrated lime or slake lime	$Ca(OH)_2$	12.5–13.5	pure = 135, commercial = 105–120	74.10	• 1 kg soluble in 630 L of water • absorbs CO_2 from the air forming $CaCO_3$ which may form a film on the water • cheapest form of water treatment • protective clothing and goggles should be worn
Quicklime or burnt lime	CaO	12.5–13.5	pure = 179, commercial = 120–150	56.08	• 1 kg soluble in 835 L of water, converting to $Ca(OH)_2$, generating considerable heat • hazardous, protective clothing and goggles should be worn • store away from moisture
Burnt dolomite	CaO MgO	12.5	pure = 214, commercial +80–160		• hazardous, protective clothing and goggles should be worn • store away from moisture • Mg salinity
Cement kiln dust (CKD)	$CaCO_3$ + $MgCO_3$ + CaO/NaCl	12.6	73.6		• composition depends on source material • hazardous to skin • not to be used near waterbodies which could be affected by sodium content • possible Ca:Mg imbalance in plants

5.4.2 Treatment Techniques

Treatment of ASS by neutralisation will be undertaken in a controlled environment; on a bunded treatment pad. This may be a temporary structure set up at a particular location in order to treat ASS generated from the near vicinity prior to removal of the treated soil to another location, or it may be a structure established at the location in which the treated ASS will remain after treatment. Treatment pads will be established with at least a compacted clay base, a guard layer, a leachate collection system and with bunding. Further details of the requirements for construction of the treatment pad are provided in Section 5.4.3 below.

The untreated ASS should be placed on top of the guard layer in layers of 150mm to 300mm thickness. The amount of neutralising agent to be added should be pre-determined based on the results of laboratory testing of the soils, the effectiveness of the neutralising agent and with a calculated factor of safety. The neutralising agent should be spread evenly over the ASS layer and then worked into the soil matrix. Effective treatment may require reworking several times to ensure adequate blending of the neutralising agent into the soil. Verification of the effectiveness of the treatment shall be undertaken as described in Section 5.4.4 below.

Tracking of the treated soil is a necessary part of the treatment process to ensure that the location of each batch of ASS (treated and untreated) is spatially defined. This enables the treatment of each batch of ASS to be correlated with the results of initial testing and then subsequently, the results of verification with each specific batch of treated ASS.

5.4.3 Technical Considerations

Technical considerations relevant to the treatment of ASS by neutralisation relate mainly to:

- treatment pad design;
- containment of stormwater and bund capacity;
- stockpile management;
- re-use of treated material; and
- management of retained water.

Treatment Pad Design:

As described in Section 5.4.2 above, there are four essential elements that must be included in the design of treatment pads; a base (compacted clay or other appropriately impermeable layer), a guard layer, a leachate collection system and bunding. A schematic cross section of a treatment pad is presented below as Figure 3 (referenced from *Queensland Acid Sulfate Soil Technical Manual, Soil Management Guidelines*, 2002 (Dear *et. al.* 2002)).

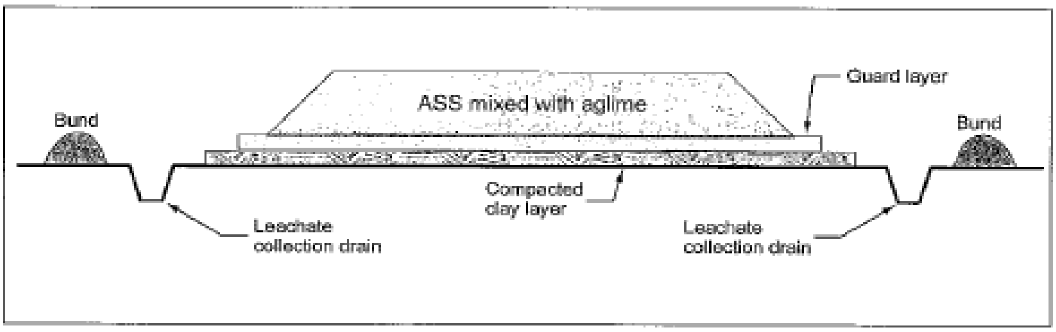


Figure 3: Schematic cross section of a treatment pad

If the base is construction of compacted clay, the layer (0.3-0.5m thick) should be constructed from low permeability (clay) soil and compacted such that it forms a trafficable layer. This should be compacted sufficiently to restrict infiltration. A guard layer of neutralising agent should be placed across the surface of the treatment pad prior to the placement of untreated ASS. The purpose of the guard layer is to neutralise any acidic leachate generated by the treatment material during the neutralisation process. The calculation procedure for the guard layer rate is provided in Dear *et. al.* 2002 as follows:

"The rate of neutralising agent used in the guard layer (per square metre) should be based on 0.2 times the average of the potential and existing acidity for every metre depth of the soil to be treated (i.e. if 2m of soil. are to be treated in the treatment pad, then twice 0.2 times the neutralising agent required to neutralise the acidity should be spread as a guard layer). The safety factor of 1.5 to 2.0 is recommended for all guard layers. The safety factor may need to be increased for sands and for treatment pads that are adjacent to environmentally sensitive areas. For example:

- SCR=l.9%
- TAA = 125 mol H^+/tonne
- Existing + Potential Acidity = (125: 623.7) + 1.9 = 2.1%
- 0.2 times the average of the potential and existing acidity = 0.2 x 2.1% = 0.42%S
- Depth of soil on treatment pad = 2m
- The situation would require 39 kg $CaCO_3/m^2$ of soil as the guard layer for 2m (vertical) of fill

In all cases a minimum of 5kg fine ag-lime per m^2 per vertical metre of fill should be used in the guard layer. See the *Laboratory Methods Guidelines* for information about determining existing and potential acidity."

The guard layer is placed to protect the quality of underlying groundwater and is not part of the treatment process for the following reasons (Dear *et. al.* 2002):

- "gypsum and insoluble iron and aluminium coatings can form on the neutralising agent placed in the guard layer, which reduces the neutralising capacity of the layer;
- over time, excess water that is passing though the treatment pile may channel its flows through preferred paths, whereby only a fraction of the guard layer is intercepting and neutralising potential acid flows;
- it is difficult to ensure that there has been adequate mixing of the neutralising agent with the soil; and

- the amount of neutralising agent in the guard layer will generally be insufficient to treat all the acidity from the overlying soils placed on the pad."

A synthetic membrane may be used in place of the compacted clay and guard layers, however, due to the treatment method requirement that the ASS be spread in layers <300mm there is a high potential for this membrane to be damaged. As part of any proposal to use a synthetic membrane it must be demonstrated that the ASS can be treated without damaging the membrane.

It should be noted for a permanent treatment pad arrangement, that guard layers may need to be applied between each compacted ASS layer as a precaution in environmentally sensitive areas, areas with high levels of sulfides or where soils are difficult to blend. For temporary treatment pads, the guard layer may need to be reapplied if it is disturbed during the removal of the treated soil.

Sizing of the treatment pads will be governed by a number of factors relating largely to the amount of space required to retain untreated ASS, the amount of space required to spread the untreated ASS to the required layer thickness and the amount of space required to hold the treated material whilst waiting for the results of verification testing. In general terms this relates to the expected throughput of the volume of ASS, drying blending, testing and compaction time (for permanent treatment pads). Other factors such as the useability of the treatment pads e.g. following rainfall may dictate the throughput rate.

Containment of Stormwater and Bund Capacity:

Within the design of the treatment pad, stormwater runoff must be contained until it can be tested and treated to meet discharge requirements. Diversion drains must be installed to divert stormwater away from the ASS.

The capacity of the bunded area must be designed and sized in accordance with the *Erosion and Sediment Control – Engineering Guidelines for Queensland*, Queensland Division of the "Best Practice Erosion and Sediment Control" International Erosion Control Association (IECA) Australasia, 2008. Design of the treatment pads must take into account local rainfall and evaporation. Data relating to rainfall and evaporation in the Gladstone area have been obtained from the Bureau of Meteorology and are presented in Appendix B.

In intertidal areas this will require a higher level of planning and management. For example, where works occur close to the high tide area or in areas where little tidal inundation occurs, it may be feasible to bund the area of disturbance in order to contain any stormwater. Alternatively, where greater tidal inundation occurs, it may be more practical to have a mobile tanker on standby to which water can be pumped and removed off-site for treatment or alternatively establish a holding tank or basin in the vicinity of the works but above the high tide mark.

Generally, works in intertidal areas will require careful time planning due to regular inundation of the works areas.

<u>Stockpile Management</u>:

Stockpiling of ASS prior to treatment is considered a high risk activity; however, in certain circumstances it may be necessary. Dear *et.al.* 2002 states that:

"The risks of stockpiling large volumes of untreated ASS may be very high even over the short-term. Stockpiling small volumes of untreated ASS should only be undertaken as a short-term activity. For example:

- part of a day's extraction of clay may be stockpiled over a weekend before strategic reburial; or
- due to weather slowing treatment or problems with obtaining laboratory results, space in neutralising treatment areas may not be available as quickly as was anticipated in earthworks strategies, leading to the creation of small stockpiles before changes can be made to earthworks programs."

Potential risks associated with stockpiling include:

- the potential for soils to become mixed, thereby making the identification of soils associated with a particular testing dataset difficult;
- incorrect matching of soils to their testing results may lead to the application of incorrect liming rates; and
- where coarse textured soils are stockpiled in oxidising conditions without treatment, significant quantities of acid can build up and changes in soil chemistry can occur making the material difficult to treat.

The Dear *et. al.* 2002 provides information on indicative maximum periods for stockpiling untreated ASS for short term and medium term stockpiling as outlined in Table 6 and Table 7 below. For each scenario as well as long term stockpiling, particular management protocols are recommended, these become more stringent the longer the stockpiles are to be held.

Table 6: Indicative Maximum Periods for Short-Term Stockpiling of Untreated ASS

Type of Material		Duration of Stockpiling	
Texture Range (McDonald et at. 1990)	**Approximate Clay Content (%)**	**Days**	**Hours**
Coarse texture Sands to loamy sands	<5	Overnight	18 hours
Medium texture Sandy loans to light clays*	5-40	2 days	48 hours
Fine texture Medium to heavy clays and silty clays*	≥40	5 days	120 hours

* Most likely categories for QCLNG Project

Some variation to these timeframes may be necessary depending upon individual circumstances e.g. climatic circumstances such as hot weather in which some sands may begin to oxidise within a matter of hours and will require the timeframes for stockpiling to be reduced. Appropriate operational delay times should be determined well prior to the creation of the stockpile for the specific circumstances. The use of a guard layer under the short-term stockpiles is recommended in most circumstances.

Table 7: Indicative Maximum Periods for Medium-Term Stockpiling of Untreated ASS

Type of Material		Duration of stockpiling	
Texture Range (McDonald et al.1990)	**Approximate Clay Content (%)**	**Days**	**Weeks**
Coarse texture Sands to loamy sands	≤5	14 days	2 weeks
Medium texture Sandy loans to light clays*	5-40	21 days	3 weeks
Fine texture Medium to heavy clays & silty clays*	≥40	28 days	4 weeks

* Most likely categories for QCLNG Project

Management to reduce the oxidation of sulfides and the collection and treatment of all leachate and runoff water will need to be implemented during the stockpiling period.

Dear *et. al.* 2002 state that:

"A guard layer of a suitable neutralising agent MUST be placed under all medium-term stockpiles. In addition the following management strategies may need to be implemented to manage risk:

- the volumes stockpiled should not exceed more than 1 week's volume of extraction;
- all stockpiles will need to be bunded and diversion banks installed upslope to prevent run-on water. Bunds and diversion banks should not be constructed out of untreated ASS or other materials that may be a source of contaminants to the environment. The materials used should have an appropriately low permeability to avoid leakage;
- leachate collection and treatment systems should be installed;
- the surface area of the stockpile is minimised to reduce exposure to atmospheric oxygen. This may involve shaping the stockpile, and/or capping or lining it with a material that will minimise drying by wind and sun and prevent rainfall entering the stockpile. The cap or liner will need to cover the sides of the stockpile as well as the top;
- keep the surface of the material moist using a spray of water or neutralising solution. The spray should be carefully managed to prevent over wetting the material producing leachate or runoff, and should be a fine-mist to prevent disaggregation of the soil from the stockpile surface; and
- construct erosion and sediment control structures."

Guidance is provided in Dear *et. al.* 2002 for the placement of the guard layer as follows:

"The rate of neutralising agent used in the guard layer of medium term stockpiles should be based on 0.3 times the average potential and existing acidity of the stockpile/m^2 per vertical metre of soil that is to be temporarily placed in the stockpile. If the stockpile is 2m high, then 2 to 3 times the neutralising agent required to neutralise the potential and existing acidity should be spread as a guard layer. A 1.5 to 2 times safety factor is also required for medium term stockpiles. Also see notes on Guard Layers in Section 8.

For sandy textured soils, in environmentally sensitive areas, or in-situations where the medium term time frames cannot be met, a higher rate of neutralising agent in the guard layer will be warranted.

The potential and existing acidity of the soil can be measured by a range of laboratory methods (see *Laboratory Methods Guidelines*)."

Note: These timeframes do not apply to monosulfidic black oozes. These materials should not be stockpiled without a risk assessment, and the implementation of strict environmental management protocols.

Re-Use of Treated Material:

In a general sense, the addition of lime to ASS should have the effect of modifying the engineering properties of the ASS, such that the treated material may be suitable for reuse as general (or potentially select) fill. The beneficial effects of the addition of lime to ASS are to generally reduce the plasticity, moisture content and optimum moisture content of the treated materials, provided that 'sufficient' lime is added. Even so, it may be necessary to undertake secondary processing of the lime treated ASS; for example, to dry the treated soil so that its moisture content is close to its optimum moisture content for compaction.

If 'insufficient' lime is added, then ASS materials after treatment are generally found to be of high plasticity and/or too 'wet' to properly compact and are therefore generally only suitable for use as fill in-situations where the fill is not required to provide support to structures, pavements or other settlement sensitive areas of development etc.

If treated ASS are proposed to be used as a source of general or select fill, the geotechnical properties of the treated materials (and hence their suitability), must be confirmed by appropriate geotechnical testing.

Management of Retained Water:

Water may be retained within bunded treatment pad areas especially following storm events. In order to maintain the functionality of the treatment pads, this water will require testing, treatment and disposal outside the bunds. Similarly, if, over time, water is retained within the treatment pad bunds resulting from the accumulation of stormwater in excess of that able to evaporate, this will need to managed by disposal outside the bunds.

