14. GROUNDWATER

This chapter describes the groundwater systems within and surrounding the project area, assesses the potential impacts of the project on values associated with the groundwater systems and describes the measures through project design, construction and operations to manage impacts on groundwater values.

This chapter is informed by the Arrow LNG Plant Groundwater Impact Assessment prepared by Coffey Environments Australia Pty Ltd (Appendix 7, Groundwater Impact Assessment).

The objective for groundwater are shown in Box 14.1 and are based on legislative guidelines and policies described below.

Box 14.1 Objective: Groundwater

- To avoid or reduce potential adverse effects to groundwater values from construction and operation of the project.

14.1 Legislative Context and Standards

This section describes the Commonwealth and state legislation, guidelines and policies designed to protect groundwater environmental values. These provide the framework within which the groundwater impact assessment was performed.

Commonwealth guidelines relevant to the management of groundwater include:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC/ARMCANZ, 2000). These guidelines provide for the sustainable use of Australia's water resources by protecting and enhancing their quality, while maintaining economic and social development. These guidelines have been used to develop groundwater environmental values for the project, and have been used as groundwater quality criteria where parameters were not available in the Queensland Water Quality Guidelines 2009 (DERM, 2009b).
- Australian Drinking Water Guidelines 2004 (ADWG 2004) (NHMRC, 2004). The guidelines provide guidance to the Australian community and the water supply industry on what constitutes good quality drinking water. These guidelines were used to assess impacts on potable groundwater sources.

State legislation and guidelines relevant to the management of groundwater include:

- *Water Act 2000* (Qld). This act provides for the sustainable management of water and other resources in Queensland. The act has developed water resource plans to define the availability and allocation of water. Curtis Island does not fall within the area covered by a water resource plan. Project activities on the mainland do fall within this boundary.
- *Petroleum and Gas (Production and Safety) Act 2004* (Qld). This act ensures petroleum activities are undertaken in a safe, efficient and viable manner. If a petroleum activity unduly affects an existing water bore, restorative measures must be implemented so the owner of the bore receives a suitable supply of water or is compensated.

- *Environmental Protection Act 1994* (Qld). This act provides for the protection of Queensland's environment by promoting ecologically sustainable development. Subordinate to the act are:
  - Environmental Protection Regulation 2008, which provides for the effective administration and enforcement of the objectives and provisions of the Environmental Protection Act.
  - Environmental Protection (Water) Policy 2009 (EPP (Water)), which aims to achieve the objectives of the Environmental Protection Act in relation to Queensland's waters. This policy defines the relevant water quality guidelines as the Queensland Water Quality Guidelines 2009 (DERM, 2009b) and the ANZECC/ARMCANZ (2000) guidelines.
- Queensland Water Quality Guidelines 2009 (DERM, 2009b). These guidelines provide for the protection of aquatic ecosystems in regional and subregional areas of Queensland. The guideline region relevant to the Arrow LNG Plant is the 'Central Coast'. These guidelines have been used as groundwater quality criteria where appropriate.
- State Planning Policy 2/02: Planning and Managing Development Involving Acid Sulfate Soils 2002. This policy sets out the planning and assessment criteria for developments that may disturb acid sulfate soils in low-lying coastal areas.

14.2 Assessment Method

This section describes the assessment method used for the groundwater impact assessment. The assessment method has adopted the significance (sensitivity and magnitude) approach.

The geographical study area provides context for assessing impacts related to the project and encompasses the project area and the wider Gladstone region.

Impacts were considered for the LNG plant site and marine infrastructure located on Curtis Island and the proposed temporary workers accommodation facilities (TWAF 7 and TWAF 8), launch site 1, and the feed gas pipeline and associated mainland tunnel entrance. Launch site 4N and dredge sites were excluded from the impact assessment as these sites are in the marine environment where groundwater impacts are not relevant.

