FINAL REPORT

GLNG Project - Dredge Material Placement Facility

Groundwater Assessment

Prepared for

Santos Ltd

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Table of Contents

Tables

Figures

Executive Summary

A high level evaluation of the proposed dredging and dredge material placement facility site was conducted to determine the site suitability from a groundwater perspective. The preliminary hydrogeology assessment was based on dredge material disposal methodology details, the EIS groundwater study of the LNG facility site, sediment physical and chemical characteristics, and a literature review. In order to assess the suitability of the proposed site for dredge material disposal from a groundwater perspective the Waste – Aquifer Separation Principle (WASP) methodology was used.

The dredge material was recognised to comprise mainly uncontaminated sand with limited acid generating potential. The large size of the dredge material placement facility site (approximately 120 ha footprint) and the saturated nature of the dredge material indicate that there is the potential to generate seepage, which could potentially migrate from the bunded area and off site. The resultant seepage could potentially alter groundwater quality due to increased salinity.

An evaluation of the groundwater resources indicates two separate groundwater regimes within the proposed dredge material placement facility footprint. These two regimes include:

- Shallow hyper saline groundwater resources within the intertidal zone, which is underlain by mudflats. The groundwater associated with the mudflats has limited environmental value and have no beneficial use. This portion of the site would not be markedly impacted by possible saline seepage from the dredge material placement facility.
- Discrete fractured and weathered aquifers within the competent Wandilla Formation. An existing bore within the footprint indicates that the groundwater resources can provide limited quantities of groundwater, which is suitable for stock watering. These discrete aquifers therefore have limited beneficial value.

An assessment of the unsaturated zone within the Wandilla Formation indicates that, due to permeability and the shallow depth to groundwater, the groundwater is vulnerable to a surface contaminant source. Groundwater resources will, therefore, require protection through improving the barrier between the dredge material and the groundwater table, especially during the initial deposition of wet dredge material directly on the ground.

Seepage from the dredge material, through or under the retaining bunds on the Wandilla Formation, could potentially alter groundwater quality and cause waterlogged areas. The zone of influence caused by the possible seepage can be immediately adjacent to the site or could migrate further depending on the underlying structures. This will depend on site specific permeability, head pressures, and geological structure (preferential flow paths) data.

The initial assessment of the Laird Point dredge spoil placement facility indicates that the site is currently suitable for dredge material disposal, from a groundwater perspective, within the intertidal zone. Limited to low levels of groundwater protection are required for the aquifers associated with the Wandilla Formation. The inclusion of groundwater protection measures, such as including compacted clay bases, in the final disposal site design will allow for the reduction of the risk to the groundwater regime

The evaluation of groundwater resources within Laird Point dredge material placement facility indicates that the site is suitable for dredge material disposal if such mitigation measures are adopted.

Introduction Section 1

Capital and maintenance dredging, to develop the GLNG loading facility and improve navigation, is proposed off-shore of Curtis Island in Port Curtis. The dredging will facilitate the movement of ships to and from the proposed LNG facility.

According to the HR Wallingford report (HR Wallingford, 2009) dredging operations will initially occur at the navigation approach to the Materials Off-Loading Facility (MOF). A total of some 100,000 m^3 is anticipated to be dredged. This material is assumed as 50% suitable for using as construction and 50% as soft clay, to be used for landscaping. The placement site for this material is unclear at present, it may either be utilised some 1.5 km from the MOF (on a haul road or the materials reception area) or at the existing Fisherman's Landing facility. The Fisherman's Landing site is licensed to receive dredged material. No additional details or designs regarding the MOF dredge material are available. As the dredge material will either be used for beneficial use or deposited at a licensed site it has not been considered further in this assessment.

Following the MOF dredging the main dredging operations, which include the navigation approach channel, berthing, and manoeuvring areas, a total of 8,000,000 m^3 *in-situ* is anticipated to be dredged. The disposal of this dredge material on land above the high water mark is being considered. Various sites were considered for the land based receiving facility and Santos requested the evaluation of the site south of Laird Point. **Figure 1** presents the proposed dredge material placement facility site, labelled Laird Point.