Requirements of for testing of retained water prior to discharge to be determined in consultation with DERM and the applicable EPC Contractor(s).

Where pH adjustment is required, it may be more effective to use one of the soluble neutralising agents such as hydrated lime. Any adjustment of pH must be undertaken within the containment area and must not be undertaken in natural watercourses or water bodies. Table 8 below is provided as a guide to the quantity of pure neutralising agent that may be required to adjust the pH of retained water based on Dear *et. al.* 2002.

Table 8: Indicative Minimum Quantity of Pure Neutralising Agent Required to Raise From Existing pH to pH 7 for a Megalitre of Low Salinity Acid Water

Current Water pH	[H+] (mol/L) (mol/L)	H+ in 1 Megalitre (mol)	Ag-lime to Neutralise 1 Megalitre (kg pure CaCO3)	Hydrated lime to Neutralise I Megalitre (kg pure Ca(OH)2)	Sodium Bicarbonate to Neutralise 1 Megalitre (kg pure NaHCO3)
0.5	.316	316 228	15 824	11 716	26 563
1.0	.1	100 000	5004	3705	8390
1.5	.032	32 000	1600	1185	2686
2.0	.01	10 000	500	370	839
2.5	.0032	3200	160	118	269
3.0	.001	1000	50	37	84
3.5	.00032	320	16	12	27
4.0	.0001	100	5	4	8.4
4.5	.000032	32	1.6	1.18	2.69
5.0	.00001	10	0.5	0.37	0.84
5.5	.0000032	3.2	0.16	0.12	0.27
6.0	.000001	1	0.05	0.037	0.08
6.5	.00000032	.32	0.016	0.012	0.027

Notes on Table 8:

1. 1 m^3 = 1,000 litre = 1 kilolitre = 0.001 Megalitre
2. Correlations between current water pH and [H^+] (mol/L) do not account for titratable acidity. The titratable acidity component should be included in any calculations of neutralising agent requirements.
3. Agricultural lime has a very low solubility and may take considerable time to even partially react. While ag-lime has a theoretical neutralising value of 2 mol of acidity (H^+), this tends to be only fully available when there is excess acid. This, together with it's very low solubility, means that much more ag-lime beyond the theoretical calculation will generally be required.
4. Hydrated lime is more soluble than ag-lime and hence more suited to water treatment. However, as $Ca(OH)_2$ has a high water pH, incremental addition and thorough mixing is needed to prevent overshooting the desired pH. The water pH should be checked regularly after thorough mixing and allowing sufficient time for equilibration before further addition of neutralising product.
5. Weights of material given in the table above are based on theoretical pure material and hence use of such amounts of commercial product will generally result in under treatment.
6. To more accurately calculate the amount of commercial product required, the weight of neutralising agent from the table should be multiplied by a purity factor (1001 Neutralising Value for ag-lime) or (148/ Neutralising Value for hydrated lime).
7. If neutralising substantial quantities of ASS leachate, full laboratory analysis of the water will be necessary to adequately estimate the amount of neutralising material required.
8. Neutralising agents such as hydrated lime $Ca(OH)_2$, quick lime CaO, and magnesium oxide MgO neutralise 2mol of acidity (H^+), while sodium bicarbonate $NaHC0_3$ and sodium hydroxide NaOH neutralise only 1mol of acidity.

Application of the neutralising agent may also be a critical factor in the effectiveness of treatment, SPP2/02 *Planning and Managing Development Involving Acid Sulfate Soils* recommends the following as methods to potentially increase the efficiency of the neutralising process:

"…… the neutralising agent should be mixed into a slurry before adding. A slurry can be prepared in a concrete truck, cement mixer or large vat with an agitator. Methods of application of the slurry include:

- spraying the slurry over the water with a dispersion pump;
- pumping the slurry into the waterbody with air sparging (compressed air delivered through pipes) to improve mixing once added to water;
- pouring the slurry out behind a small motorboat and letting the motor mix it in;
- incorporating the slurry into the dredge line (when pumping dredge material); or
- using mobile water treatment equipment such as the `Neutra-mill' and `Aqua Fix' to dispense neutralising agents to large water bodies."

Results of water testing should be maintained on site. Field test results will be recorded on the Water Quality Monitoring form (or similar) provided in Appendix C.

5.4.4 Performance Criteria and Verification Testing

Following treatment of ASS, the following performance criteria must be attained

1. The neutralising capacity of the treated soil must exceed the existing plus potential acidity of the soil; and
2. Post-neutralisation, the soil pH is to be greater than 5.5; and
3. Excess neutralising agent should remain within the soil until all acid generation reactions are complete and the soil has no further capacity to generate acidity, this is best achieved by the use of a good quality neutralising agent.

Demonstration of compliance with these performance criteria may be undertaken by verification testing or by use of a "lime register" allowing verification that appropriate quantities of lime have been applied. Methodology to be used to ensure that performance criteria have been met to be determined in consultation with DERM and the applicable EPC Contractor(s).

5.5 ***Hydraulic Separation***

5.5.1 Potential Environmental Risk

Key risk issues have been identified in the treatment of ASS by hydraulic separation as follows:

Site Management:

The handling and movement of material won from hydraulic separation techniques is made more difficult by the higher level of process technology. Tracking of materials is essential to ensure the performance criteria are met prior to material leaving the site. Off-site management of the won materials may be difficult to implement and enforce.

<u>*Oxygen Exposure:*</u>

There are several stages during the process where sulfides may be exposed to oxygen, potentially leading to oxidation of the sediments and the release of acid. Key areas of potential risk from oxygen exposure are during:

- Extraction of sediments;
- Delivery of sediments to the process stream;
- During each step of the separation process; and
- Following the separation process.

In addition the stockpiling of sediments awaiting separation may lead to them drying out, oxidising and generating acid in the event of rainfall. It is important to manage stockpiles of untreated ASS in accordance with the guidance provided in Section 5.4.3.

<u>*Inefficient Separation:*</u>

Hydraulic separation using either sluicing or hydrocycloning is not 100% effective in removing sulfides and not all material is suitable for treatment using this process. Where poor separation occurs, clumps of sulfidic rich sediment may remain within the washed sands. Post treatment handling of the sands is likely to result in these materials being exposed to oxygen rich environments and potentially drying, oxidising and generating acid leachate. If there are inefficiencies in the separation process, further treatment of separated material by neutralisation may be necessary. If hydraulic separation is adopted, facilities should be available to conduct neutralisation if required. Alternatively, the materials may need to be re-processed.

<u>*Management of Process Water:*</u>

Hydrocycloning generally uses a closed water circuit, which may become progressively enriched with non-settling fines. These fines may impede the separation process. Eventually this dirty water will require separate treatment or replacement. Such process waters may become acidic, and if so will require neutralisation.

<u>*Variable Stratigraphy:*</u>

Highly variable soil stratigraphy poses the greatest threat to the hydraulic separation process. The better the characterisation of a site, the more informed the decision to use hydraulic separation becomes. As a general rule, it is best only to attempt hydraulic separation where good characterisation data is available.

Experience suggests that sandy soils with minor layers of silts and clays can be effectively separated, however, the presence of heavy marine clays or cemented bands within the sandy soils make the separation process inefficient. Therefore, it is unlikely that this process will be appropriate in most cases for the QCLNG Project.

Sulfidic Fines:

There are a number of potential issues associated with the management of the sulfidic fines generated in the hydraulic separation process:

- calculation of the volume that may be generated;
- physical handling of the fines post separation;
- the presence of existing acidity in the fines; and
- the potential for fines to oxidise after reburial.

The volume of sulfidic fines that may be produced from the hydraulic separation process is difficult to calculate in advance based on in-situ material identification. Due to the high potential for fines to remain suspended in water for a prolonged period of time, there will be a 'bulking' that will occur. The material is generally difficult to dewater and compact. Assessment of the mineralogy of the sediments pre-treatment may be useful in estimating the extent to which they will bulk due to suspension in water. Regardless, it is important to allow a sufficient factor for this bulking of the sulfidic fines and account for this in any management plan.

Post separation handling of the sulfidic fines is best undertaken either by:

- storing them in an anoxic environment; or
- drying them sufficiently to allow neutralisation treatment.

Storing in an anoxic environment requires particular care to avoid oxygenation of the waste stream by the generation of turbulence or spraying. Demonstration of the credentials of the proposed anoxic storage environment must be undertaken prior to the placement of the sufidic sediments.

Neutralisation presents the greatest potential environmental risk in the handling and management of the sediments whilst they dry. It is recommended that any such storage be conducted in a structure similar to the treatment pad described in Section 5.3.3 above whereby there is hydrological separation from potential receiving environments.

Separated sulfidic sediments with existing acidity that are managed by reburial in an anoxic environment may still release acid and result in the acidification of waterways. In turn, the high acid content may leach Aluminium and iron from the sediments into the waterways.

Reburial of sediments in bodies of water that may experience significant movement either by movement and flow of water or by turbulence from wind, rainfall and flood events, can result in oxidation of unoxidised sediments.

Prior to deciding on the disposal destination for sulfidic sediments, care must be taken to understand the oxidation state of the sediments and the environment into which they will be deposited. These must be carefully weighed up when deciding on the management of these sediments.

The use of hydraulic separation for previously dredged fines is unlikely to be efficient as the proportion of sand is generally minimal compared with other sediments. In addition, these sediments may be partially oxidised and therefore, require a much higher level of treatment by neutralisation.

5.5.2 Technical Considerations

The processes involved in hydraulic separation are described in Dear *et. al.* 2002 as follows:

"<u>Sluicing</u>:

(Hydro)sluicing has become the common term for the process whereby sulfidic fines are hydraulically separated from sands at the discharge point during a dredging operation and the heavier sands are then used as fill. In these situations, the `sluice' is the artificial channel for conducting water or regulating flow from or into a still water body or pond (receptacle). Sluicing is a form of settling-based separation operated in a continuous process stream (as opposed to a batch type settling process that might apply to a sedimentation basin removing suspended solids). Sluicing is a relatively complex form of settling separation due to it being a continuous process. Further complexity is added by the goal to `settle' the heavier or larger particles out of the slurry at a given location, while retaining the fine particles (including sulfides) in suspension until the end of the sluicing channel where fine particles are settled in a still water body. This should be sufficiently deep if it is to be the final repository of sulfidic materials.

The sulfidic fines remain in a stable, wet, and largely unoxidised condition throughout the process as they are kept in suspension by the turbulence of the water. They are then returned to an anoxic, preferably anaerobic (reducing) environment, at the base of the water body where they may be capped (if possible). Alternatively, the sulfidic fines may be washed down to a collection point for partial dewatering and neutralisation (Dobos and Neighbour 2000). It should be noted that the drying of sulfidic fines would present a high environmental risk.

<u>Enhancing the removal of sulfidic fines during sluicing</u>

Several methods are available to enhance the removal of sulfidic fines during sluicing. The following dredging operation control features have been demonstrated in southeast Queensland sites to aid separation of sulfidic fines from the coarse fraction (from Dobos and Neighbour 2000):

- use of a `bucket wheel cutter suction dredge', not a `suction dredge';
- ensure dredge material that contains significant amounts of sulfidic clay lenses or coffee rock layers also contains sufficient sand to ensure the break-up of clumps of clay and coffee rock;
- dredge continuous peat or clay horizons separately, and handle them independently at the discharge point by strategic reburial or neutralisation;
- when basement clays or continuous clay horizons are intersected, there is greater potential for the material to form clay balls;
- increase the water-to-solids ratio if dredging materials high in sulfides or organic matter;
- pause repeatedly, or pump slugs of water at the end of each arc;
- use pumps and pumping arrays that produce high turbulence in the flow, as this will promote abrasion and liberation in the pipeline;
- ensure a turbulent flow by incorporating tight bends or right angles in the pipe;

- increase the residence time in the pipeline by increasing its length;
- keep the discharge pond relatively small and water in it turbulent to ensure that the fines remain in suspension and do not settle out and concentrate near the discharge point;
- have a swamp dozer or excavator continually working and shaping the discharge area, keeping the sulfidic fines overflow in one well-defined steep, fast flowing channel all the way to the point of discharge to the permanent sulfidic fines storage location;
- maintain attention at the discharge point to prevent the build up of fines `fans' that drain through previously washed sands, leaving the fines buried in the fill; and
- flushing the sluicing channel with excess water at shut down will help prevent the exposure of fines over nights and weekends, which may result in acidification.

Some or all of the above may be implemented on a case-by-case basis, depending on the site and the materials to be dredged, and cost-benefit analysis.

<u>*Hydrocycloning*</u>:

Hydraulic separation using hydrocyclones is used extensively in the mining and extractive industries, particularly in **sand and gravel screening.** Cyclones are centrifugal classifiers used primarily to separate particles based on their size and density (see Figure 5). In operation, a slurry feed is introduced to the hydrocyclone under pressure and the solid particles of different weights in the `feed' are separated by centrifugal drag and to some extent gravity.

Hydrocycloning is one of the most effective mineral separation methods for uniform or constant feeds. However, greater process control is required as the material fed to the hydrocyclone becomes increasingly variable. Hydrocycloning may not be effective in separating the fine grained sulfides if the material is too variable, clayey, or cemented.

A sand particle suspended in the slurry rotating in the hydrocyclone will tend to move towards the wall of the cyclone if the centrifugal force acting on it is greater than the drag force created by the velocity of the feed flow. If the drag force of the fluid velocity is greater than the centrifugal force generated by the hydrocyclone, then the fine particle will tend to move inwards.

Hence larger particles tend to move to the outside wall of the cyclone and are discharged from the spigot at the bottom of the hydrocyclone. The resulting process stream is called the target-flow and should contain the desired sand or gravel product. The target-flow must meet the performance requirements stated for ASS being treated by hydraulic separation techniques.

Smaller particles (including the sulfidic fines) generally move to the centre of the hydrocyclone and are discharged through the vortex finder at the top of the cyclone, along with most of the fluid from the feed slurry. This process stream is called the reject-flow and must be managed to prevent the oxidation of sulfides (for example by strategic reburial) or treated using neutralising techniques.

Like sluicing, hydrocycloning is not a perfect separation method, hence the need for both constant management of the process, and verification testing of the target-flow product. Problems can result from taking short-cuts resulting in some coarse particles in the reject-flow, or (of greater concern to an ASS manager) entrainment of fine-grained sulfidic particles with the target-flow product.

Occasionally, the source material may be re-processed to obtain multiple size fractions of the product, e.g. coarse sand, fine sand of similar density. The sulfidic fines should be removed during the first round of separation during the hydrocycloning process, and processed once with minimal exposure to oxygen.