14.2.1 Baseline Assessment

The existing groundwater environment was characterised by a desktop study including review of:

- Groundwater impact assessments previously undertaken in the vicinity of the study area, including the Gladstone LNG Project (URS, 2009b; 2009c) and the Western Basin Dredging and Disposal Project (GHD, 2009b).
- Arrow LNG Plant related technical studies such as geotechnical report for the Shell Australia LNG Plant Project (Coffey Geotechnics, 2009).
- Geological and hydrogeological data and maps, including the Rockhampton 1:250,000 geological map (Geological Survey of Queensland sheet FS 56-13), the 1:100,000 "Gladstone Special" geological map (Geological Survey sheet 9150 & Part 9151, March 2006) and the Groundwater Resources of Queensland Map (DERM, 2011e).
- DERM groundwater vulnerability maps (Stenson, 2002). These maps define the relative approximate susceptibility of an area to groundwater pollution. Groundwater vulnerability in Queensland is assigned according to physical characteristics including recharge, aquifer media, soil media, topography and hydraulic conductivity. Groundwater vulnerability ranges from low, low to moderate, moderate, moderate to high, high.

- DERM Water Management System database for groundwater user entitlement data (ANRA, 2011).
- Groundwater bore data from the DERM groundwater database (2011f) and from other groundwater studies (URS, 2009b and GHD, 2009b) in the vicinity of the study area.

Groundwater salinity was characterised using the following criteria (Fetter, 2001):

- Freshwater: total dissolved solids (TDS) = 0 to 1,000 mg/L.
- Brackish: TDS = 1,000 to 10,000 mg/L.
- Saline: TDS = 10,000 to 100,000 mg/L.
- Brine: TDS = more than 100,000 mg/L.

Groundwater monitoring in bedrock (deeper) aquifers was not undertaken in the study area.

The groundwater data was evaluated against the ANZECC/ARMCANZ (2000) guidelines for livestock drinking water, and against the guidelines for freshwater and marine environments (relevant where groundwater has the potential to discharge into surface water bodies, groundwater dependant environments, and marine environments).

14.2.2 Significance Assessment

The groundwater impact assessment used the significance approach to assess project impacts on groundwater environmental values. The significance approach is described in more detail in Chapter 9, Impact Assessment Method, and the specific criteria developed for the groundwater impact assessment are described below.

Environmental values are a measure of how we value the environment and can be a quality or physical characteristic of the environment that is conducive to ecological health, public amenity or safety (*Environmental Protection Act 1994*). The EPP (Water) Policy provides a framework for identifying groundwater environmental values and establishing water quality guidelines and objectives to enhance or protect Queensland waters.

The environmental values, as described in the policy, to be enhanced or protected, and that are relevant to this groundwater assessment, include:

- High ecological value waters; the biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued.
- Slightly disturbed waters; the biological integrity of an aquatic ecosystem that has effectively unmodified biological indicators but slightly modified physical, chemical or other indicators.
- Moderately disturbed waters; the biological integrity of an aquatic ecosystem that is adversely affected by human activity to a relatively small but measurable degree.
- Highly disturbed waters; the biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than the above-mentioned waters.
- Waters that may be used for agricultural purposes; the suitability of the water for agricultural purposes.
- Waters that may be used for drinking water; the suitability of the water for supply as drinking water.
- Waters that may be used for industrial purposes; the suitability of the water for industrial use.

For the purpose of the impact assessment, the first four EPP (Water) values have been grouped into a category called ‘Groundwater to support aquatic ecosystems’. The last three values have been grouped into a category called ‘Groundwater for consumptive or productive uses’.

Some EPP (Water) values have not been considered in this assessment because the groundwater features supporting these values do not occur or have a very low likelihood of occurring in the study area. These include:

- Waters that may be used for recreation or aesthetic purposes.
- Waters that may be used for producing aquatic foods for human consumption.
- Waters that may be used for aquaculture.
- Waters with cultural and spiritual values (e.g., wells and springs with anthropological, archaeological, historic, sacred or scientific significance).