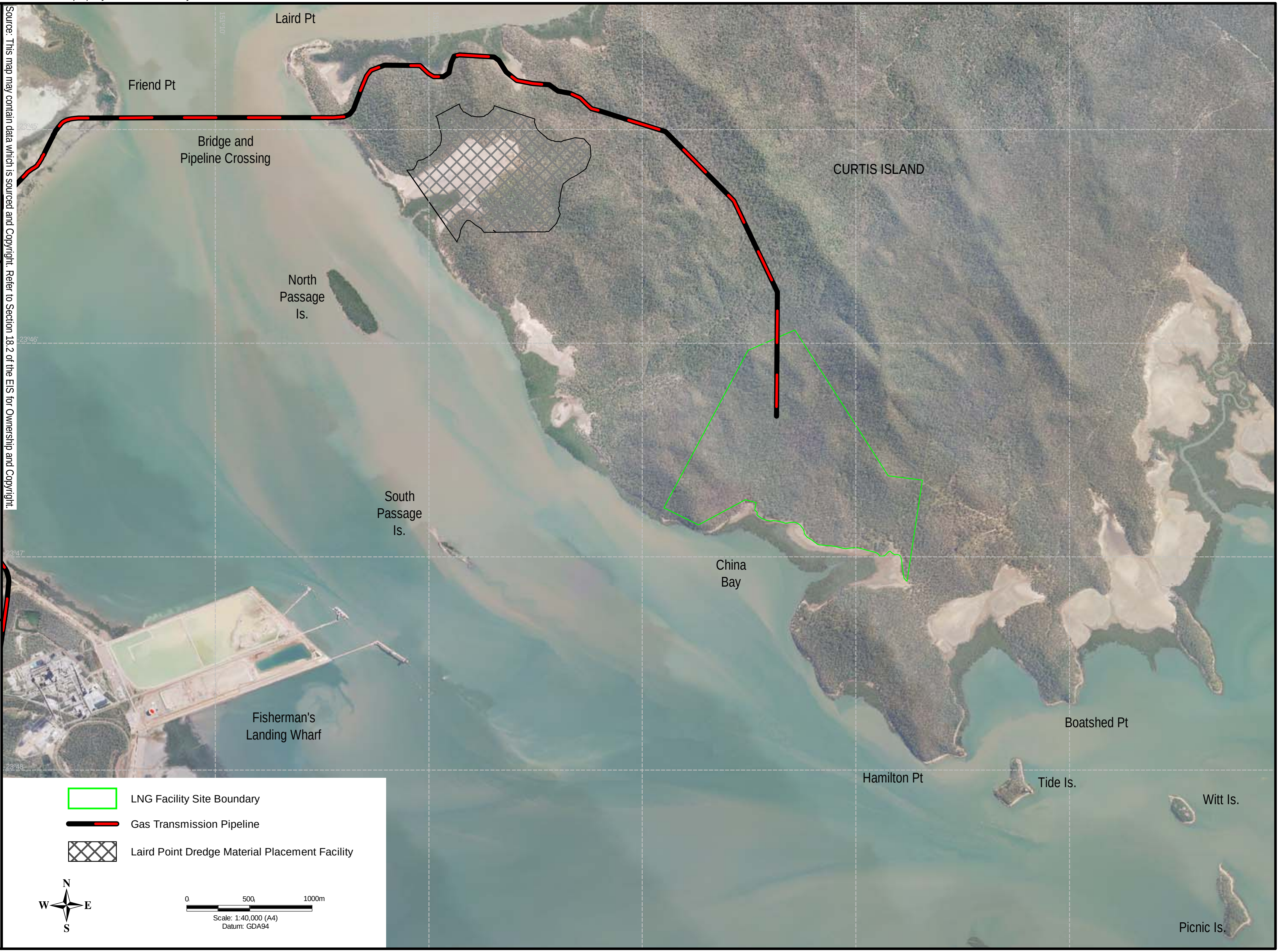
A high level evaluation of the Laird Point site was proposed to determine the suitability of disposing marine dredge material from a groundwater perspective. This was done to assist in making informed decisions, allowing for the evaluation of all biophysical and social aspects associated with the proposed on-shore disposal.

The preliminary hydrogeology assessment was based on preliminary dredge disposal methodology descriptions, the EIS groundwater study of the LNG facility site, an evaluation of the physical and chemical characteristics of the sediment, and a literature review. The proposed dredge material disposal facility has been detailed in the HR Wallingford report; these details were utilised during the site suitability assessment.

In order to assess the suitability of the proposed site for dredge material disposal from a groundwater perspective the Waste – Aquifer Separation Principle (WASP) methodology was used. The WASP model considers three distinct components, which play a role in defining the suitability of a particular site for waste disposal. These are:

- The potential hazard posed by the dredge material;
- The barrier between the base of the dredge material and the groundwater; and
- The groundwater resource, current use and potential.

The evaluation of potential hazards, groundwater vulnerability, and groundwater environmental value allowed for the compilation of comments and recommendations with regards to the Laird Point site from a groundwater perspective.



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Client

Project

GLADSTONE LNG PROJECT
HYDROGEOLOGICAL ASSESSMENT
DREDGE MATERIAL PLACEMENT FACILITY

Drawn: RG | Approved: JB | Date: 22-03-2009

Job No: **4262 6220** | File No: 42626220-g-755c.wor

Title

DREDGE MATERIAL PLACEMENT FACILITY LOCATION

Figure: **1**

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The disposal of marine dredge material on an on-shore enclosure is proposed. Initial plans for dredge material placement indicate that this will be achieved by pumping material directly to the disposal site. The intention is to create a bunded area, covering an area of approximately 120 ha, with airspace (dredge material disposal void) of 13.2 million m^3. Total volumes of marine dredge spoil to be placed within the on-shore enclosure are estimated at 8,000,000 m^3 (HR Wallingford, 2009).

A preliminary design for the Laird Point site, compiled by HR Wallingford (see Appendix DD), includes an external bund. The external bund will close off the intertidal zone and is to be constructed to a final height of 18 m. Retaining bunds will be included on the landward side to provide a continuous basin. The reception lagoons within the bunded area could potentially be lined with an "impermeable" membrane. Sand reception pits, weir boxes, and settlement discharge ponds are envisaged within the bunded area. Dredge material and transport water will cascade under gravity from pond to pond, allowing for retention and settlement of the dredge material, until the water is of suitable quality for disposal.

The selected dredge method, to excavate the marine sediments, is envisaged to utilise a cutter suction dredge (CSD). This method is considered suitable based on water depth data, sea conditions, and it has been implemented successfully at the other dredge operations within the area.

The rate of dredge material production is estimated at 150,000 m^3/week (silty sand). The volume of transport water, based on a maximum 30% solid to water ratio, will be ~ 500,000 m^3/week (830 L/s). The material will be pumped along a ~ 6 km long temporary pipeline from the dredge to the placement facility.

The potential impacts of the land-based disposal facility, on the groundwater, will vary depending on the final design. Additional design criteria have been considered, which require additional detail in order to further evaluate the proposed dredge material disposal site. These considerations include:

- Dewatering;
- Deposition; and
- Retaining bunds.