Enhancing the removal of sulfidic fines during hydrocycloning

Hydrocyclone separation performance can be affected by the following:

- design variables - dimensions, spigot diameter etc (and hence design classification performance);
- operating variables - feed rate, feed pressure and concentration of solids in the feed slurry;
- compositional variability of the feed slurry (grainsize distribution, ratio of clays to sand, sulfide content etc.);
- if the material being processed is fairly consistent, it is theoretically possible to establish a relationship between the quantity of fines entrained with the target-flow and the mass fraction of water discharged with the reject-flow. This may have benefits to the ASS manager if a relationship can also be established with the results of verification analysis; and
- cyclone efficiency can be graphed for various particle size fractions and may assist in the selection of an appropriate hydrocyclone to achieve the desired results."

Management of ASS in the use of hydraulic separation techniques will principally be achieved by:

- good ASS site characterisation;
- the use of pilot trials before commencement;
- the use of containment structures to provide hydrogeological separation;
- the use of guard layers
- good quality control
- the use of 'in-line' neutralisation;
- good earthworks/dredging strategies; and
- cradle to grave management of sulfidic fines.

Good ASS Site Characterisation:

Good ASS site characterisation will result in better decisions with regard to the viability of the use of hydraulic separation techniques. Key issues to be aware of if considering the use of these techniques are: the a good understanding of the spatial distribution of sulfides in the sediments; the levels of sulfides present in the sediments; and the physical characteristics of the sediments. Areas of high levels of sulfides should be avoided or should be anticipated to allow for additional management and treatment. Significant areas of high plasticity fines and/or cementation should be avoided as the treatment of these sediments is generally inefficient.

Pilot Trials:

Due to the difficulties in achieving efficient separation of sulfidic fines from coarser materials, the use of pilot trials or bench tests may assist in deciding whether hydraulic separation is a viable option for managing ASS. Dear *et. al.* 2002 recommends that pilot trials be conducted on material gathered from a "relatively small area of up to 1 hectare."

Containment Structures:

The basic principles described for containment for treatment by neutralisation should be applied where hydraulic separation is utilised. This includes the use of bunds and separation drains. The capacity of the bunded area must be designed and sized in accordance with the *Erosion and Sediment Control – Engineering Guidelines for Queensland*, Queensland Division of the "Best Practice Erosion and Sediment Control" International Erosion Control Association (IECA) Australasia, 2008. Design of the treatment pads must take into account local rainfall and evaporation. Data relating to rainfall and evaporation in the Gladstone area has been obtained from the Bureau of Meteorology and is presented in Appendix B.

Where hydraulic separation varies from neutralisation, is in the handling of sulfidic fines. This is discussed in more detail later in this section, however, the use of settlement ponds to concentrate the fines is recommended. The capacity of the ponds should be designed in accordance with the *Erosion and Sediment Control – Engineering Guidelines for Queensland*, Queensland Division of the "Best Practice Erosion and Sediment Control" International Erosion Control Association (IECA) Australasia, 2008 and using local meteorological data relevant to the Gladstone area. Management of these ponds should ensure that no discharge occurs until the sulfidic fines have settled.

Guard Layers:

Guard layers used for hydraulically separated material utilise similar principles to those used in neutralisation treatment. However, the Dear *et. al.* 2002 suggests "a thin layer of washed sand with the neutralising agent incorporated into it may also act as a more effective guard layer. This layer will intercept and neutralise any significant acidity that may be produced (assuming that water flows down through the washed sand and through the guard layer), and will assist in protecting groundwater quality."

The design of treatment pads used for material generated from hydraulic separation should comply with that required for general ASS treatment. Some variance in the rate of neutralising agent application may be necessary depending on the projected thickness of the washed sand and the existing and potential acidity of the washed sediments. Based on potential environmental risk, the rate of neutralising agent application may need to be increased where the receiving environmental values warrant higher protection, or after poor performance of the hydraulic separation process Dear *et. al.* 2002. provides the following advice in relation to calculation of the guard layer application rate.

"Most sites will require a minimum blanket rate of .5 kg fine ag-lime/m^2 per vertical metre of fill placed. If 2m of soil are to be placed, then 10kg of fine ag-lime/m^2 should be spread as a guard layer. This rate may need to be increased in sites that have difficulty achieving effective separation or in an area where the receiving environmental values warrant higher protection."

<u>*Quality Control*</u>*:*

Control over the quality of the end product following hydraulic separation is necessary to ensure that clumps of cemented grains, clay balls, clay-silt aggregates and dense matted organic matter which may contain significant quantities of sulfide are not present adhering to the washed sand. If this is not detected, the sand may leave the site and generate long term issues associated with the release of acid leachate. Early detection of these issues as part of a quality control program is important in mitigating long term environmental risk.

Accurate tracking of the soils is critical to the quality control process. It is recommended that washed sand material be stockpiled in layers less than 1m until each batch has been verified. This allows neutralising agent to be more readily applied if it is deemed necessary.

<u>*In-Line Neutralisation*</u>*:*

The quality and potential to generate acid of the washed sand resulting from the hydraulic separation process can be controlled by in-line neutralisation. At a broad level, the advantages of this approach include:

- maintaining process waters within acceptable pH range;
- providing additional neutralising capacity to the sulfidic fines; and
- providing additional neutralising capacity to the coarse product of the process.

Dear *et. al.* 2002 makes the following comments on this concept:

"In-line methods to neutralise washed fill and the sulfidic fines are generally untried, and will require validation using small-scale pilot trials before being implemented on a larger scale. In making such methods work in the field, management issues that will need to be addressed include:

- correct selection of the type of neutralising agent to treat the desired fraction. For example a soluble neutralising agent to treat the water fraction, or a relatively insoluble neutralising agent to be deposited with the sediment fraction;
- correct selection of the particle size of neutralising agent to ensure its entrainment and deposition with the desired fraction of the suspended sediment. For example a superfine particle to be entrained with the sulfidic fines and coarser particles to be entrained with the coarse sand and gravel fractions;
- deciding where in the process stream to add the neutralising agent to the slurry for most effective treatment of the desired process stream;
- accurate dosing with the neutralising agent to ensure that the relevant type and amount of existing and/or potential acidity is neutralised. This will be greatly dependent on the soil type, the existing/potential acidity characteristics, and the rate of slurry pumping; all will vary dynamically, depending on the source material. If the latter is too variable, this technique may require overdosing, which in turn will raise treatment costs (and the upper pH level needs to be kept in mind also);
- determining the mixing efficiency that can be achieved; and

- selecting appropriate verification analysis methods given the presence of the neutralising agent in the soil."

Earthworks/Dredging Strategies:

An earthworks strategy must be compiled to ensure the processing and handling of the sediments can be managed within the system that is established. It must account for the processing of material, the verification of the washed product and the handling of the sulfidic fines (including settlement and ultimately, reburial). It must consider delays caused by inclement weather and a reasonable level of failure of the verification tests.

Where material is to be retrieved by dredging, Dear *et. al.* 2002 recommends that a 'bucket wheel cutter suction dredge' be used for more efficient ASS management. "A 'bucket wheel cutter suction dredge' contains a series of buckets on the wheel of the dredge that assist the mechanical cutting of the material to be dredged. This in conjunction with suction will break up the material more effectively than a `suction dredge' alone. A `suction dredge' may use water jets to help loosen the sediments. The arc is the angle between which the dredge swings and cuts. After the dredge cuts each arc, the material above it generally collapses to the basement, and is further cut and suctioned during the next sweep of the dredge. The dredging operator must be able to break up all the material and keep it in suspension until it reaches the settling area."

Cradle to Grave Management of Sulfidic Fines:

Sulfidic fines are the most likely source of environmental harm from the hydraulic separation process. They must be managed from cradle to grave. This includes good management of pre-treatment material, prevention of oxidation during processing, management of the resultant sulfidic fines in an anoxic environment until they have settled, treatment if necessary and ultimately, reburial in an appropriate location. The details of this management will vary from site to site and scenario to scenario.

5.5.3 Performance Criteria and Verification Testing

Performance criteria for washed, hydrosluiced or hydrocycloned soil where only residual levels of sulfides or pyrite are to remain, are:

- target of ≤18 moles H^+/tonne (0.03%S);
- no sample shall exceed 25 moles H^+/tonne (0.04%S);
- if any single sample exceeds 18 moles H^+/tonne (0.03%S), then the average of any 6 consecutive samples (including the exceeding sample) shall have an average not exceeding 25 moles H^+/tonne (0.03%S);
- if more than one sample in any six consecutive samples exceeds 25 moles H^+/tonne (0.03%S), then the average of any six consecutive samples (including the exceeding samples) shall have an average content not exceeding 16 moles H^+/tonne (0.03%S).

An exception to these criteria is where the separated material is to be used in concrete, when higher levels of sulfides may be acceptable depending upon the industry requirements for the concrete manufacture. Appropriate handling of sediments that do not comply with the above performance criteria is necessary.

Failure to meet the above performance criteria may be addressed either by reprocessing of the sediments or by further treatment using neutralisation.

Verification testing should be undertaken by sampling the washed soil. The rate of verification testing should comply with **Error! Reference source not found.** above.

5.6 *Strategic Reburial*

5.6.1 Potential Environmental Risk

Key risk issues have been identified in the management of ASS by strategic reburial as follows:

- Existing acidity; and
- Potential for oxidation

Existing Acidity:

Strategic reburial is inappropriate for AASS as the existing acidity contained within the soil matrix may be a source of acid leachate that may enter waterways over time. As a result, heavy metals especially aluminium and iron may be mobilised from the soil as a result of the low pH environment. It may be feasible if the existing acidity is neutralised prior to reburial.

Potential for Oxidation:

The potential for oxidation from PASS strategically buried under water varies with the nature of the material and the potential oxygenation of the water under which it is buried.

In general terms, blocky non-dispersive clay rich soils are less likely to oxidise due to the exposure of only a small proportion of their sulfide content to ambient dissolved oxygen in the water. In addition, these blocks may form an outer skin or rind, thereby preventing oxygen being further transported into the block. The sulfidic fines in these materials are likely to resist becoming suspended in the water column during disturbance events such as heavy rainfall and floods.

However, unconsolidated fine grained sulfidic materials are more likely to oxidise due to the substantially larger surface area they present for oxidation, especially when suspended. They are more likely to become suspended in the water column due to their physical properties.

The nature of the waterbody in which the reburial occurs is also a factor in the oxidation potential; still waters which may only be disturbed occasionally by heavy rainfall and/or flood will contain less oxygen and therefore pose less risk. Flowing water and shallow water that may be readily disturbed will contain a higher level of oxygen and thereby pose greater risk. In general, the risks decrease with increasing depth of water beneath which the material is buried. Studies in south east Queensland have indicated that sulfidic fines require a minimum water column above them of 4m.

Risk assessment taking into account these various conditions, should be undertaken prior to committing to strategic reburial. Such a risk assessment will need to account for the risk of acid generation in the long term, under both `steady-state' or normal conditions, and also under `extreme' or infrequent weather conditions (such as flooding and cyclonic winds). The factors that need to be considered should include the sulfide concentration, texture and dispersive nature of the materials proposed for re-interment, and the degree to which the materials may interact with the overlying (oxygenated) water, as a result of all potential processes. As risk of oxidation increases, it may be necessary to undertake a limnological study to quantify the various oxygen transport processes.

5.6.2 Technical Considerations

The principles of strategic reburial are described in the Dear *et. al.* 2002 as follows:

"Strategic reburial requires a void into which **potential** ASS will be placed. Areas of non-ASS, or soils that can be effectively treated by other means can be excavated for the creation of such voids. The void may be deep (e.g. within the base of a lake, canal or artificial wetland) and covered by standing or surface waters. Alternatively the void may be beneath the groundwater table, and hence also below compacted non-ASS or neutralised material (see Figure 4 and Figure 5). **Potential** ASS should be placed in anoxic, preferably anaerobic (reducing), conditions at the base of a void where sulfide oxidation and hence acid generation, is permanently precluded.

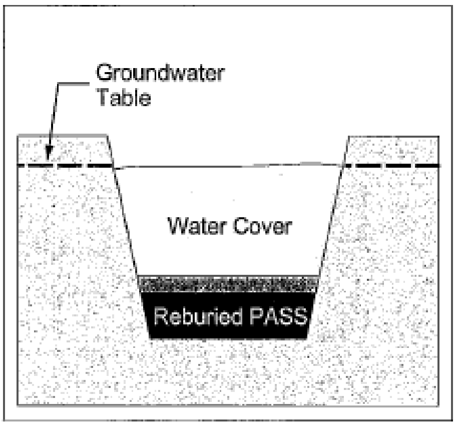


Figure 4: Schematic diagram of strategic reburial below surface or standing water

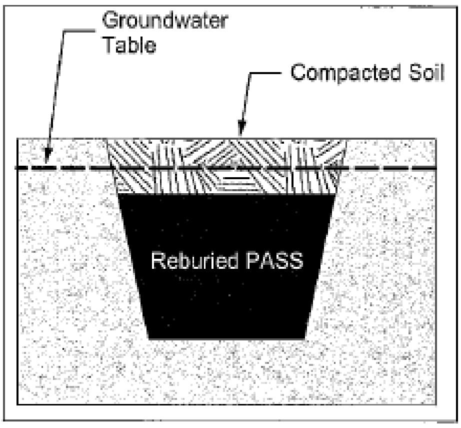


Figure 5: Schematic diagram of strategic reburial below groundwater and compacted soil

A range of different materials can be strategically reburied, varying from blocky non-dispersive clays through to sulfidic fines created during (hydro)sluicing and hydrocycloning. The risks associated with strategic reburial depend in part on the nature of the material to be reburied. Materials that are easy to resuspend e.g. sulfidic fines, pose much greater risks than blocky non-dispersive clays."

This technique is most appropriate for PASS, however it may be possible to manage ASS that have undergone some level of oxidation and have been treated using a neutralising agent. The practicalities and intensity of management processes involved in the latter increases costs and environmental risks.

In order for strategic reburial to be successful, the ASS must have undergone zero or minimal oxidation and oxygen must be excluded from their final reburied location. The reburial location must be carefully selected and designed to ensure void space is available when needed. Part of this process is to ensure that timelines for earthworks have been calculated and met so that the necessary reburial conditions are achieved.