The sensitivity of existing groundwater systems has been defined based on the EPP (Water) values they support, the rarity of occurrence, resilience, dynamicism and rehabilitation potential as follows:

- Conservation status. Elements of the groundwater system as defined by the EPP (Water) related to the suitability of water to support aquatic ecosystems and consumptive and productive uses. Groundwater systems with very high conservation status contain intrinsic properties able to support significance amounts of potable supply, agricultural use, and the production of aquatic food for human consumption. Very low conservation status is obtained when attributes of the groundwater system are unable to support any EPP values.
- Rarity of occurrence. The abundance or distribution of a groundwater system or aquifer type, and availability of equivalent or representative systems. This sensitivity is very high in groundwater systems when attributes of the system are highly unique and there are no known alternatives; and very low when attributes of the groundwater system are common and ubiquitous.
- Resilience to change. Where groundwater properties such as water level, pressure changes and porosity remain stable in the event of disturbance. Groundwater systems with very high sensitivity are those where intrinsic properties of the system are very susceptible to ground disturbance, and the overall function of the groundwater system is likely to be permanently altered in the face of change. Systems with very low susceptibility to change are those where intrinsic properties are resilient to disturbance.
- Dynamicism of existing environment. A function of hydrogeological processes within groundwater systems. Groundwater systems with high sensitivity are those with low recharge rates indicating slow recovery periods. Systems with very low sensitivity are those with high recharge rates indicating short recovery periods.
- Rehabilitation potential. Systems with high sensitivity to rehabilitation are those where potential rehabilitation of impacts on values following disturbance would be very limited. Systems with very low sensitivity are those where rehabilitation could be successfully achieved following disturbance to all values.

The magnitude of each impact relates to the geographical extent, duration and severity of that impact. The criteria for assessing magnitude are outlined in Table 14.1.

Table 14.1 Magnitude criteria for groundwater impacts

Level of Magnitude	Description
Very Low	Impact is restricted to within the area of activity or footprint. No short-term or long-term impacts are likely on environmental values.
Low	Minor impacts are likely on environmental values, but impacts are likely to be short in duration only, with rapid recovery following end of impacting activity. Impact may extend beyond the area of activity or footprint, but is localised and restricted within the impacted aquifer.
Moderate	Minor impacts on environmental values, which may persist over time. Moderate impacts on environmental values, but of short duration only, with rapid recovery following end of impacting activity. Impact may extend beyond the area of activity or footprint and potentially across aquifers.
High	Moderate impacts on environmental values, which may persist over time. Major impacts on environmental values, but of short duration only, with rapid recovery following end of impacting activity. Impact may extend across significant areas and multiple aquifers.
Very High	Irreversible or persistent major impacts are likely on environmental values. No recovery from such impacts in the foreseeable future. Impact may extend across regional areas.

The significance of impacts (prior to mitigation) was assessed based on the sensitivity of the value being impacted and the magnitude of the impact on that value (Table 14.2). Residual impact (post mitigation) was assessed using the same matrix, taking into account how mitigation measures reduce the magnitude of impact.

Table 14.2 Significance assessment matrix

	Magnitude				
Sensitivity	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Very Low	Very low	Very low	Low	Low	Moderate
Low	Very low	Low	Moderate	Moderate	High
Moderate	Low	Moderate	Moderate	High	High
High	Low	Moderate	High	High	Very high
Very High	Moderate	High	High	Very high	Very high

14.3 Existing Environment and Environmental Values

This section describes the existing groundwater environment in the study area and the sensitivity of groundwater environmental values.

14.3.1 Regional Groundwater Systems

In the study area aquifers can range up to tens of metres in thickness influenced by topography and geological setting. Three types of groundwater aquifers may occur within the physical settings of the study area:

- Shallow aquifers (unconfined). Alluvial or estuarine formations commonly form shallow unconfined aquifers in the vicinity of stream systems (typically alluvium, including gravel, sand silt and clay) and coastal areas (sand, silt and clay). The study area is likely to contain shallow aquifers (less than 8 m below ground level (m bgl)) within unconsolidated Quaternary alluvial or estuarine deposits, colluvial deposits and shallow fractured rock. These aquifers are likely to occur in the vicinity of surface water streams and rivers such as the Calliope River and Auckland Creek as well as near the coastal areas of Port Curtis. Within the area of disturbance, this aquifer type is likely to occur under lower lying areas of the LNG plant site, shoreline areas of the LNG plant marine infrastructure, TWAF 7, TWAF 8, shoreline areas of launch site 1, and the mainland tunnel entrance and tunnel spoil disposal area.