Settlement

The methodology for settling of sediment – water mix dredge material and the settling of dredge material is yet to be developed. However, the preliminary design identifies that the dredge material will be pumped directly to the Laird Point disposal facility site. The settlement of dredge material will be governed using bunds, weirs, and control points, which will reduce mixture velocity. The transport water will be contained on site until the water quality is suitable for discharge. This implies that the proposed disposal facility can have potential impacts related to artificial recharge of the groundwater. These impacts depend on the volumes and quality of seepage.

The transport water used in the dredging process will require settlement of fines to acceptable levels[1] of suspended solids before discharge to the marine environment could be considered. The reduction in the volumes of water through discharge will aid in managing water on site, especially during the wet season.

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[1] Discharge levels to be determined based on legislation and agreements with relevant authorities.

Section 2 Project Description

A centralised confinement facility could be considered to allow for the dewatering of the sediment. This could include an area for rehandling, which will allow for the beneficial use of the dredged sediments. The dewatered sediments can be used as fill material for bunds.

Any dewatering and beneficial use of dredge material will reduce the potential threat of the disposal site on the groundwater resources.

Deposition

The dredge material is considered to consist of clay, silt, sand, gravel, and shell fragments. Sections within the envisaged dredge material area are recognised to be potential acid sulfate soils; however, acid generation potential is reduced due to the acid neutralising capacity of the material. The neutralising capacity is due to megascopic carbonate forms, shelly fragments, and microscopic sources, foraminiferal components. The dredge material is also recognised to contain naturally elevated concentrations of metals, which could potentially mobile once oxidised.

Based on the proposed deposition method of discharging sediment – water mix into a series of bunds and weirs, variable settlement may occur. The deposition of sediments will allow for differential settlement, with larger or denser material depositing close to the discharge points and allowing for fines to migrate away from the discharge points. The buffer capacity of the shelly fragments and carbonate sediments may be removed from areas of potentially finer acid generating material due to separation during settling, resulting in the fine material possibly having increased leachability potential within the down gradient disposal area.

The deposition methodology will consider these potential acid generating materials to reduce exposure to oxygen and reduce acid production potential. Options regarding the management of acid sulfate soil have been considered in the GLNG EIS submission. These will be included in the dredge management plan (DMP), which will be developed to provide input into the design, construction and operation of the dredging and dredge material placement facility.

Retaining bunds

The preliminary design for the Laird Point site provides some details of the retaining bunds. Detailed designs have not been developed, especially for the landward side area in the saddles between the surrounding hills, which form the boundaries of the proposed disposal site. The designs should consider measures to protect against seepage from the dredge material under and through the retaining bunds.

Seepage migration of water through and below the bund walls can allow migration of poor quality water off site. The zone of influence caused by the possible seepage will depend on site specific permeability, head, and geological structure (preferential flow paths) data. Construction details and final designs for the bunds around the entire site will be required to more fully assess seepage potential.

The threats associated with the dredge material have been considered. The disposal of dredge material has the potential to produce seepage due to the transport water volumes. Metals could potentially be mobilised due to acid generation and dissolved solids (salinity) could be washed from the dredge material by rain.

The threat posed is essentially proportional to the volumes and quality of seepage produced. The threat is therefore seen as a factor of the size of the site and the amount of dredge material to be deposited. The footprint of the proposed site is ~ 120 ha allowing for an airspace volume of 13.2 million m^3. The volume of dredge material and transport water to be contained will depend on dewatering, discharge approach, and sediment reuse. The proposed large footprint and recognised seepage potential indicates that the disposal site poses a potential threat to the groundwater resources.

The threat depends on the dredge material composition (contaminant source potential), transport water quality, and the volumes and quality of seepage from the site.

Sampling of the dredge material allowed for the identification of the marine sediment composition. These samples were also analysed, at an analytical laboratory, to determine the contamination status of the material. Refer to the Coastal Environment Study and the Sediment Study of the EIS for in depth description of the marine sediments (URS, 2009).

The marine dredge material consists predominantly of sand (63 µm to 2 mm) with clay and silt. Minor amounts of gravel were recorded in the sediment samples, which were taken offshore in a linear band running parallel with the south western coast of Curtis Island.

The sediment samples were analysed to determine the contamination status, as marine contamination may have occurred in the study area. Potential contaminant sources include sewer outflow, fuel spills, municipal and industrial disposal, runoff, and atmospheric deposition. The samples were analysed for the following analytes:

- Total metals;
- Nutrients;
- BTEX compounds;
- Total petroleum hydrocarbons;
- Polynuclear aromatic hydrocarbons;
- Organochlorine pesticides;
- Organophophorous pesticides;
- Organotin compounds;
- Phenolic compounds;
- Polychlorinated biphenyls;
- Radionuclides;
- Triazine pesticides;
- Carbamate pesticides; and

- Phenoxyacetic acid herbicides

The sample results were compared to the following guidelines:

- The Queensland Environmental Protection Agency 1998 Environmental Investigation Levels;
- The National Environmental Protection Council 1999 Health-based Investigation Levels; and
- The Environment Australia 2002 National Ocean Disposal Guidelines (NODG) for Dredged Materials.

The majority of the samples are considered uncontaminated when compared to the various guidelines. Elevated concentrations of total metals; nickel, mercury, and antimony, were recorded in several of the samples, when compared to the NODG guidelines. Elevated manganese, copper, arsenic, and chromium were recorded in some samples when compared to the Queensland EPA levels. No organic compounds, above guideline levels, were recorded.

The results from the offshore acid sulfate soils (ASS) assessment revealed that while shallow, near shore accreted silt/clay sediments retained a high potential acid sulfate soil (PASS), the seabed sequence within the main marine passage where dredging is proposed revealed a negative Net Acidity, i.e. has excess buffering capacity (GeoCoastal, 2008).