Strategic reburial is based on the main principle of maintaining PASS in anoxic, preferably anaerobic (reducing) conditions at all times, and limiting or excluding oxygen from the reburied soils. When considering strategic reburial, it needs to be remembered that oxygen can be carried by both water and atmospheric gas, and can be transported into and through soils by:

- physically disturbing the soils and exposing them to air;
- stockpiling soils, which promotes their drainage, opening up pore spaces within the soil, and allowing both advective and diffusive flow of oxygen into the soils; and/or
- placing soils under the groundwater table where flowing groundwater may cause the steady delivery of potentially oxygenated waters through the reburied soils; this is of most significance to porous or uncompacted soils (e.g. under appreciably sloping ground or in a preferred groundwater flow pathway such as a paleochannel).

The use of strategic reburial in-situations where the soil has potential **and existing acidity** is a high-risk activity, which requires more complex site management and site supervision, a greater reliance on technology and higher costs. Large-scale use of this management strategy is not recommended, unless there are only minor amounts of existing acidity that can and have been fully treated, and adequate safeguards to protect the surrounding environmental values can be guaranteed.

5.6.3 Performance Criteria and Verification Testing

Performance criteria for strategically reburied PASS are:

1. PASS are maintained in anoxic, preferably anaerobic (reducing) conditions at all times.
2. Soils with significant untreated existing acidity are not interred.

A verification testing procedure should be implemented to demonstrate that materials with existing acidity are not being reburied utilising soil and/or water pH data gathered during the reburial process. If soil pH drops below 5.5, then samples of the soil should be analysed in a laboratory using either Chromium Suite or SPOCAS testing to determine how much existing acidity is present.

Failure to satisfy these performance criteria may necessitate the re-excavation of the soils and neutralisation of the existing acidity.

5.7 *Other Options*

There are a range of other less acceptable options available for the treatment and management of ASS, which include:

- vertical mixing;
- above ground capping;

- hastened oxidation;
- sea water neutralisation;
- offshore disposal of ASS; and
- self neutralisation.

Of the above options, the latter four are generally considered to be unacceptable due to their high potential environmental risk or they have been found to be generally ineffective and/or there is a lack of scientific data to substantiate them. In order to justify using any of the above options, a risk assessment will be required. A brief description of the key elements of a risk assessment for, each option is provided below:

5.7.1 Vertical Mixing:

Vertical mixing relies on the natural buffering capacity of non-ASS horizons found amongst ASS horizons and is only suitable for 'self neutralising' soils. Generally, the buffering horizons contain crushed shells, coral, skeletons, foraminifera or deposits of finely ground limestone. The technique is most effective with coarse grained soils with low levels of sulfide.

5.7.1.1 *Potential Environmental Risk*

Environmental risks associated with vertical mixing relate mainly to insufficient mixing of ASS materials with materials containing neutralising agents. In addition, the buffering capacity of the neutralising layer must be sufficient to balance the ASS and the buffering materials (crushed shells etc.) must be in a physical condition to provide adequate neutralisation. Generally, it is desirable for the buffering materials to be finely crushed providing greater surface area than larger pieces.

In order to justify the use of vertical mixing to Regulatory authorities, sites must be well characterised and the stratigraphy well described.

The ultimate disposal location, material handling procedures and mixing protocols will all be required to be detailed as part of any submission to allow vertical mixing to be used.

5.7.1.2 *Management Considerations*

As a minimum, the following management issues need to be followed when vertical mixing is adopted for the management of ASS:

- soils must be adequately mixed;
- stormwater and groundwater must be monitored extensively and frequently;
- a neutralising agent will need to be incorporated into the mixing process unless there is an abundance of highly `reactive' neutralising materials within the soils;
- any processing areas should be bunded and diversion banks installed upslope to prevent run-on water during mixing. Bunds and diversion banks must not be constructed out of untreated ASS or contaminated materials. The bund materials used should have an appropriately low permeability to avoid leakage; and
- a guard layer of a suitable neutralising agent will need to be placed under the mixing area in accordance with Section 5.4.3 of this document.

Dear *et. al.* 2002 notes that "It is considered inappropriate to classify the soil as a non-ASS by averaging the acidity or %S within all the soil horizons." It is important therefore, that this is not used as part of an argument for the adoption of vertical mixing.

5.7.2 Above Ground Capping:

Above ground capping involves the placement of a non-porous cap over the ASS material to prevent infiltration and to reduce oxygen exposure. The greatest risk with this approach is that the cap will fail and the soils will be exposed to oxygen, they will oxidise and generate acid leachate.

5.7.2.1 *Potential Environmental Risk and Management Considerations*

Three types of 'cover' options are utilised for above ground capping; the 'oxygen' barrier, the 'supersponge' barrier and the 'reducing' cover. Of these, the first two are preferred over the third one. A brief description of each type of cover and the design considerations required to manage environmental risks, is provided below:

An 'oxygen' barrier utilises compacted clay with low hydraulic conductivity maintained at 80% saturation or better. Generally, two main issues have been identified making the use of oxygen barriers unsuitable in many settings. The first issue is constructability and difficulties associated with achieving design criteria on sloping terrain, however, this issue is lessened where the cap is horizontal. The second issue is the ability to maintain the moisture content in the cap; in Australian conditions where there are extended dry periods, this is a particular problem. It should be noted that the Gladstone area experiences a distinct dry period each year which may be detrimental to the efficient operation of one of these covers.

A 'supersponge' cover utilises a vegetated cap of sufficient thickness to absorb rain event within a set of design criteria. The cover and vegetation should absorb and utilise water (via evapotranspiration) from rainfall such that water is not transmitted to the underlying ASS and no leachate is generated. The vegetation cover including its nature, effectiveness at utilising water and its longevity plays a significant role in the suitability of this type of cover. Events such as bushfires may destroy the vegetation cover and lead to failure of the cap.

The 'reducing' cover relies on high levels of degradable organic matter to intercept and consume oxygen which may pass through the cap into the underlying ASS. Eventually the organic matter will degrade or be oxidised at which point the cover becomes ineffective.

All three above ground covers described may be suitable for short to medium term application. The reducing cover is likely to only be effective for a period of months whereas the oxygen barrier and the supersponge cover may be suitable for a few years. None of these above ground caps are considered to be a permanent solution.

5.7.3 Hastened Oxidation:

This technique is considered for soils with high concentrations of sulfidic material which may take decades to fully oxidise under natural conditions. The oxidation process is accelerated by regular wetting of the soil and mechanical turning to stimulate bacterial oxidation. This technique can only be considered where it is guaranteed that the system in which it will occur is fully contained and all leachate can be collected and treated.

5.7.3.1 *Potential Environmental Risk and Management Considerations*

Leachate from this process constitutes the greatest environmental risk. The process requires a large body of soil to be contained and handled within a closed system. The hastening of oxidation results inevitably in the generation of acid leachate with high concentrations of metals such as iron, aluminium and manganese. For heavy clays and sediments with high concentrations of sulfidic material, the process of hastened oxidation may take significant time. Over this time the leachate must be able to be contained and treated on an ongoing basis. The system must be designed such that leachate can be contained during storm and flood events.

The longevity of the leachate collection system and the reliance on the monitoring and treatment of the collected leachate are critical to the success of this process. Any proposal to use hastened oxidation will require the proponent to demonstrate commitment to maintaining and monitoring the system over a prolonged period of time, possibly beyond the life of the construction process.

Hastened oxidation is generally unsuitable for projects generating large quantities of material due to the amount of space required to hold the material whilst allowing the treatment process to occur in an effective manner.

5.7.4 Sea Water Neutralisation:

This technique uses the natural alkalinity of sea water to neutralise acid in the soils. Substantial amounts of water are used in the process all of which must be managed and ultimately discharged. There is a high level of potential risk to the receiving environment from uncontrolled water.

5.7.4.1 *Potential Environmental Risk and Management Considerations*

The potential environmental risks associated with using sea water to neutralise ASS centre around two major aspects; the consumption of carbonate-bicarbonate in the sea water and the generation of iron hydroxide and oxychydroxide precipitates.

The consumption of carbonate-bicarbonate from the sea water and the subsequent release of the water back into the environment may have a negative effect on invertebrates in the ecosystem that rely on carbonate-bicarbonate for the production of shell and exoskeletal growth (e.g. moluses and crustaceans). The generation of iron hydroxide and oxyhydroxides will deplete the dissolved oxygen in the water and may impact on sediment quality and water quality at the sediment interface. Ultimately, this may adversely effect species such as gilled organisms, filter feeders and benthic life.

The impacts of sea water neutralisation will be compounded where the water is released back into a closed or partially closed system such as an estuary.

Generally, sea water neutralisation is only considered on a case by case basis where there is already an acid and/or metal load impacting the environment and there is no other viable option. Where the use of sea water neutralisation is approved it is generally required to be used in conjunction with the application of a neutralising agent such as lime.

5.7.5 Offshore Disposal of ASS:

This technique may be applicable for dredged material. It is stringently governed by both State and Federal Legislation including the *State Coastal Management Plan - Queensland's Coastal Policy August 2001, Environmental Protection (Sea Dumping) Act 1981,* state *Environmental Protection Act 1994* and the federal *Environmental Protection and Biodiversity Conservation Act 1999.* In order to be permitted to undertake offshore disposal of ASS, compliance with the *National Assessment Guidelines for Dredging 2009* is required.

5.7.5.1 *Potential Environmental Risk and Management Considerations*

The key risk elements associated with offshore disposal of ASS are:

- the potential to smother aquatic plants and animals;
- the potential to acidify the local marine environment; and
- the potential to contaminate local waters and sediments with leached metals and other by-products of ASS oxidation.

Each of these elements can be controlled to an extent by the careful selection of a disposal site and the controlled handling of the material. Some jurisdiction have an ocean disposal ground that has been designated for the disposal of dredge sediment. Alternatively, reclamation areas such as the Gladstone Port Corporations Fisherman's Landing reclamation area may be an acceptable disposal location.

Careful handling of the material is necessary and it will need to be demonstrated that this can be achieved without oxidation of the sulfidic sediments. Alternatively this may be a suitable option if it can be demonstrated that either the material can be vertically mixed during dredging (see Section 5.7.1) or that the material is self neutralising where there is sufficient data to support either of these cases, the argument for offshore disposal will be strengthened.

5.7.6 Self Neutralisation:

Where significant amounts of shells exist within ASS, the net acidity of the ASS may be calculated to be negative, indicating that the addition of lime to neutralise the soils is not necessary. However, it will be necessary to carefully determine the size and distribution of shells throughout the ASS, as if shell sizes are too large, they may not have sufficient surface area to provide effective neutralisation. In such cases either the shells would require crushing (which is probably impractical) or addition of lime will be required.

5.7.6.1 *Potential Environmental risk and Management Considerations*

Self neutralisation relies heavily on the ability of the buffering materials within the soil to provide sufficient neutralisation during material handling. The neutralising material must be sufficiently finely ground and must remain well distributed through the sediments during handling and disposal.

In order to justify that ASS material is self neutralising, sites must be well characterised and the stratigraphy well described. The investigation results must demonstrate that the buffering material is in a physical condition to provide adequate neutralisation.

The ultimate disposal location and material handling procedures will all be required to be detailed as part of any submission to justify self neutralisation of the ASS materials.

5.8 *Intertidal Vegetation Removal*

As part of the works in the intertidal zones, vegetations including mangroves will require removal in a manner that controls risk from ASS. Where vegetation is to be removed in the intertidal zone or in onshore areas where roots may extend into ASS materials, the following general protocols may be applied although other options may also be practicable:

- the above ground portion of the vegetation should be removed first and handled separately from the below ground portion. Removal of the above ground vegetation only is preferred, with disturbance of below ground vegetation to be avoided where practicable. Where below ground removal is required:
- the below ground portion may be grubbed (removed) by dredge or excavator. If root material is to be treated separately to the soil mass, a open grabble may be used to minimise soil removal; and
- the root matter should then be chipped separately to the above ground portion and placed in a treatment pad area and blended with lime
- lime or other appropriate neutralising material should be spread over the grubbed area as grubbing progresses (rate subject to ASS conditions).

Vegetation removal in the intertidal zone must be undertaken in a controlled manner so that all disturbed material can be treated prior to the next tidal inundation.

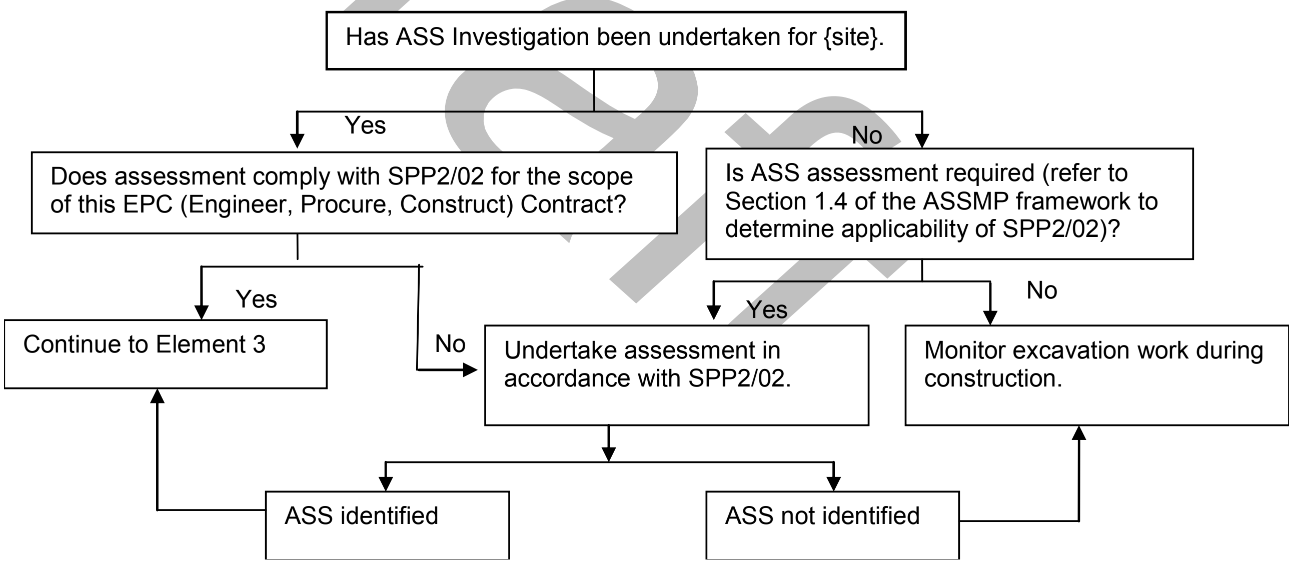
SECTION 6 - ACID SULFATE SOIL MANAGEMENT PLAN

6.1 *Objective/Target*

To ensure that during construction, the existence of ASS is identified and, where present, that they are managed in accordance with an ASSMP so as to avoid environmental harm. To meet the requirements of SPP2/02, the QASSIT *Guidelines for Investigations and the Queensland Acid Sulfate Soil Technical Manual – Soil Management Guidelines*.