- Bedrock aquifers (unconfined). Unconfined aquifers may also occur within weathered or fractured bedrock in higher topography away from surface water bodies. Unconfined bedrock aquifers may occur at higher areas of the LNG plant site, TWAF 7 and TWAF 8.
- Confined (artesian) aquifers. Aquifers within weathered rock and fractured rock underlying low permeability layers may occur in lower strata of stratified alluvium or colluvium. This aquifer type is likely to exist in the mainland foothills of the Mount Larcom Range where Quaternary sediment (alluvium and colluvium) overlies Triassic bedrock. Semi-confined aquifers are a subset of this aquifer type that can occur within fractured bedrock, zones of deeper weathering, stratified alluvium, and transition zones between weathered and fresh bedrock. Within the project area, confined aquifers could occur in the vicinity of TWAF 8 and the LNG plant site. At Curtis Island, evidence was obtained that confined conditions occur in some locations. At TWAF 8, no evidence is available to confirm confined conditions and it is assumed that the weathered bedrock is probably unconfined.

A cross section of groundwater systems through the LNG plant site is shown on Figure 14.1.

14.3.2 Groundwater Environment and Conditions

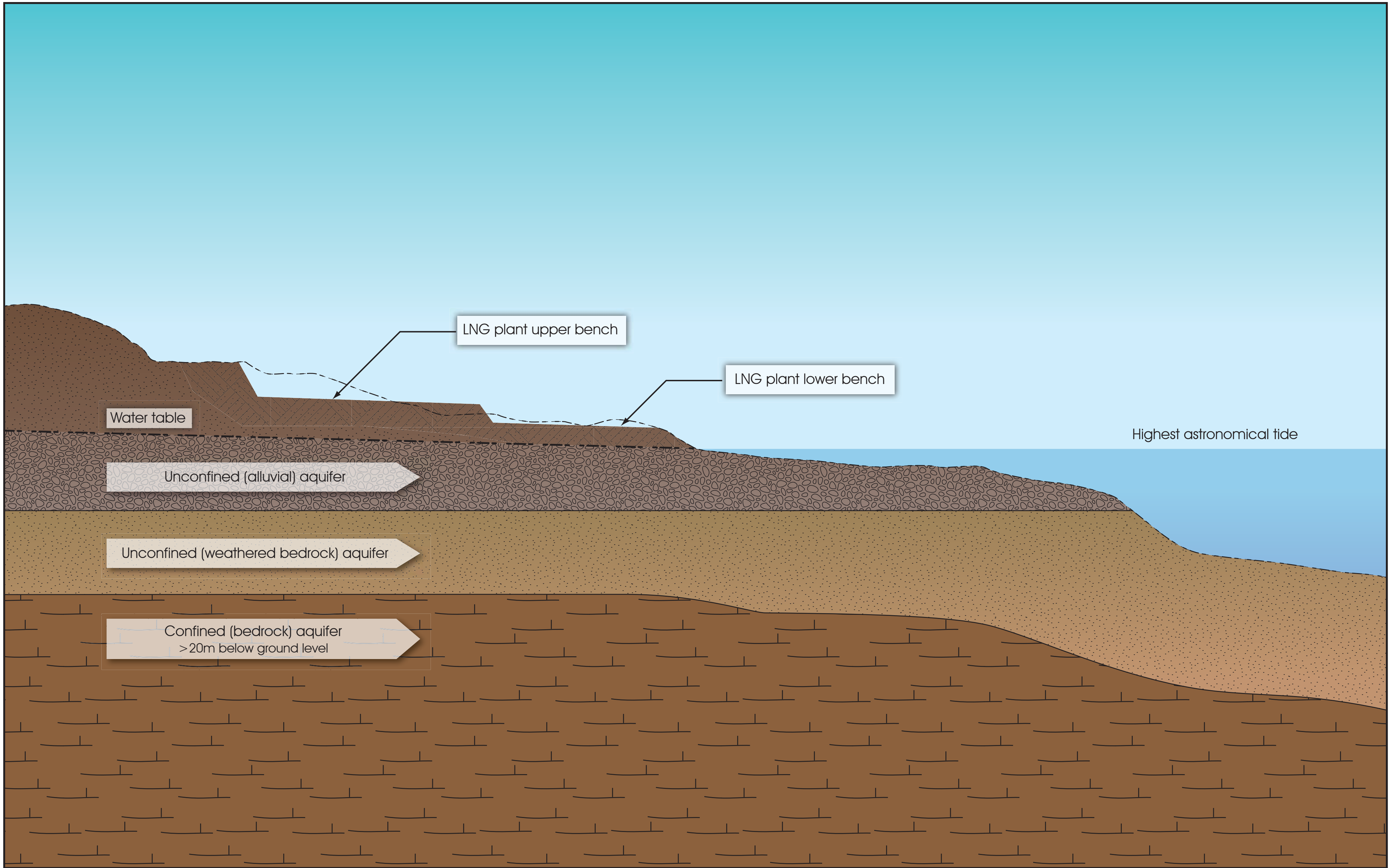
Physical and chemical properties of the groundwater aquifers are described in this section. Figure 14.2 shows the regional hydrogeology (i.e., yield, salinity and lithology) and the representative selection of groundwater bores used in the groundwater characterisation.