No leaching tests (TCLP[2] or acid rain) have been conducted on the dredge material to be disposed on-shore, thus the potential leachate characteristics are not known. However, the ASS results indicate the dredge material may have excess buffering capacity.

The transport water used in the dredging process will be sea water. This will result in salt contamination should sea water seep into the groundwater resources. Typical salinity concentrations associated with sea water are chlorine 19,000 mg/L Cl, sodium 10,500 mg/L Na, magnesium 1,200 mg/L Mg, sulfur 884 mg/L S, calcium 400 mg/L Ca, and potassium 380 mg/L K (SeaAgri, 2005).

Summary

The dredge material is recognised to comprise mainly uncontaminated sand, which has limited acid generating potential (limited potential to mobilisation metals). The sea water associated with the dredge material can potentially cause salt contamination of the underlying groundwater resources.

The large size of the footprint and the saturated nature of the dredge material indicate that the marine disposal facility has the potential to generate seepage, which can potentially migrate off site. The resultant seepage could potentially alter groundwater quality due to increased salinity. In addition seepage from the site, through or under the retaining bunds, can potentially lead to water logged areas immediately adjacent to the bunds. The daylighting of saline water could impact on the vegetation and possibly result in saline quality runoff.

[2] Toxicity Characteristic Leaching Procedure

Unsaturated Zone — Section 4

The unsaturated zone represents the barrier between the bottom of the disposal facility and the groundwater table. It is within this zone that attenuation of seepage occurs. Important processes in seepage attenuation include chemical precipitation, absorption, adsorption, dilution, dispersion, and bio-degradation. Attenuation is a complex combination of these processes and is difficult to predict. It is, therefore, the time that seepage is exposed to attenuation, which determines the threat of the seepage.

The travel time of seepage, from the bottom of the disposal site to the groundwater, depends on the hydraulic conductivity (permeability) and porosity of the unsaturated zone. Thus the longer the travel time the less the threat.

The travel time for seepage to reach the groundwater resources on site is calculated using the following formula (Calculation 1):

Calculation 1:

$$Tt = d \times i / (K / (\eta/100))$$

Where: Tt = Travel time (in days)

d = Depth of horizon (in m)

i = Hydraulic gradient (dimensionless)[3]

K = Hydraulic conductivity (m/day)

η = Porosity (%)

No site-specific groundwater level data is available for Laird Point. Groundwater monitoring bores were constructed at the proposed LNG facility, within the alluvium and fractured bedrock aquifers. For the purposes of this preliminary site suitability study the range of groundwater level data and hydraulic conductivity values obtained from these bores were utilised to provide an evaluation of the unsaturated zone.

No groundwater level data is available for the mudflats, but as this area is intertidal it is assumed that the groundwater level varies within this zone. As the groundwater quality is saline due to downward flow (discussed in Section 6) it is envisaged that the salt contamination of the dredge material seepage will not markedly affect the groundwater resources associated with the mudflats.

Table 4-1 presents an estimate of travel time of potential seepage from the bottom of the dredge material to the groundwater.

[3] i = 1 for vertical movement

Table 4-1 Travel Time Calculations

Aquifers	Porosity[4] (η)	Depth to groundwater (m)	Hydraulic conductivity (K)	Travel time (days)
Mudflats	55	variable	not known	?
Alluvium / weathered	45	1.6	3.05×10^{-3} m/day	229
		4.5	3.05×10^{-3} m/day	643
		1.6	6.43×10^{-2} m/day	11
		4.5	6.43×10^{-2} m/day	32
Fractured bedrock	10	5.6	0.01 m/day	56
		22.5	0.01 m/day	225
		5.6	1.165 m/day	0.5
		22.5	1.165 m/day	2

The maximum travel time to reach the deepest groundwater level associated with the alluvium aquifer is only 1.8 years. This indicates that the unsaturated zone, due to permeability and depth, does not form a substantial barrier to vertical seepage movement. Groundwater resources are, thus, recognised to be vulnerable to surface contaminant sources and the improvement of the barrier between the dredge material and the groundwater table would reduce the vulnerability.

Given the potential for seepage from the wet dredge material, especially during the initial stages of deposition directly onto the ground, it is recommended that a combination of lining material be considered across the disposal facility footprint. This will enhance the barrier potential of the unsaturated zone, reduce groundwater vulnerability, and minimise the potential for seepage off site.

A compacted clay liner could be considered. The clay could be sourced from within the site footprint (mudflats), the MOF dredging, or clay deposited as part of the dredge material. The compacted clay would form a low permeable base for the dredge material deposition. A geotechnical study is recommended to assess the suitability of the clay for use as a compacted clay liner as studies indicate seepage losses can occur from evaporative ponds (hyper saline environment) constructed using certain compacted clays. The viability of working with wet clay also needs to be considered.

Alternatively a geosynthetic clay (soil amendment) liner could be considered. These liners typically comprise a sodium bentonite mixed with non-clay soils. This allows for a liner, which has a permeability of ~ 10^{-6} m/s.

Other types of liners could be considered including using a geomembrane, which is a synthetic liner that can comprise reinforced plastic or High Density Polyethylene (HDPE). This type of liner is expensive and requires extensive earthworks to ensure the liner does not puncture.

It is considered that the final design and selection of liner material will be based on a risk assessment.