The objective of the ASSMP is to control acid generation from site soils and to restrict to an acceptable level any potential on-site and off-site environmental impacts from any site excavation in any proposed development area.

6.2 *ASS Investigation*



6.3 *ASS Management Strategy*

To mitigate and manage potential environmental impacts associated with ASS during site construction operations. This will be achieved as follows:

- The excavation of natural soils within the site requires a materials handling and management strategy and procedure for on-site lime treatment of ASS or the appropriate off-site treatment of the ASS (if insufficient space is available for on-site treatment) to be in place.
- Appropriate erosion control measures to limit sediment loss due to run-off from the site.
- Monitoring of waters collected within the work site, with treatment (as necessary) to a level suitable for discharge into external waterways and for disposal to the groundwater recharge system.

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6.4 *Tasks/Actions*

The following actions will be carried out prior to the commencement of construction and earthworks activities:

- ASS investigations carried out to assess soils to a minimum depth of 1m below the lowest excavation level. Soils located in areas below RL10m that have been shown to contain levels of potential acidity that exceed the QASSIT guidelines will require ASS management to restrict potential environmental impacts.
- Soils above RL10m may be residual soils and therefore are not ASS, but may be acidic due to their geologic derivation. Provided these soils can be compacted to yield a low permeability, they may be incorporated into compacted fill without treatment. However, if acidic soils cannot be compacted to provide a low permeability and/or are loosely dumped without compaction, they may require 'nominal' lime treatment to prevent acid runoff. They may also require containment.
- Requirement for groundwater monitoring and drawdown control to be determined on an activity specific basis in consultation with EPC contractor.

6.4.1 Groundwater

6.4.1.1 *Design Minimum Level*

Details to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction.

6.4.1.2 *Monitoring*

Details to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction.

6.4.2 ASS Treatment

Based on the result of the ASS testing conducted to date, it is considered that 'lower' liming rates may apply to soils recovered from above the watertable level compared with 'higher' liming rates required for soils recovered from below the watertable. It is considered acceptable to differentiate between soils recovered from above and below the watertable for the purposes of ASS treatment as a significantly lower liming rate (on average) is anticipated for soils located above the watertable.

Based on the very broad range of required liming rates for soils tested to date, it is not considered possible to reliably differentiate liming rates based on the visual categorisation of soil type, unless soils are limed at the upper end of the liming rate, which would not be economically viable or ecologically sustainable. The method detailed below may be adopted at the site for the determination of the required liming rate to neutralise excavated ASS material at the site.

Placement of untreated soils (excavated from areas where ASS has potential to occur) directly into any areas other than treatment pads or untreated material storage areas must not occur and will be strictly monitored.

The method of treating soils involves, if possible, segregation of materials into varying required liming rates. Material will then be excavated such that mixing of the excavated material occurs. The amount of material excavated and hauled to the treatment pad(s) will be governed by the capacity of the pads. Excess material may not be excavated unless it is to be taken to a specially constructed and signed storage area(s) for stockpiling of untreated soils, prior to treatment. Verification testing of treated material will be undertaken to confirm the effectiveness of the liming rate.

6.4.2.1 *ASS Treatment Pads*

Where excavated ASS is to be treated on site the following actions will be carried out during the earthworks/construction stage.

- Suitably sized dedicated ASS treatment areas will be created away from overland flow paths.
- Bunding will be constructed around the perimeter of the designated ASS treatment areas to intercept and contain run-off from the area during the soil treatment operations and to prevent ‘contamination’ of treated soils by untreated soils and/or run-off.
- The base of the ASS treatment area is to be lime treated by placement of a guard layer prior to placement of each layer of ASS. Re-treatment is required with neutralising material prior to placement of each new layer of soil to be treated, and at the conclusion of all treatment. The base of the treatment pad shall have the minimum ag-lime application rate of 10kg per square metre (or equivalent if other neutralisation agent used).
- A suitably sized drain or temporary retention basin will be constructed within the treatment bunds to collect drainage water from the treatment area in the event of heavy rainfall during the construction period. Design of this structure will be based on the “Erosion and Sediment Control – Engineering Guidelines for Queensland.” Queensland Division of the Institute of Engineers, Australia and “Urban Erosion and Sediment Control” (1992 Edition) with reference to rainfall and evaporation data provided in Appendix B.
- If insufficient space is available for a temporary retention basin, then suitably sized retention tanks may be used to collect drainage water from treatment areas and excavations.
- Drainage water or run-off collected in the retention basin/retention tanks will be tested to determine the quality of the water. If the water quality falls outside the performance indicators (described below) the water will be treated prior to discharge.

6.4.2.2 *Bulk Excavation*

- ASS to be treated shall be placed on the treatment area in layers not thicker than 0.3m. Materials will comprise a mixture of soil types which will require differing drying times as a result, these may need to be worked several times to ensure thorough mixing. of neutralising agent into the material.
- Ag-lime will be applied evenly over the surface and thoroughly blended into the soils at a rate per tonne of dry soil not less than that determined by the results of the Chromium Suite production tests or pre-excavation testing.
- Neutralisation liming rates will be based on a factor of safety of 1.5 and the use of good quality fine ag-lime with a neutralising value as close as possible to 100%.
- Once lime treatment is complete, the treated spoil may then be stockpiled for later use, incorporated directly into general site fill or disposed off-site (as appropriate).

- Selection of the most appropriate sampling locations and determination of liming requirements for neutralisation of any batch of material will be determined by a suitably qualified professional person experienced in assessing and managing ASS (ASS consultant).
- The exposed ground surface in the base of excavations should be kept moist and be lime treated with a liming rate of 10kg/m^2.
- Requirements for verification sampling or use of lime register to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction.

6.4.2.3 *Structural Excavations*

Residual soils and soils from elevations greater than RL10m are anticipated to be non-ASS and no special treatment or management regime is required provided all excavated soils are properly compacted on placement. Where structural excavations are undertaken in ASS soils at elevations below RL10m, there is the potential to disturb untreated ASS. The treatment procedure for Bulk Excavation shall be followed for structural excavations. Validated treated soils may be replaced as backfill in structural excavations.

6.4.2.4 *Trenching*

Residual soils and soils from elevations greater than RL10m are expected to be non-ASS and no special treatment or management regime is anticipated (subject to confirmation), provided all excavated soils are properly compacted on placement. Similarly, all reclamation fill placed on the site will have been treated for ASS potential and that treatment validated. Where trench excavations are undertaken in alluvial soils at elevations below RL10m, there is the potential to disturb untreated ASS. The treatment procedure for Bulk Excavation shall be followed for trench excavations. Validated treated soils may be replaced as backfill in the trench excavations.

6.4.2.5 *Cut Batters*

All cut batters in ASS (including drainage channels) shall be coated with fine ag-lime at the rate of 10kg/m^2 and the lime coating should be checked and re-limed as necessary on a daily basis during periods of exposure to oxygen.

6.4.2.6 *Strategic Reburial*

Strategic reburial of PASS may be adopted for some excavated materials. Only clay soils with Titratable Actual Acidity (TAA) plus retained acidity (as determined by either Chromium Suite or SPOCAS testing) below the QASSIT threshold of 0.03%S may be considered for reburial. Soils being considered for strategic reburial shall be sampled and tested prior to any excavation to allow TAA and retained acidity to be determined. Any soils proposed for reburial must be reinterred within 72 hours of excavation. While soils proposed for reburial are waiting for reburial, the surface of the soils shall be maintained moist by sprinkler irrigation to reduce oxygen diffusion into the soils. The soils proposed for reburial shall be stored in prepared storage areas.

6.4.2.7 *Fill Areas*

Detailed stability analysis will be conducted where fill is to be located over areas at, or below, RL10m to determine that an adequate factor of safety exists against slope instability, so that subgrade heave failure should not occur. Where factors of safety are not sufficiently high to be acceptable, the rate of placement of fill will be strictly monitored and restricted so that an acceptable factor of safety is achieved.

If subgrade failure does occur and results in soil from below the watertable being elevated above the watertable, management processes will be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction.

In areas of ASS soils that are to be covered with fill, the base of the reclamation area shall be limed at the rate of 5 kg lime per square metre per metre depth of fill.

6.4.2.8 *Diversion Drains*

Diversion drains should not be excavated below the average groundwater level in ASS areas and should not be excavated through or adjacent to non-ASS areas or through treated ASS areas if the drains are to carry acidic water. Where possible, existing drains will be used as diversion/collection drains.

Where diversion drains are located through ASS areas, drain sides and bases should be treated with ag-lime at not less that 10kg/m^2. This treatment should be repeated as required if erosion occurs.

6.4.2.9 *Protection of Treated Soils/Areas*

Lime-treated stockpiled soil shall have sediment fences and/or hay bales placed down slope to intercept any eroded material. Earthen bunds shall be constructed down slope of any filled or stockpile areas to divert run-off/drainage to a temporary retention pond. All retained waters shall be tested before entering the site stormwater system and/or adjacent waterways.

6.4.3 Groundwater

Details of groundwater monitoring and drawdown control to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction

Untreated groundwater and surface water runoff must be prevented from flowing on to or across non-ASS areas (including areas already treated to neutralise ASS and/or areas of fill comprising verified, treated materials).

6.4.4 Validation of Treatment Areas Bunds, Drains and Retention Ponds

At the completion of all ASS treatment and earthworks, the surface area of all treatment areas/retention bunds/water collection drains/retention ponds etc. shall be sampled to a depth of not less that 0.5m, at a frequency of not less than one sample per 200m^2 (or three samples minimum, whichever is greater). Each sample shall be tested using Chromium Suite testing to determine if lime treatment is required.

If the test results indicate that neutralisation is required, requirement for validation of neutralisation to be determined in consultation with DERM and the applicable EPC *Contractor(s)* .

6.5 *Construction Management Issues – ASS*

6.5.1 Acidic – Non ASS

Soils may be encountered that are acidic (due to the site geology), but that have negligible potential for the future oxidation of sulfur (as confirmed by, for example, Chromium Suite testing). Whilst such soils are acidic, they are not ASS and this ASSMP Framework does not apply. Requirement for management of these soils to be determined in consultation with DERM and the applicable EPC Contractor(s)..

If such soils are placed in loose stockpiles and exposed to the weather, they may leach acid and may therefore require the construction of a containment bund such that run-off can be collected and tested prior to leaving the site. Alternatively, the acid, non ASS soils may be uniformly compacted in accordance with an appropriate engineering specification, to reduce their permeability and minimise water penetration.

6.5.2 Groundwater Management – ASS Areas

Activities that result in fluctuations of groundwater and in particular long-term lowering of the groundwater table should be avoided, as these may lead to exposure of in-situ ASS to oxygen. Acidic flushes can be brought to the surface as a result when the groundwater rises again or through evapotranspiration or as a result of fill emplacement (Dear *et. al.*, 2002). It is preferable to maintain groundwater levels in a steady state and works to be avoided in ASS areas include:

- construction of deep drains etc. which lower the groundwater table;
- operation of drains which do not have gates or `drop boards' to maintain groundwater levels;
- significant water level fluctuations during dry periods caused by the operation of drains;
- uncontrolled groundwater extraction and drawdown from dewatering bores; and
- dewatering or drainage of construction sites.

If 'voids' are created below the level of the permanent groundwater table for the strategic reburial of ASS, the ASS then lies below the re-established groundwater table and a layer of compacted soil is placed on top of it (see Figure 4). However, this technique will not be suitable for sites where the groundwater table takes an extended period to re-establish.

Factors or conditions that might result in the transport of significant amounts of oxygen to the reburied sulfides (e.g. by providing unexpected or preferred pathways for oxygen or oxygenated groundwater flow, immediately after reburial, or in the future) should be identified on a site-specific basis and include (Dear *et.al.,* 2002):

- geological discontinuities such as faults or shears, or well jointed basement rocks, through which appreciable groundwater flows might occur;
- placement of ASS where groundwater flows will transport significant oxygen to the sulfidic materials;
- placement of ASS where groundwater levels are lowered to expose the ASS due to seasonal fluctuations or drought;

- placement of ASS materials in locations where future off-site development might periodically or permanently lower the groundwater table around the re-buried materials;
- placement of ASS materials in locations that are likely to be disturbed in the future by re-development or the need to install or upgrade in-ground services; and
- placement of wet, low density dredge or hydrocycloned fines without first dewatering, may lead to the sinking of the capping material, squeezing the fines upwards, above the permanent groundwater table.

ASS should be placed at least 0.5 m below the lowest recorded groundwater table level to ensure that the ASS is not exposed to a source of oxygen during periods of extended drought. Areas with limited reliable groundwater information should ensure reburial occurs below a conservative estimate of the lowest possible level of the groundwater table.

6.5.3 Fill Embankment Stability – ASS Areas

Management of fill embankment stability to be determined in consultation with DERM and the applicable EPC Contractor(s)...

6.6 *Performance Indicators*

6.6.1 Treated ASS

Chromium suite testing carried out for validation of applied liming rates will be deemed to be acceptable if the net acidity level recorded is <10 moles H+/tonne or <0.02%S equivalent.

6.6.2 Retained Water

Laboratory testing of all collected water will be carried out prior to off-site discharge. Test levels considered acceptable to be determined in consultation with DERM and the applicable EPC Contractor(s).

6.6.3 Groundwater

6.6.3.1 *Quality*

Testing of groundwater will be carried out during the dewatering process to determine if it is acceptable for on-site reuse in groundwater re-charge trenches. .

6.6.3.2 *Level*

Groundwater levels in the monitoring bores will be checked during bulk earthworks, until the water level in adjacent excavation areas reaches 0.1m above the average groundwater level. The groundwater level in the monitoring bores should not fall below the same level.

6.7 Frequency/Timing

6.7.1 Treated ASS

The sampling and testing of any lime treated ASS will be subject to validation testing which will be repeated for each batch at treated soil until satisfactory results are obtained.

6.7.2 Retained Water

When run-off accumulates, water quality in drains or retention basins will be monitored regularly during the construction period, particularly following substantial rainfall events. Retained water will be sampled, tested and treated to a level acceptable prior to discharge to external waterways. Sampling is to be in accordance with the GWMP.