Groundwater Recharge

Diffuse recharge (recharge resulting from the infiltration of rainfall) is likely to be the dominant recharge process for shallow aquifer systems, due to the relatively high rainfall within the study area. Diffuse recharge involves deep percolation of infiltrated rainwater through the subsurface to the watertable. In warm humid environments, diffuse recharge rates can be moderate to high, leading to shallow water tables where potential evaporation is moderated by higher humidity and does not exceed rainfall significantly (compared with drier temperate or semi-arid climates). The study area receives regular rainfall with a bias towards higher rainfall occurring between October and March and diffuse recharge may be higher during this period.

Diffuse recharge may occur in upland areas (where deeper aquifer formations outcrop) to the west of the mainland project area as well as on Curtis Island to the north and northwest of the LNG plant site. Deeper aquifers may be recharged through leakage from overlying shallow aquifers. Groundwater recharge is likely to be higher in areas where water loss through evapotranspiration is low (i.e., where there is less vegetation cover). Curtis Island is highly vegetated and evapotranspiration rates are likely to be high.

Long term average (2000 to 2009) recharge rates on the mainland have previously been measured as approximately 14 mm/year in upland tree covered areas to approximately 49 mm/year in lower lying grassland areas (GHD, 2009b). Groundwater recharge on Curtis Island has been estimated to be 1 mm/year for shallow (less than 8 mbgl) aquifers and 3 mm/year for deep (more than 20 m bgl) aquifers (URS, 2009b). The wide variation in recharge measurements and estimates illustrates the difficulty in reliably quantifying this aspect of aquifers.