[4] Porosity values obtained from Driscoll, 1986

Geology

The majority of Curtis Island is underlain by late Devonian to early Carboniferous aged Wandilla Formation, which forms part of the Curtis Island Group. The Wandilla Formation comprises low grade metamorphosed sediments, which include mudstone, sandstone, siltstone, jasper, chert, slate, and schist. The metamorphism is associated with the complex structural geology within the study area, which relates to the New England orogeny (folding, faulting, and uplift) and faulting associated with the Narrows Graben structure. Structural deformation has produced steeply dipping foliations in the Wandilla Formation. Vertical foliations are also present. These result in north-northwest trending ridges of more competent quartz greywacke and flatter areas of altered mudstone. The tectonic activities are recognised in the mineralisation of the Wandilla Formation, which contains minor gold, silver, turquoise, and manganese mineralisation on the islands in Port Curtis and on the mainland around Gladstone.

Quaternary aged alluvial and colluvial deposits, comprising silt, sand, and gravel, overlie the Wandilla Formation units. The overburden is between 0.5 and 1.5 m thick on the high-lying ridges and 3 to 5 m thick on the flat areas. Thicker alluvium has been deposited along the drainages lines draining the island. Quaternary aged mud, sand, and gravel estuarine deposits flank the shores in many places. The lithology logged during drilling in the Wandilla Formation at the proposed LNG facility site included mudstone, sand, gravel, and weathered greywacke. The sediments within the alluvium and estuarine deposits comprise clay, sandy clay, sand, and gravel.

Site Geology

The Laird Point site is underlain by Tertiary aged coastal tidal flats, mangrove flats, supratidal flats and grasslands, which comprise sand and mud. These sediments overlie mudstone, arenite, and chert units of the Wandilla Formation. The majority of the proposed site is underlain by units of the Wandilla Formation (**Figure 2**). No geological structures (faults, intrusive dykes) have been mapped within the Laird Point site (1: 100 000 Geological Series map Gladstone Special).

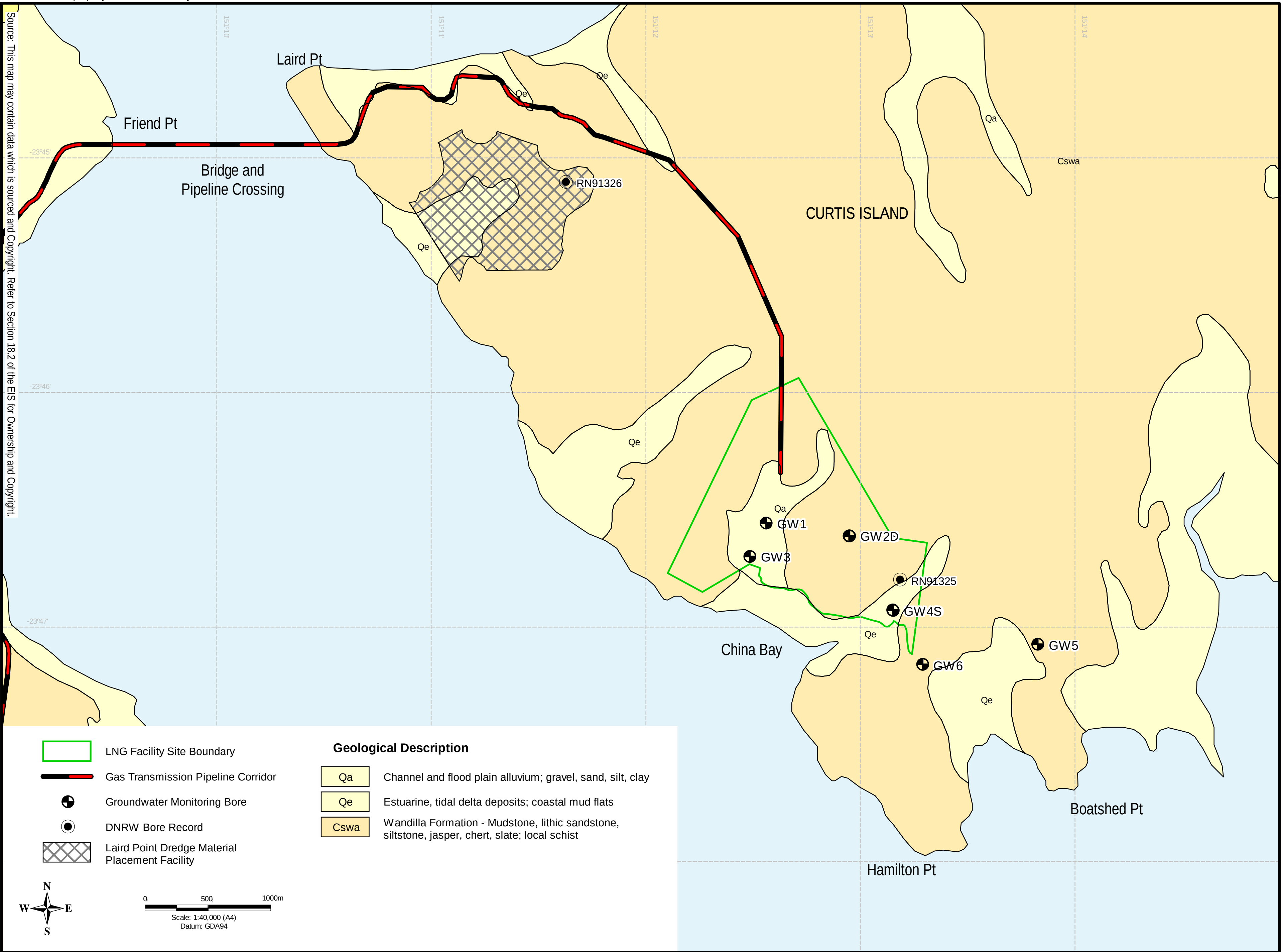
Hydrogeology

The groundwater potential of the Wandilla Formation sediments, in their unaltered state, is limited due to low primary permeability and storage. The groundwater resource can be enhanced through secondary alteration, such as faulting and fracturing. Based on the underlying complex structural geology and existing bore it is recognised that discrete zones of alteration occur within the Wandilla Formation units on site.