6.7.3 Groundwater

6.7.3.1 *Quality*

Groundwater seepage pH is to be monitored during any pond/excavation dewatering process. If the groundwater exceeds the performance criteria then treatment will be required prior to discharge on-site to recharge trenches.

6.7.3.2 *Level*

The reduced level (RL) of groundwater in groundwater monitoring bores should be checked daily. If the groundwater level is less that 0.1m above the average groundwater level, the groundwater recharge system shall be adjusted until the water level reaches this level.

6.8 Contingency Plan

If lime treatment of ASS is unsuccessful (whereby performance targets are not being met as indicated by the validation testing and water quality testing procedures) then:

- the earthworks schedule will be reassessed and action taken to determine the problems causing the breach of standards;
- if the problems are related to ineffective implementation of the ASSMP, then the plan will be audited by a person nominated by the EPC Contractor (and approved by QGC) to ensure improved implementation and compliance. Monitoring and testing will be increased to ensure compliance with the established standards; and
- any significant changes to the ASSMP will be subject to discussions between the EPC Contractor, QGC and the Regulator (currently the Queensland Department of Environment and Resource Management (DERM)).

If re-charge strategies put in place to control groundwater drawdown during the dewatering process are not sufficient, then additional groundwater re-charge will be undertaken as a matter of priority until groundwater levels conform to the required RL.

An appropriate supply (but not less than 2 tonnes) of hydrated lime or other appropriate soluble neutralising agent and suitable distribution equipment shall be kept on the site at all times to adjust the pH of surface waters if required. Hydrated lime or similar may only be applied under the direct supervision of the ASS Consultant who shall ensure that it is added in small increments so as not to cause unduly high water pH levels (i.e. above 8.5). The hydrated lime or similar shall be stored in a covered and bunded area to prevent accidental release to waters. For additional guidance on suitable neutralising agents and their application, refer to Section 5.4.3 of this ASSMP Framework.

6.9 ***Responsibility***

Implementation of the ASSMP for a site is the responsibility of the EPC Contractor for that particular site.

6.10 ***Reporting***

The EPC Contractor shall report weekly to QGC on:

- compliance with the ASSMP;
- the effectiveness of the operating strategies to manage ASS;
- problems in implementing ASSMP management strategies;
- compliance with ASS testing requirements, run-off control and materials handling;
- effectiveness of any corrective action adopted;
- volume and extraction location of ASS excavated and tonnage treated during the period; and
- ASS testing results prior to neutralisation and post neutralisation verification test results.

The form of weekly report(s) required shall be agreed with the QGC (in consultation with Queensland's Department of Natural Resources and Water) prior to commencement of construction.

All reports are to be cross referenced by date and number and shall form a permanent record of ASS treatment conducted on site.

SECTION 7 - MONITORING AND COMMUNICATION

7.1 ***General Monitoring***

The responsibility for general environmental monitoring rests with all personnel engaged in the project. More specifically the EPC Contractor shall be responsible for monitor element of the construction process within their scope to ensure that appropriate environmental protection/procedures are in place. The EPC Contractor will report any non-conformances to QGC.

Requirement for a third party ASS expert on site to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction.

7.2 ***Consultation***

Environmental issues during construction that need to be communicated to the DERM (e.g. road closures, water quality decisions, after hours work, nuisance activities):

Gary Kane
Community Response Unit
DERM
Telephone: 1300 130 372

If as a result of environmental management, safety is jeopardised, safety shall take precedence over environmental management and the Gladstone City Council/Port Authority shall be notified.

7.3 ***Environmental Complaints***

The EPC Contractor will investigate all environmental complaints and these shall be recorded on the project records (draft Complaints Register provided in Appendix C). The Register will detail the nature of any complaint and the proposed course of action considered necessary.

Where considered appropriate, the Principal Contractor shall notify the QGC Representative of complaints received. Complaints received by QGC or their Representative may also be registered on the project records and be subject to investigation by QGC as appropriate.

7.4 ***Environmental Incidents***

Should an environmental incident occur during the course of the works, the witness shall make every effort to inform the EPC Contractor so controls can be implemented to minimise any environmental harm that may be caused.

7.5 *Environmental Training*

As part of site induction/training, all personnel engaged in site works shall be made aware of the Acid Sulfate Soil Management Plan in order to promote a general awareness of the environment and to minimise any potential impact. Evidence of environmental induction of personnel shall be maintained on the project records (Record of ASSMP Induction form provided in Appendix C).

The Contractor's supervisory staff and all staff engaged by the Contractor or Sub-Contractors who may be involved in the earthworks or drainage on the site shall be trained in the appropriate handling and treatment of acid sulfate soils. The training shall be undertaken by a suitably experienced ASS consultant (or other party with suitable experience/qualifications) prior to commencement of earthworks construction and shall include:

- an outline of the sensitivity of the area to environmental harm;
- the potential for acid generation on the site and its likely impacts;
- description of the ass soils on the site and how to identify them;
- details of the strategies in the ASSMP for the management of works such that ASS soils are not exposed;
- details of the strategies in the ASSMP for the treatment and handling of ASS soils which are exposed on the site;
- details of the strategies for the management of the watertable and oxygen diffusion to prevent oxidation of in-situ ass;
- details of the responsibilities of the individuals attending the training in implementing the above management strategies; and
- details of reporting and monitoring responsibilities.

Training shall be repeated at six monthly or at other appropriate intervals, in order to ensure that all staff remains fully aware of their environmental responsibilities. Induction and training courses shall be conducted for all new staff on the site who may be involved in earthworks and drainage prior to their commencement of work on the site.

SECTION 8 - AUDITING

Compliance with the ASSMP should be audited by the Environmental Manager. Audit protocol and timing to be determined in consultation with DERM and the applicable EPC Contractor(s) prior to commencement of construction...

The results of the audit will be retained in Company records and conveyed to QGC including any areas requiring improvement. Methodologies for improving environmental performance will be discussed and agreed with the auditor and documented for reference in future audits.

All environmental records including audit records should be retained and be available for review by the DERM as required.

SECTION 9 - REFERENCES

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SECTION 10 - GLOSSARY

AASS - Actual Acid Sulfate Soil

A.H.D. - Australian Height Datum - this datum has been adopted by the National Mapping Council as the datum to which all vertical control for mapping is to be referred. Generally approximates mean sea level

Aerobic - said of conditions that can exist only in the presence of free oxygen. Cf. Anaerobic

Antecedent - preceding in time or order

Aquifer – rock or sediment in a formation, group of formations or part of a formation that is capable of storing and transmitting

Asthenosphere - the layer of the Earth below the lithosphere, which is weak and in which isostatic adjustments take place, magmas may be generated, and seismic waves attenuated. It is part of the upper mantle (Bates & Jackson, 1987)

Colluvium - a general term applied to any loose, heterogeneous and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow continuous downhill creep (Bates & Jackson, 1987)

EPC – Engineer, Procure, Construct

Facies - an areally delimited, mappable sedimentary body associated by either character or depositional provenance

Foraminifer - a microscopic, primarily marine organism (protozoan of the subclass Sarcodina, order Foraminifera) characterised by the presence of a test of one or more chambers composed of secreted calcite

Geomorphology - 'the science that treats the general configuration of the Earth's surface; specif. the study of the classification, description, nature, origin, and development of present iandforms and their relationship to underlying structures, and of the history of geologic changes as recorded by these surface features' (Bates and Jackson, 1987)

Groundwater – subsurface water in a zone of saturation, including water below the watertable

Holocene - Holocene is the name of a geological time epoch commencing 10,000 years ago and extending to present. Pre-Holocene is the time proceeding this epoch. The Immediate time epoch preceding is the Pleistocene time epoch, however, sediments immediately underlying those of Holocene-age may have been deposited much earlier than the Pleistocene, and are therefore referred generally as pre-Holocene in age

Hydroisostatic - as sea level rises over broad continental shelves the additional weight of the water creates subsidence on the outer shelf which is compensated for by a rise of the inner shelf and coastal plain.

Incipient - beginning, coming into, or in an early (or initial) stage of existence

Intercalated - said of layered material that exists or is introduced between other layers of a different character (Bates & Jackson, 1987)

Intersticed - an intervening space of time; an interval between actions

Interstitial water - subsurface water in the voids of a rock or pores of a sediment (i.e. or porewater)

Interfluve - area between rivers; esp. the relatively undissected upland or ridge between two adjacent valleys containing streams flowing in the same general direction (Bates & Jackson, 1987)

Jarosite – an acidic pale yellow iron sulfate mineral

Laterite - a highly weathered red subsoil or material rich in secondary oxides of iron, aluminum, or both (Bates &Jackson, 1987)

Leachate – the soil constituent that is washed out from a mixture of soil solids

Microtidal -spring tide range <2m

Mesotidal - spring tide range of 2m to 4m

Mol Wit - a unit of measurement of acidity determined through laboratory testing: moles of hydrogen ions per tonne of soil

Neutralising – the process by which acid produced is counteracted by the addition of a base (e.g. lime)

Oxidised – process of chemical change involving the addition of oxygen

Palaeo - denoting great age or remoteness in regard to time - ancient conditions PASS - Potential Acid Sulfate Soil

PASS – Potential Acid Sulfate Soil

Piedmont - lying or formed at the base of a mountain or mountain range; e.g. a piedmont terrace or pediment. (Bates &Jackson, 1987)

pH_{KCl} - the pH (measure of acidity or alkalinity) *of a* suspension prepared in the laboratory involving 1:40 (weight/volume) soil in a solution of 1 M potassium chloride

Pisolitic - the texture of rock made up of pisoliths or pea-like grains (Bates & Jackson, 1987)

Pleistocene - a time epoch of the Quaternary period. it began 2 million to 3 million years ago and extended to the commencement of the Holocene epoch 10,000 years ago.

Prodelta - extension of the delta influence beyond the delta front as a wedge of fine sediment gently sloping to the floor of the basin

Progradation - the building forward or outward toward the sea of a shoreline or coastline

Proto - first in time, earliest, original, primitive

Pyrite – pale bronze or brass yellow, isometric material: FeS_z

QGC – Queensland Gas Company Limited

Quaternary - a time period beginning 2 million to 3 million years ago and extending to present. This time period encompasses the Pleistocene and Holocene time epochs

SPOCAS – Suspension Peroxide Oxidation Combined Acidity and Sulfur

Stillstand - a term that describes the stabilisation of sea level at around its present level (c.a.6,500 years ago, Thom and Roy, 1985) following a rapid rise in the early Holocene epoch.

Subaerial - conditions and processes that exist or operate in the open air (Bates & Jackson, 1987)

Supratidal - just above high tide level

Swale - a long, narrow, generally shallow, trough-like depression between two beach ridges

TAA – Titratable Actual Acidity

Thalweg - the line connecting the lowest or deepest points along a stream bed or valley; the line of maximum depth

TPA – Titratable Potential Acidity

Transgression - the progressive marine incursion of the land surface as sea level rises

Watertable – portion of the ground saturated with water; often used specifically to refer to the upper limit of saturated ground

Winnowing - selective sorting or removal of fine particles by wind or water

Vadose - upper soil water zone which is aerated by watertable fluctuations

Vugh- a relatively large and usually irregular void [often infilled by different material or sediment] in a soil, but not normally connected to other voids of comparable size (Bates & Jackson, 1987)

APPENDIX A

LOCAL LIME SOURCES

Sources of agricultural lime/hydrated lime

- *Cement Australia*, Fisherman's landing
  (http://www.cemaust.com.au/driver.asp?page=main/operations/manufacturing%20operations/gladstone%2C%20queensland)
  (07) 4940 1138
- *Hanson Concrete Plant* – Cement, Lime, Plaster and Concrete Manufacturers
  Rye St, South Gladstone, QLD, 4680
  (07) 4979 1210
- *Bona's Concreting and Steel Fixing* - Cement, Lime, Plaster and Concrete Manufacturers
  (07) 4972 1554

APPENDIX B

BUREAU OF METEOROLOGY DATA

Wind Information

Only wind information for 2 sites

Wind direction annually for 9am and 3pm are attached.

Site 1: Gladstone Airport http://www.bom.gov.au/climate/averages/tables/cw_039326.shtml

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean 9am Windspeed (km/hr)	16.9	15.8	16	14.5	13.1	12.4	12.1	12.3	14	15.9	16.1	15.9	14.6
Mean 3pm Windspeed (km/hr)	24	22.8	23.6	21.8	18.1	17	16.8	19.8	21.3	22.6	22.8	23.1	21.1

Site 2: Gladstone Radar http://www.bom.gov.au/climate/averages/tables/cw_039123_All.shtml

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean 9am Windspeed (km/hr)	15.7	16.5	16.4	15.6	13.5	12.4	11.6	11.4	12.9	14.8	15.1	14.8	14.2
Mean 3pm Windspeed (km/hr)	23.4	23.2	23.3	21.5	18	15.6	16.1	18.3	21	22.3	23	22.8	20.7

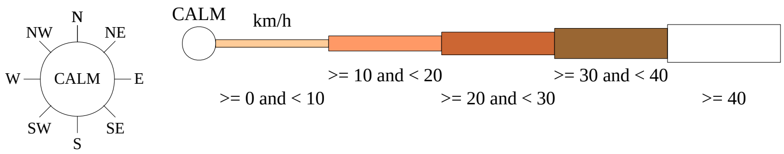
Rose of Wind direction versus Wind speed in km/h (26 Oct 1993 to 30 Jun 2008)

Custom times selected, refer to attached note for details

GLADSTONE AIRPORT

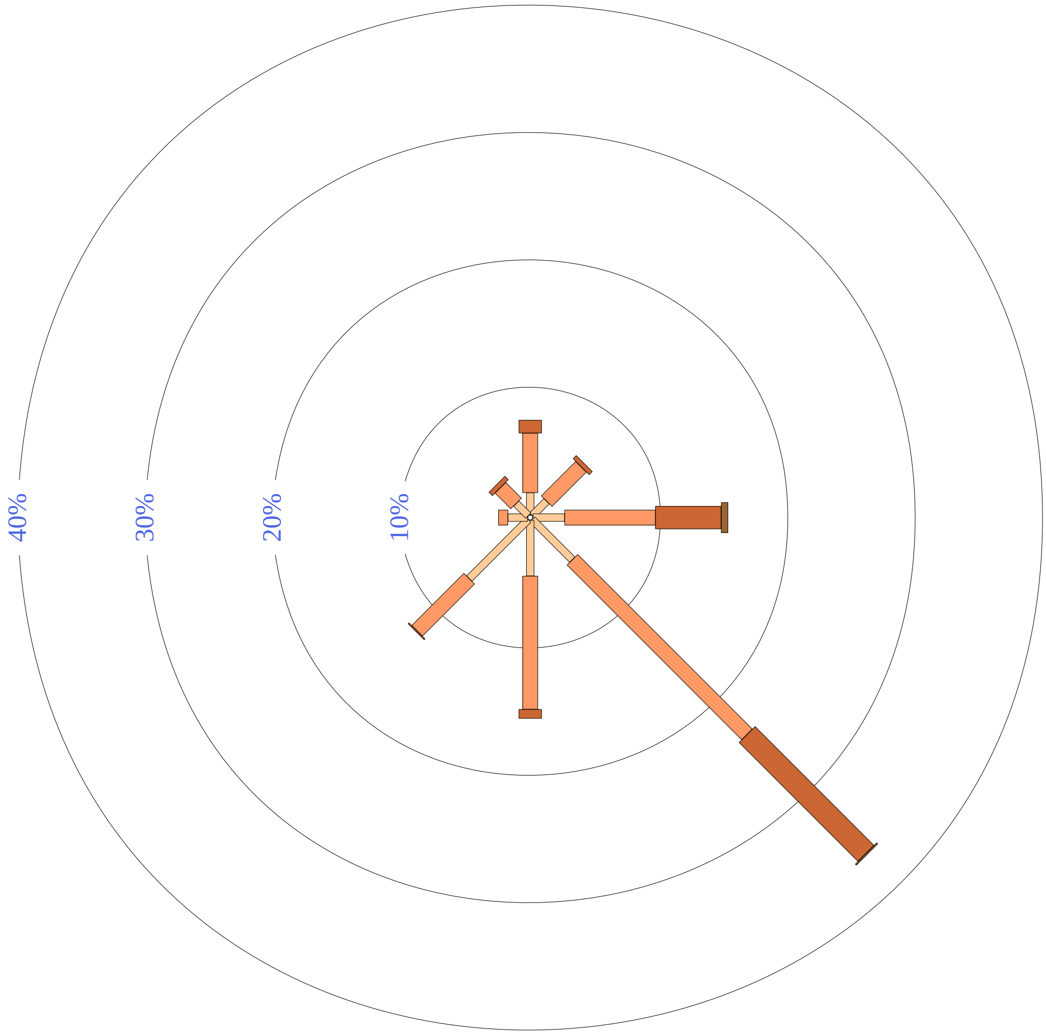
Site No: 039326 • Opened Oct 1993 • Still Open • Latitude: -23.8697° • Longitude: 151.2214° • Elevation 16.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.



9 am
5219 Total Observations

Calm 1%



Rose of Wind direction versus Wind speed in km/h (26 Oct 1993 to 30 Jun 2008)

Custom times selected, refer to attached note for details

GLADSTONE AIRPORT

Site No: 039326 • Opened Oct 1993 • Still Open • Latitude: -23.8697° • Longitude: 151.2214° • Elevation 16.m

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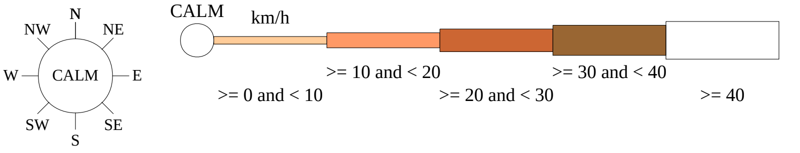
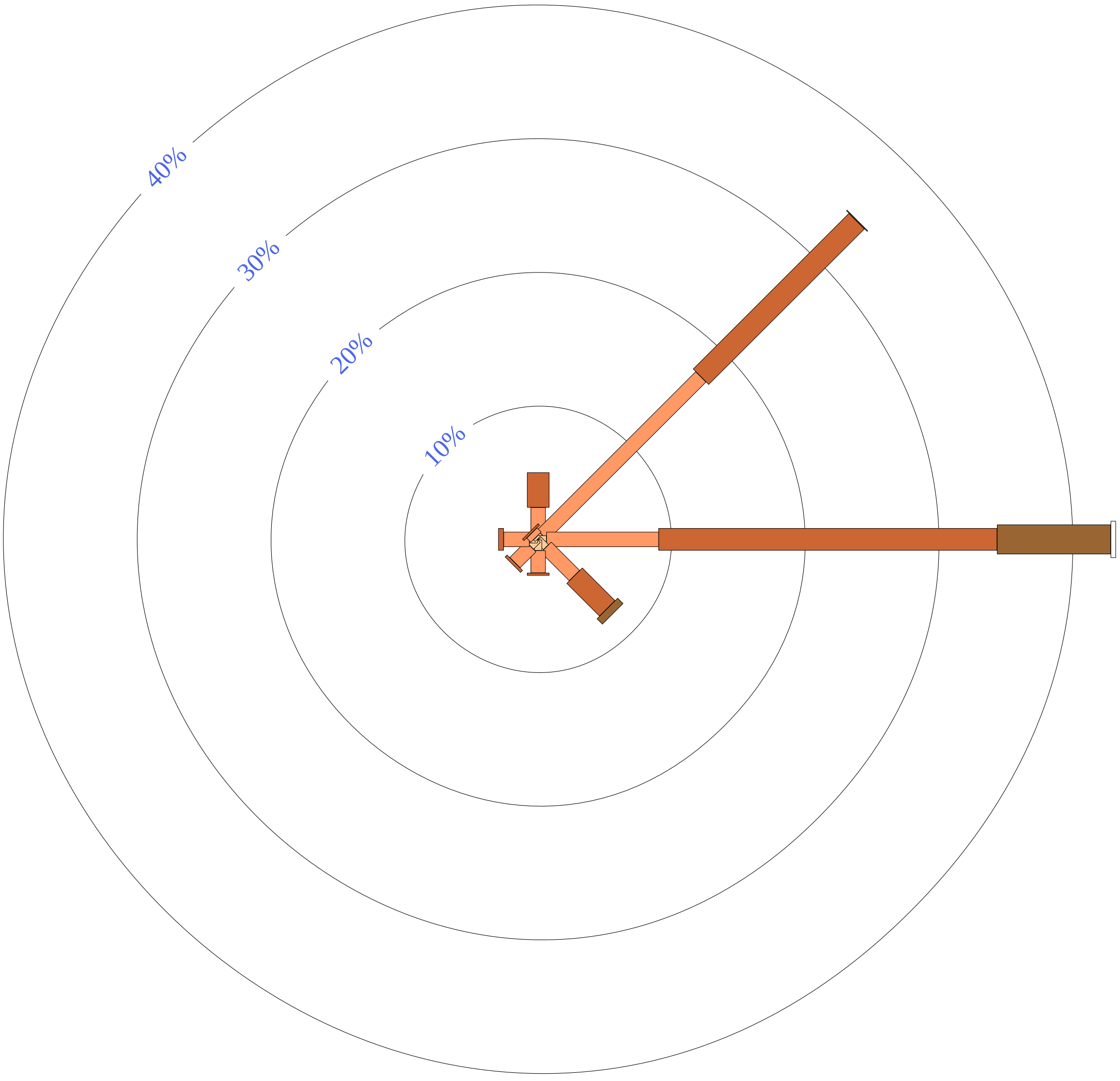


3 pm
5228 Total Observations

Calm *



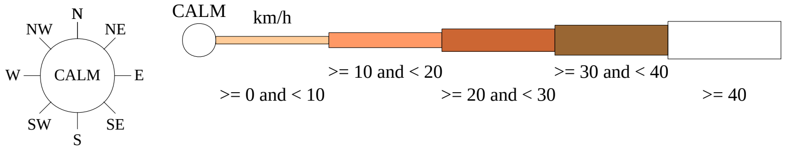
Rose of Wind direction versus Wind speed in km/h (02 Dec 1957 to 30 Jun 2008)

Custom times selected, refer to attached note for details

GLADSTONE RADAR

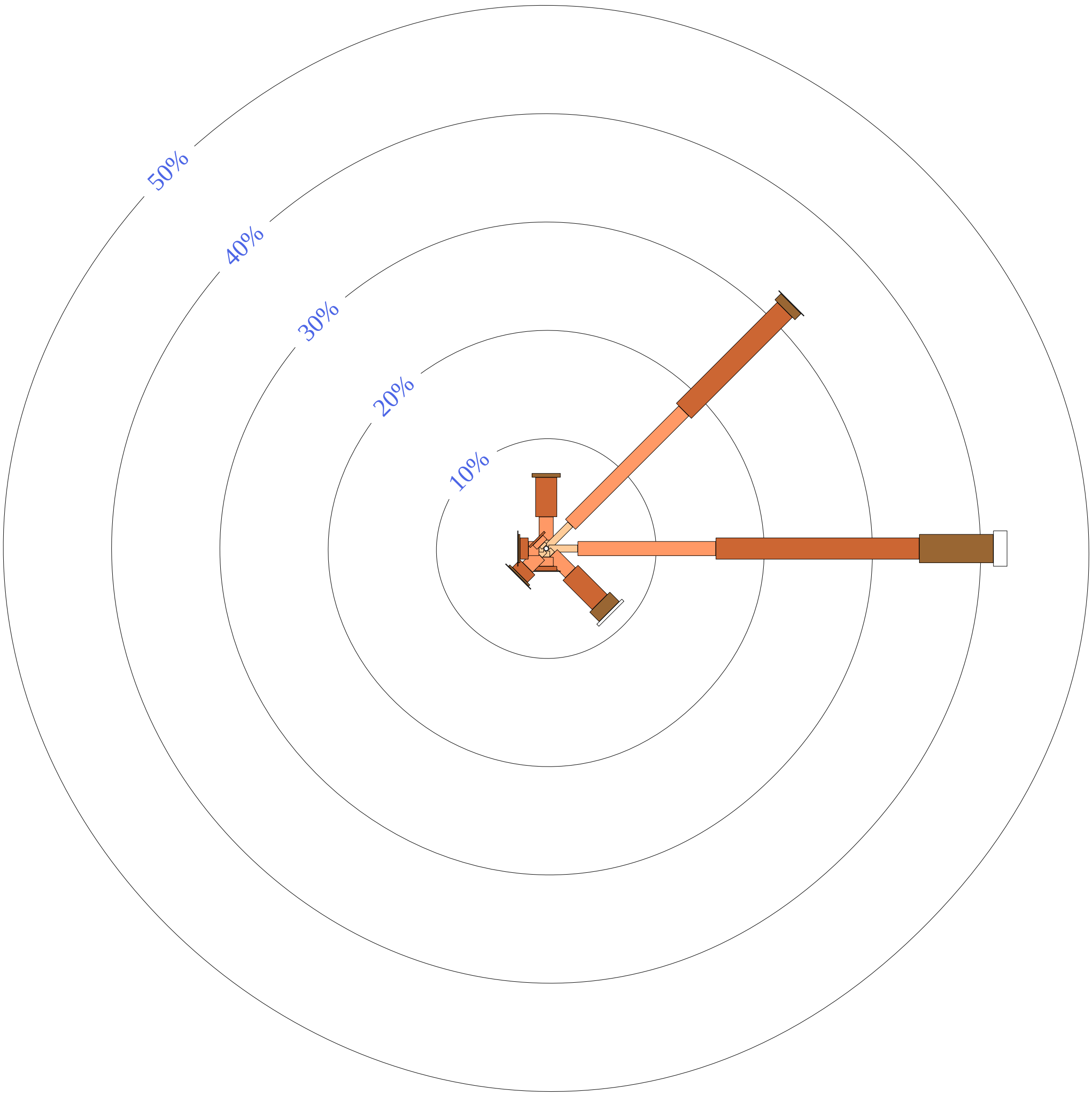
Site No: 039123 • Opened Jan 1957 • Still Open • Latitude: -23.8553° • Longitude: 151.2628° • Elevation 74.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.



3 pm
18244 Total Observations

Calm 1%



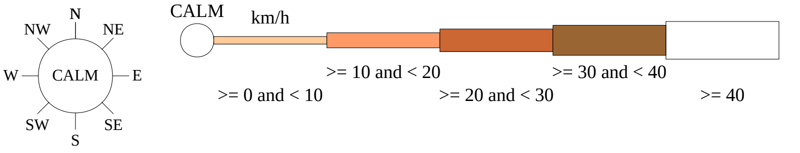
Rose of Wind direction versus Wind speed in km/h (02 Dec 1957 to 30 Jun 2008)

Custom times selected, refer to attached note for details

GLADSTONE RADAR

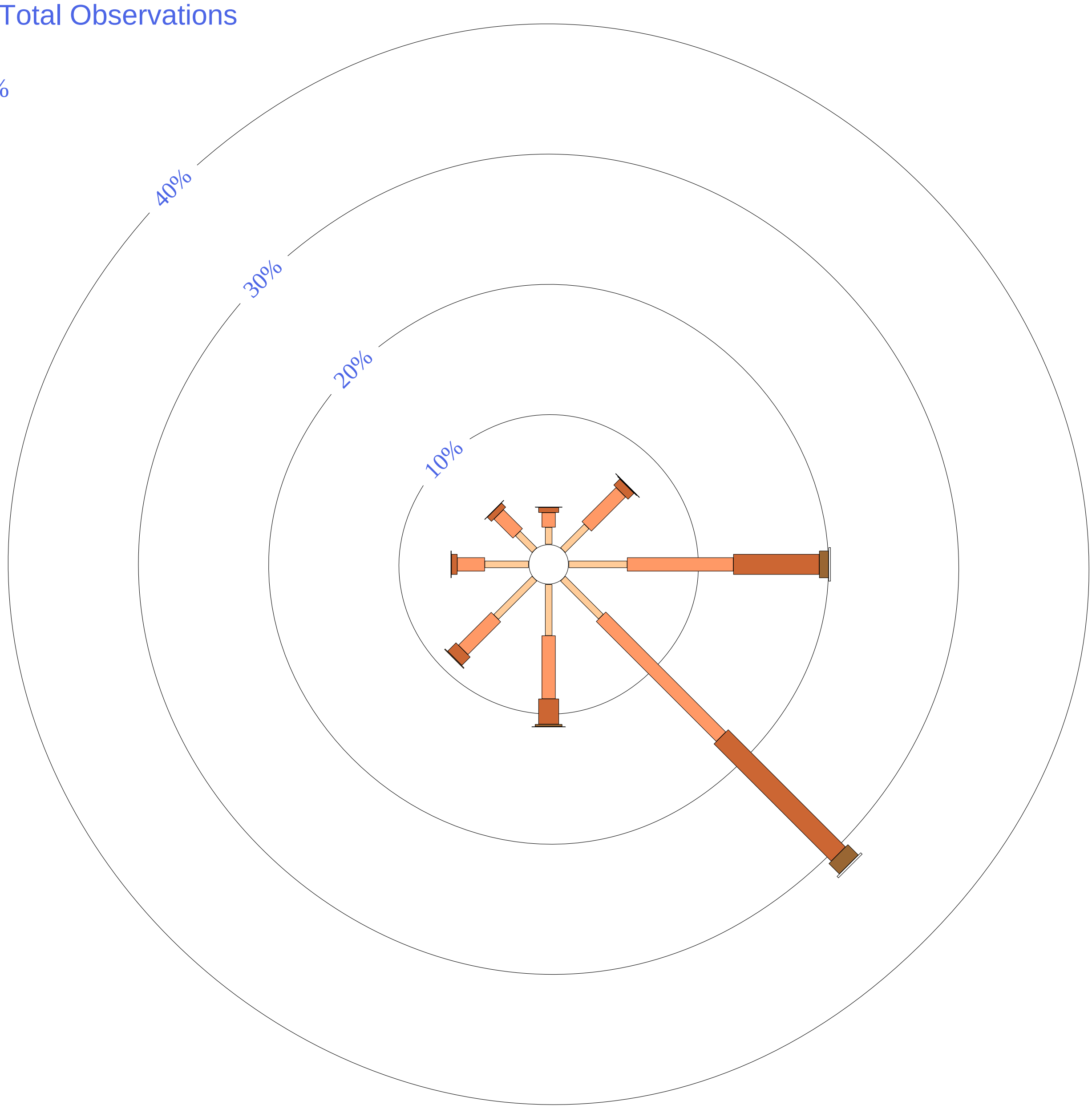
Site No: 039123 • Opened Jan 1957 • Still Open • Latitude: -23.8553° • Longitude: 151.2628° • Elevation 74.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.