The installation of groundwater monitoring bores at the proposed LNG facility allowed for the identification of groundwater within several different units, including:

- Unconsolidated alluvial deposits along the drainage lines;
- The transition zone between weathered and competent bedrock;
- Fractures within the bedrock directly below the transition zone; and
- Zones of deeper weathering.

Falling head tests were conducted within the monitoring wells to provide estimates of the hydraulic conductivity of the various aquifers and aquitards. A summary of the monitoring bores and the resultant aquifer test data is presented in **Table 5-1** and the location of these bores are shown on **Figure 2**.



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GLADSTONE LNG PROJECT
HYDROGEOLOGICAL ASSESSMENT
DREDGE MATERIAL PLACEMENT FACILITY

Drawn: RG | Approved: JB | Date: 23-02-2009

Job No: **4262 6220** | File No: 42626220-g-756c.wor

Title

CURTIS ISLAND GEOLOGY GROUNDWATER BORES AND DREDGE MATERIAL PLACEMENT FACILITY LOCATION

Figure: **2**

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Table 5-1 Monitoring Bore Data Summary

Monitoring Bore ID	Hole depth (m)	Static groundwater level (mbgl)	Static groundwater level (m AHD)	Aquifer / Aquitard Material	Hydraulic Conductivity (m/day)
Alluvial Deposits					
GW4S	7.7	4.4	-1.2	Clay and Sandy Clay	4.4×10^{-3}
GW5	3	1.6	1.6	Clay and Sandy Clay	6.4×10^{-2}
GW6	5	4.6	1.8	Clay with trace sand	3.1×10^{-3}
Wandilla Formation					
GW1	22.2	9.8	1.7	Fractured greywacke	1.2
GW2S	6	Dry	Dry	Silty, Sandy Clay and Mudstone	NAD
GW2D	24	22.5	1.7	Weathered greywacke	1.8×10^{-2}
GW3	6	2.4	0.01	Fractured greywacke	NAD
GW4D	27	5.6	-0.11	Sand and Gravel greywacke	9.6×10^{-1}

NAD - Not Able to be Determined: bore was dry or the recovery was very slow.

Based on the Curtis Island geology, surficial cover, and underlying structures it is envisaged that additional groundwater resources could be associated with buried palaeovalleys, fresh water lenses associated with the Ghyben-Hertzberg Relationship[5], and the intertidal mudflats.

Palaeovalleys

Based on the structural geology it is envisaged that palaeovalleys may occur on Curtis Island, possibly within the Laird Point embayment. The palaeovalleys are typically filled with gravel and sand and overlain by clay-rich estuarine deposits.

The palaeovalleys typically contain confined aquifers with saline groundwater quality. The permeable sands and gravel allow for increased aquifer transmissivity and storage. The aquifers, which can result in artesian flows, are envisaged to be limited in size (due to poor interconnectivity) and have little or no recharge.

Based on the marine deposition environment it is assumed that the groundwater quality would be saline and thus have limited suitability for use. The limited groundwater potential and suitability for use reduces the environmental value of the groundwater associated with palaeovalley deposits.

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[5] Aka the Ghyben-Herzberg Principal which states that where readily permeable aquifers exist in coastal zones, for every 1 m of water-table height above sea level, the fresh water – saltwater interface will be about 40 m below sea level. The principle reflects the fact that freshwater is 1/40 less dense than sea water.

Section 5 Groundwater Resource Evaluation

Fresh water resources

Curtis Island receives regular rainfall which can allow for the recharge of shallow weathered aquifers with fresh water. Unconfined aquifers associated with the zones of deeper weathering, estuarine, alluvial, and colluvial deposits, which are recently recharged, can contain fresh groundwater. Limited interaction or mixing of groundwater is expected as the fresh water remains on top of the more saline groundwater (identified during drilling). The stratification is governed by the Ghyben-Herzberg Relation, due to a physical relation based on the difference in densities of saline (sea) water and fresh water.

The volumes of fresh water will depend on the aquifer characteristics, namely the effective storage and permeability. The fresh water is recognised to flush the estuarine deposits and drain into the sea. A water balance for the entire Curtis Island indicates recharge, defined as deep drainage, is only 1.3% of rainfall. Based on the following figures:

Area:	578 km^2
Precipitation:	506,772 ML
Runoff:	70,367 ML
Evapotranspiration:	429,753 ML
Deep drainage:	6,651 ML

(Data source: Land use data sourced from the Bureau of Rural Sciences. Precipitation data sourced from the Australian Bureau of Meteorology. All other data derived from the Bureau of Rural Sciences' steady-state annual water balance model).

The volume of fresh water recharge, which is recognised as the sustainable yield (groundwater harvest potential) of the aquifers, is calculated to be limited at 115 m^3/ha/year. The volumes of fresh groundwater are, thus, recognised to be limited.

Mudflats

No drilling or aquifer assessments have been conducted within the intertidal mudflats. Based on the inundation of these areas it is recognised that the groundwater associated with these deposits would be hyper saline.

Previous studies indicate groundwater flow is downward within most mudflats, and lateral flow generally is towards a creek or the sea. The downward flow indicates that surface water is recharging the mudflat. Recharge from the surface occurs during spring tides when high tides flood the mudflat areas. The downward flow of surface seawater into the mudflats indicates that the mudflats accumulate salts from seawater by evaporation after flooding. The downward flow may be driven by density differences that occur when the salts left on the mudflat after surface waters have evaporated are redissolved by the next high tide. The combination of downward head and greater density water pushes the more saline water to the bottom of the mudflats.

Possible mechanisms that induce brine accumulation in the mudflats include evaporative pumping and seawater flooding. Although information on regional groundwater is unavailable for the mudflats, the geology of the area indicates that low permeability units are envisaged at depth below the mudflats. These low permeability units would restrict upward groundwater flow. In addition, the downward groundwater heads in the shallow aquifer indicate that contributions from deeper groundwater are not expected to be significant.

The saline groundwater reduces the suitability for use, thus the environmental value of the groundwater associated with mudflats is recognised to be limited.

Potential aquifers

The following aquifers that could potentially be and may be[6] utilised for stock watering within the Laird Point study area include:

- Perched aquifers, containing fresh recently recharged groundwater;
- Alluvium aquifers, adjacent to drainage lines;
- Weathered (intergranular) aquifers; and
- Fractured rock aquifers.

Groundwater usage

Curtis Island lies alongside the Central Queensland Coast from southern Keppel Bay to Gladstone. Curtis Island is separated from the mainland by the mangrove lined tidal channels of The Narrows. Although the fourth largest island in Queensland it is relatively undeveloped.

The main activities on the island have been recreational use based around the small settlement of South End and a few grazing and forestry enterprises. The northern portion of Curtis Island is a National Park, which extend along the east coast. No resorts or developments have yet been constructed on the island. As such the main water supply for potable water on the island is rain harvesting.

No significant groundwater usage has been registered on the Department of Natural Resources and Water (DNRW) groundwater database within the study area. Only two boreholes have been registered on the entire Curtis Island (578 km^2), located within the south-western portion of the island. The limited available information for these bores is summarised in **Table 5-2**.

Table 5-2 Registered Groundwater Bores

Bore	Depth	SWL	Yield	Aquifer	Comment
RN91326	30 m	10.6 mbgl	0.52 l/s	Fractured mudstone	Limited data, possibly brackish quality
RN91325	27.3 m	10.6 mbgl	3.0 l/s	Fractured mudstone	EC = 12,000 µS/cm, used for stock watering

The location of these bores is shown on **Figure 2**.

Bore RN91326 is located within the proposed footprint of the Laird Point site. This bore will have to be backfilled and sealed and an alterative source obtained to replace the affected supply. Additional data is required to determine a specific water replacement plan to ensure the same volumes of water of the same or better quality are made available to the bore owner.

[6] An existing bore is located within the Wandilla Formation within the proposed footprint. Only limited data is available regarding this bore thus the aquifer intersected during the bore construction is not known.

Section 5 Groundwater Resource Evaluation

Monitoring bores

Drilling intersected shallow (< 8 m) unconfined and semi-confined aquifers, which comprise poor quality brine groundwater. The shallow aquifers are associated mainly with alluvium material deposited along drainage lines. These aquifers have low permeability (Table 5-1), 0.003 to 0.06 m/day, and receive limited rainfall recharge. The alluvium material has limited saturated thickness, thus the shallow groundwater has limited abstraction potential or use. The shallow groundwater resources within the study area are considered to have limited environmental value.

Zones of secondary alteration, weathering and fracturing, were recorded in the borehole logs indicating secondary permeability, which is recognised in the hydraulic conductivity calculations for the deeper boreholes (> 20 m). The deeper groundwater resources are brackish with salinity concentrations at lower values than the upper groundwater resources. The drilling results indicate discrete zones of secondary alteration.

The groundwater, from both shallow (< 8 m) and deep (> 20 m) boreholes, is recognised as not suitable for discharge into the fresh or marine water environments due to elevated dissolved metals, when compared to the ANZEEC guidelines[7]. The groundwater is not suitable for domestic use due to elevated salinity concentrations but can be used for livestock watering.

The limited DNRW information and the results of the monitoring bore drilling indicate that areas of enhanced groundwater resources are located within discrete alteration zones, which can include fracturing, faulting, and deeper weathering. The aquifer potential of the unaltered sediments is negligible.

Environmental Protection (Water) Policy Environmental Values

The environmental values of the groundwater have been assessed according to the values identified in the Environmental Protection (Water) Policy 2008. The environmental values to be enhanced or protected are:

- Biological integrity of a pristine or modified aquatic ecosystem;
- Suitability for primary, secondary, and visual recreational use;
- Suitability for minimal treatment before supply as drinking water;
- Suitability for use in agriculture;
- Suitability for aquacultural use;
- Suitability for producing aquatic food for human consumption;
- Suitability for industrial use; and
- Cultural and spiritual values of the water.

The review of available data allowed for a preliminary assessment of the groundwater resources associated with the lithologies present on the proposed site. The available information allowed for an initial evaluation to the groundwater resource environmental values, these include:

[7] The Trigger Levels for Freshwater Ecosystems – 95% protection level of species; The Trigger Levels for Marine Ecosystems – 95% protection level of species; and The Livestock Drinking Water Guidelines – Beef

Biological integrity of a pristine or modified aquatic ecosystem

The groundwater quality results for the majority of the groundwater samples collected from the LNG facility monitoring bores contain elevated dissolved solids and metal concentrations when compared to the ANZEEC guidelines Trigger Levels for Freshwater and Marine Ecosystems. The groundwater is recognised to discharge into the sea and can provide baseflow to the surface water channels. Based on the groundwater quality results obtained this naturally occurring discharge into the water resources occur at concentrations above the ANZEEC guidelines. The groundwater discharge is unaltered as it has not been impacted as the LNG area is undisturbed.