9 am
18321 Total Observations

Calm 8%



APPENDIX C

FORMS

WATER QUALITY MONITORING

Location	*pH*	*Turbidity*	*Dissolved Oxygen*	*Inspection*		*Comments*
				Date	*Time*	

COMPLAINTS REGISTER

Date	*Complaint*	*Complainant*	*Action*	*Sign Off*

Record of ASSMP Induction

Date	*Person Inducted*		*Inducted By*	
	Name	*Position*	*Name*	*Position*

APPENDIX D

SITE SPECIFIC ASSMP PROFORMA

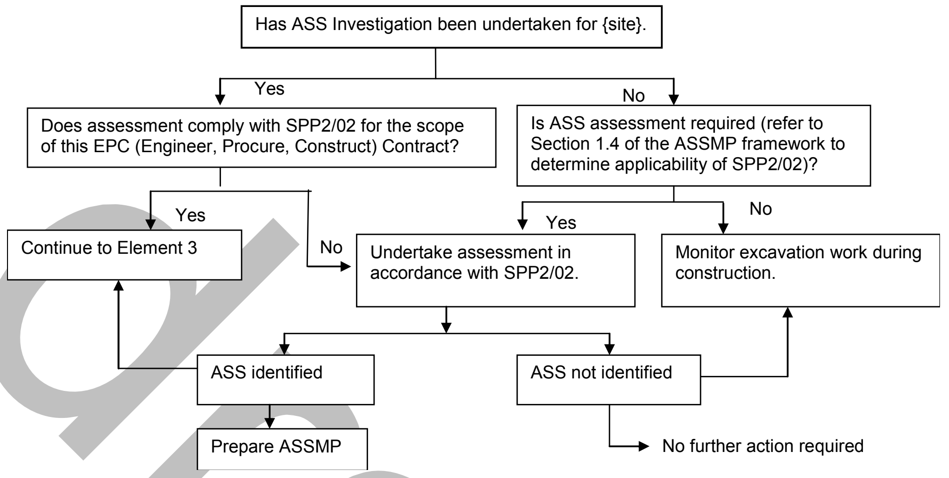
Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

Element	Acid Sulfate Soil Management Plan
1. Objective/Target	The objective of the Acid Sulfate Soil Management Plan (ASSMP) is to control potential acid generation from the ASS and to restrict to an acceptable level, potential on site and off site environmental impacts especially to water and air) for bulk excavation and filling works associated with the development of the upstream QCLNG plant at Curtis Island, Gladstone, Queensland. This ASSMP must be completed with reference to the QCLNG Project Acid Sulfate Soils Management Plan Framework.
2. EPC Contract Site Details	1. Site location description 2. Do the works involve disturbance of soil below RL10mAHD (this does not include the installation of driven piles) ☐ Yes - go to Question 3 ☐ No - no further ASS management action required 3. Are the works to be conducted: ☐ onshore ☐ offshore ☐ in the intertidal zone 4. Volume of material to be disturbed ________ Approx. ASS ___________ Approx non-ASS ___________ 5. Is the groundwater table to be lowered? ☐ Yes - a GWMP is required ☐ No - no GWMP required 6. Do site works include filling over 'soft soils'? ☐ Yes - a Fill Stability Assessment is required ☐ No - no Fill Stability Assessment required - Does the Site Geology include Holocene/Pleistocene deposits or areas below RL5m AHD? ☐ Yes - continue through ASSMP Proforma ☐ No - no further ASS action required

Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

Element	Acid Sulfate Soil Management Plan
	
3. Works to be Undertaken	Provide a detailed description of work to be undertaken including: - Purpose of excavation e.g. pipeline construction removal of mangroves etc. - Excavation methodology - Extent of area (provide plans) - Extent of depth (provide construction/bulk earthworks drawings as appropriate) - Any permits required (provide copy) From above please provide a copy of any GWMP and/or Fill Stability Assessment (as required).
3. ASS Management Strategy	To mitigate and manage potential environmental impacts associated with ASS during site construction operations. This will be achieved by the following strategy/strategies (refer to Section 5 of the ASSMP Framework for details) (tick the appropriate box/boxes): ☐ Avoidance ☐ Minimisation ☐ Neutralisation ☐ Hydraulic Separation – sluicing ☐ Hydraulic Separation – hydrocycloning ☐ Strategic Reburial ☐ Vertical Mixing[1.] ☐ Above Ground Capping[1.] ☐ Off-shore Disposal[1., 2.] Notes: 1. These ASS management strategies require approval to adopt and will require justification *2. Off-shore disposal will require compliance with the National Assessment Guidelines for Dredging, 2009.*

Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

Element	Acid Sulfate Soil Management Plan
	Regardless of the strategy/strategies adopted, any opportunity to minimise disturbance of ASS should be reviewed and adopted where possible.

4. Tasks/Actions	The following actions must be carried out as a minimum prior to the commencement of and during the construction of earthworks activities (select as appropriate for the adopted strategy/strategies). Information to assist in the provision of information is provided in the ASSMP Framework Document. ☐ Neutralisation (refer to Section 5.4 of the ASSMP Framework) Prior to Commencement: • Determine volume of ASS material to be disturbed. • Determine neutralisation rate based on site specific ASS results. • Nominate the neutralisation material(s) proposed to be utilised (refer to Table 5 in Section 5.4.1 of the ASSMP Framework). • Provide details of the treatment pad design including the bund capacity (refer to Section 5.4.3 of the ASSMP Framework). • Provide details of stockpile management plans (including stockpiles of both ASS and neutralising agent) (refer to Section 5.4.3 of the ASSMP Framework). During Earthworks: • During bulk earthworks ASS will be treated with the required neutralisation rates the specific site ASS soils. The success of treatment is to be verified as per Section 5.4.4 of the ASSMP Framework. • Treatment pads will be constructed and maintained in accordance with the approved design. Note - ASS soils (if any) can either be treated on-site if sufficient space exists or off-site • Any lime-treated stockpiled (previous ASS) soil shall have sediment fences and/or hay bales placed downslope to intercept any eroded material. • All retained waters would then be tested before off site discharge to nearby waterways as described in Element 6 below. • Once neutralisation treatment is complete, the treated spoil may then be stockpiled for later re-use on site or off-site disposal (as appropriate). • All stockpiles must be continuously monitored for compliance with the stockpile management plan. ☐ Hydraulic Separation – sluicing or Hydrocycloning (refer to Section 5.5 of the ASSMP Framework) Prior to Commencement: • Provide a detailed description of the intended process including any relevant design drawings. • A discussion of why this is the most appropriate option and how it will work with due consideration for site specific geology. • Provide a description of the management protocols for:

Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

  - management of sediments to prevent oxygen exposure;
  - management of process water;
  - management of sulfidic fines including treatment; and
  - materials tracking procedures.

  (refer to Section 5.5.1 of the ASSMP Framework)

During Earthworks:

- Once separation is complete, the separated sand/gravel fraction will be stockpiled for later re-use on site or off-site disposal (as appropriate). The success of treatment is to be verified by undertaking Suspension Peroxide Oxidation – Combined Acidity and Sulfur (SPOCAS) or Chromium Suite analyses. The rate of verification testing is described in Element 6 below.
- Once separation is complete, the separated sulfidic fines will be handled in accordance with the management plan prepared and approved. Where treatment of the fines is undertaken using neutralisation, the success of treatment is to be verified as per Section 5.4.4 of the ASSMP Framework.
- All retained waters would then be tested before off site discharge to nearby waterways as described in Element 6 below.
- Treated sulfidic fines will be reburied in accordance with the management plan prepared and approved. Documentation tracking these materials including their final reburial location will be maintained.

☐ Strategic Reburial (refer to Section 5.6 of the ASSMP Framework)

Prior to Commencement:

- Provide a detailed description of the intended process including any relevant design drawings and reburial locations.
- Provide evidence that the material contains only minimal or no existing acidity.
- Provide details of strategies to manage sediments to prevent oxygen exposure.

During Earthworks:

- Documentation tracking the ASS materials from cradle to grave including their final reburial location will be maintained.

☐ Vertical Mixing (refer to Section 5.7.1 of the ASSMP Framework)

Prior to Commencement:

- Describe the mixing process proposed.
- Provide justification that the site has been sufficiently characterised to use vertical mixing.
- Provide detailed scientific discussion including site specific data and justification supporting the use of vertical mixing. This document will need to be site specific and will require consideration of the characteristics of the material being disturbed as well as the environmental setting in which the strategy will be undertaken.

☐ Above Ground Capping (refer to Section 5.7.2 of the ASSMP Framework)

Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

	Provide detailed scientific discussion and justification supporting the preferred strategy. This strategy will require approval from DERM and full data required by the *National Assessment Guidelines for Dredging, 2009.* ☐ Off-shore Disposal (refer to Section 5.7.5 of the ASSMP Framework) Prior to Commencement: Provide detailed scientific discussion and justification supporting the preferred strategy. This strategy will require approval from DERM and full data required by the *National Assessment Guidelines for Dredging, 2009.*
5. Performance Indicators	<u>Verification Testing</u> Laboratory testing using either SPOCAS or Cr suite should be undertaken with results compared against the following performance criteria: ☐ Neutralisation (refer to Section 5.4.4 of the ASSMP Framework) • The neutralising capacity of the treated soil must exceed the existing plus potential acidity of the soil; and • Post-neutralisation, the soil pH is to be greater than 5.5; and • Excess neutralising agent should remain within the soil until all acid generation reactions are complete and the soil has no further capacity to generate acidity, this is best achieved by the use of a good quality neutralising agent. ☐ Hydraulic Separation – sluicing or Hydrocycloning (refer to Section 5.5.3 of the ASSMP Framework) • target of ≤18 moles H^+/tonne (0.03 %S); • no sample shall exceed 25 moles H^+/tonne (0.04 %S); • if any single sample exceeds 18 moles H^+/tonne (0.03 %S), then the average of any 6 consecutive samples (including the exceeding sample) shall have an average not exceeding 25 moles H^+/tonne (0.03 %S); • if more than one sample in any 6 consecutive samples exceeds 25 moles $H^{+/}$tonne (0.03 %S), then the average of any 6 consecutive samples (including the exceeding samples) shall have an average content not exceeding 16 moles H^+/tonne (0.03 %S). ☐ Strategic Reburial (refer to Section 5.6.3 of the ASSMP Framework) • PASS have been maintained in anoxic and anaerobic conditions at all times; • Soils with significant untreated existing acidity have not been interred.

Site Specific Acid Sulfate Soil Management Plan Proforma
QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

5. Performance Indicators	<u>Retained Water</u>: Laboratory testing of retention basin/tank drainage water will be carried out for pH, dissolved oxygen and turbidity. Levels of these parameters considered acceptable are as follows: pH 6.5 to 8.5 pH units Turbidity <20NTU Dissolved Oxygen >80% saturated Laboratory analysis for the following parameters should also be performed (as per the State Planning Policy 2/02 *'Planning and Managing Development involving Acid Sulfate Soils'*) if the pH <6.5: • Bicarbonate • Calcium • Carbonate • Chloride • Colour • Dissolved magnesium • Filtered aluminum • Magnesium • Sulfate • Total and dissolved iron
6. Frequency/ Timing	<u>Verification Testing</u> For neutralisation treatment, verification shall be as per Section 5.4.4 of the ASSMP Framework. <u>Retained Water</u>: For all accumulated run-off, water quality in drains or retention basins/tanks will be monitored regularly (frequency based on total volume retained and holding capacity) during the construction period, particularly following substantial rainfall events. Retained water will be sampled, tested and treated to a level acceptable for discharge to external waterways.
7. Contingency Plan	If management of ASS is unsuccessful whereby performance targets are not being met as indicated by the validation testing and water quality testing procedures. • The earthworks schedule will be reassessed and action taken to determine the problems causing the breach of standards. • If the problems are related to ineffective implementation of the ASS Management Plan, then the plan will be audited and measures develop for improved implementation. Monitoring and testing will be increased to ensure compliance with the established standards. • Any significant changes to the Management Plan will be subject to discussions with the relevant regulatory authorities.
8. Responsibility	The satisfactory implementation of the ASSMP is the responsibility of the EPC Contractor.

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QCLNG – {Site}
Curtis Island, Gladstone, Queensland

Contractor's Name:
ASS Consultant:

9. Reporting	The contractor undertaking the treatment of the ASS shall report to the EPC Contractor on: • The effectiveness of the operating strategies. • Problems in implementing the ASSMP management strategies. • Compliance with testing requirements, run-off control and materials handling. • Effectiveness of any corrective action adopted. Audits and reporting will be undertaken as outlined in Section 8 of the ASSMP Framework.

Prepared by: ____

Approved by (QGC Representative): ____