The groundwater contribution to baseflow and the assurance of the biological integrity by maintaining the water quality so the plants and animals living in the local waterways can survive is recognised to be limited compared to the surface runoff and tidal water. Thus the ecological values of groundwater discharge and baseflow to the biological integrity of the aquatic ecosystem is limited.

Existing Groundwater Dependent Ecosystems, if any, need to be identified on site and around the proposed dredge material placement facility and monitored to ensure the possible impacts of the proposed activities are minimised on any potentially sensitive landscapes.

Suitability for recreational (primary, secondary, and visual) use

This category of environmental values is considered extraneous in relation to groundwater.

Suitability for minimal treatment before supply as drinking water

All groundwater samples collected in and adjacent to the proposed LNG facility site are recognised to not be suitable for drinking purposes and thus would require treatment to achieve recognised drinking water quality guidelines. This groundwater would require complex and expensive treatment, such as reverse osmosis, to achieve drinking water quality to satisfy the Australian Drinking Water Guidelines 2004.

Issues of salinity and the ease of obtaining a rainwater tank supply are factors which preclude the usage and potential for usage of the groundwater as a drinking water source.

Suitability for use in agriculture, aquaculture, aquatic food for human consumption

The groundwater quality data indicates that the salinity is above the range recommended for irrigation of crops. Thus the groundwater appears to have limited potential use in terms of irrigation, depending on crop type, soil type, and irrigation regime.

Due to the saline nature of the groundwater it is assumed that only mariculture (aquaculture practiced in marine environments) could be considered. Algaculture (the production of kelp/seaweed and other algae), fish farming, shrimp farming, or oyster farming, depending on suitability of habitat may be possible. Aquaponics, which integrates fish farming and plant farming, could also be possible.

It is envisaged that these activities would require reliable and assured water supplies. The available information (Section 5) regarding usable aquifers and water balance (recharge) indicates limited discrete groundwater resources. It is therefore considered that sea water would be utilised instead of the limited groundwater.

Suitability for industrial use

The groundwater quality is generally suitable for a large number of industrial processes including; cooling water, process water, utility water, and wash water. As industrial processes require particular water quality, specific hydrochemical data will be required to evaluate suitability for use.

Section 5 Groundwater Resource Evaluation

Limited opportunities for industrial use are currently available on Curtis Island. Industrial users tend to require large volumes of water which would be unsustainable for the groundwater resources identified within the study area.

Cultural and spiritual values

Available data does not indicate any groundwater resources which are considered to have cultural and spiritual values. Any culturally significant values, from an anthropological, archaeological, historic, sacred, or scientific significance, need to be identified when finalising the design of the dredge material disposal facility.

Summary

An evaluation of the groundwater resources indicates two separate groundwater regimes within the proposed dredge material placement facility footprint. These two regimes include:

- Shallow hyper saline groundwater resources within the intertidal zone, which is underlain by mudflats. The groundwater associated with the mudflats has limited environmental value and have no beneficial use. This portion of the site would not be markedly impacted by possible saline seepage from the dredge material placement facility.
- Discrete fractured and weathered aquifers within the competent Wandilla Formation. An existing bore within the footprint indicates that the groundwater resources can provide limited quantities of groundwater, which is suitable for stock watering. These discrete aquifers therefore have limited beneficial value.

Site Suitability — Section 6

A review of the data presented allowed for an initial assessment of the Laird Point dredge material disposal site. The data indicates:

- The large site footprint and use of sea water to transport dredge material provides the potential for seepage;
- There is a potential risk of seepage through and below the proposed retaining bunds;
- The unsaturated zone is recognised as a poor barrier, which provides limited protection to the groundwater resources;
- Seepage could potentially result in the increase in the salinity of the groundwater; and
- The groundwater is, in places, suitable for use for stock watering.

Based on these factors the initial assessment of the Laird Point dredge disposal site indicates that the site can potentially impact on the groundwater resources associated with the discrete aquifers within the Wandilla Formation. These groundwater resources are, however, limited as the aquifers are regarded not to contain groundwater in significant exploitable quantities.

The aquifer types present on site and the saline hydrochemistry allow a rating of the aquifer vulnerability which indicates that limited to low levels of groundwater protection are required for these aquifers.

It is therefore considered that should sufficient engineering be included in the design, the threat to the groundwater would be reduced. The design could include:

- Selection and implementation of low permeable base to the dredge material;
- Compaction of the material below the base;
- The construction of monitoring wells, adjacent to the disposal facility bunds, that can be converted to scavenger wells if required;
- The use of dewatering, flocculants, and binding agents;
- Disposal or dredge methodologies to control acid generation potential; and
- Maximising beneficial use of the dredged sediments.

Section 7 Comments and Recommendations

The Laird Point site, based on limited site-specific data, could be utilised for marine dredge material placement depending on the final design. Site specific data is required including:

- Drilling and constructing monitoring bores on and adjacent to the bunds to determine the baseline shallow (< 10 m) and deep (> 20 m) groundwater characteristics and ambient hydrochemistry;
- Construct well points and conduct aquifer tests within the mudflats, alluvium, and colluvium deposits to determine the baseline characteristics and ambient hydrochemistry;
- Conduct variable head tests, slug tests, and pump out tests to obtain aquifer hydraulic parameters;
- Hydrocensus of existing groundwater bores to collect baseline data and develop a suitable water replacement plan;
- Backfilling of bore RN91326 and the implementation of a water replacement plan;
- Evaluate geology and underlying structures to determine possible preferential flow paths for groundwater and contaminant migration;
- Evaluate potential seepage migration through and under the retaining bunds and assess possible water logging; and
- Assess final disposal facility design and reassess risks to the groundwater resources.

References Section 8

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Section 9 Limitations

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of conditions as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

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