Source:
Coffey Environments
Note:
Not to scale

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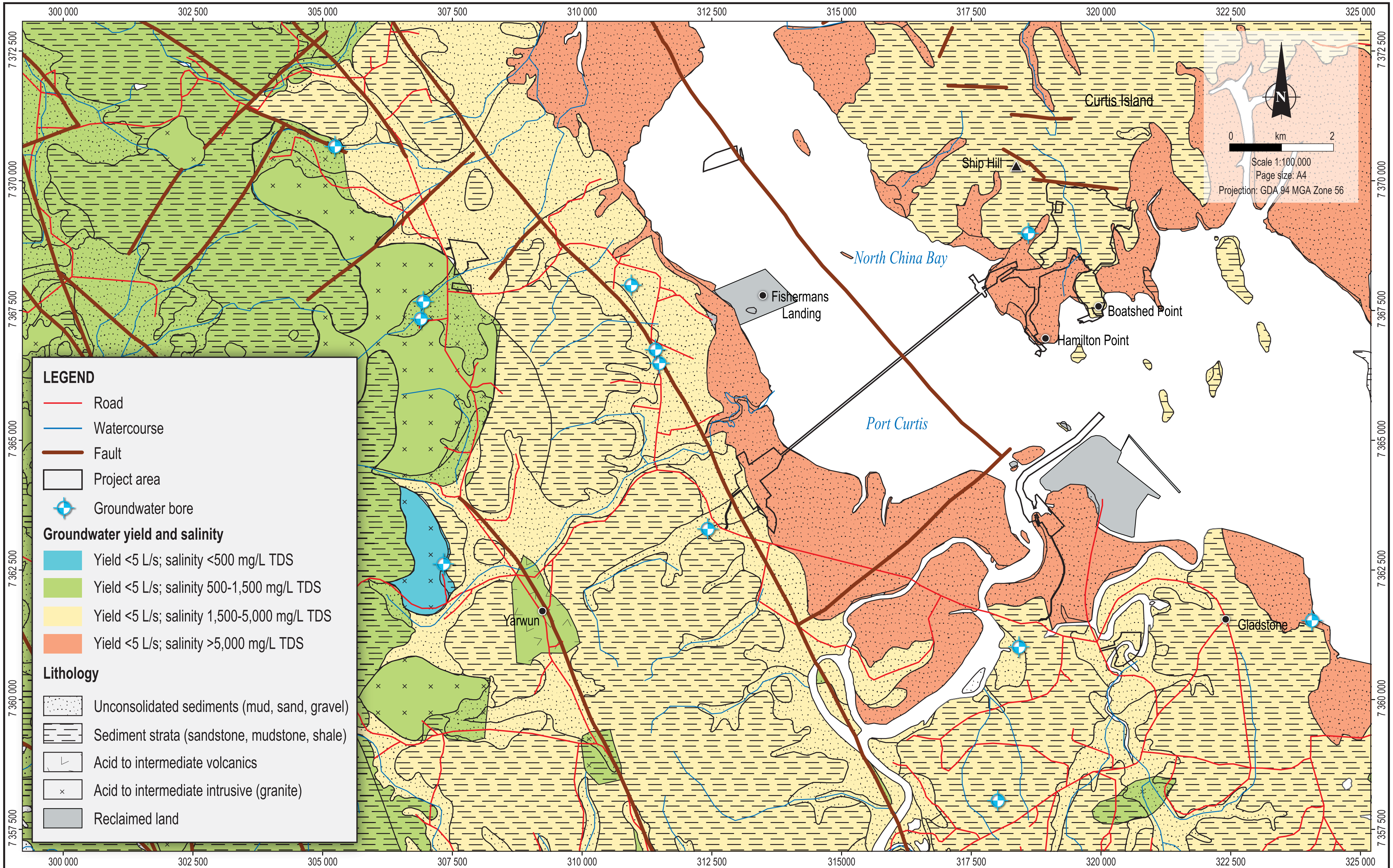
Curtis Island groundwater systems conceptual section through LNG plant site

Figure No: 14.1



Source:
Place names, roads, watercourses and faults from DME. Feed gas pipeline and project area from Coffey Environments.
Lithology from DME, categories interpreted by Coffey Geotechnics.
Groundwater yield and salinity modified by Coffey Geotechnics from Groundwater Resources Commission, 1987, Groundwater Resources of Queensland (1:2,500,000)
Groundwater bores from DERM, Coffey Geotechnics, GHD, 2009 [R480] and URS, 2009 [R478]. Imagery from SPOT (2004-2007).

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File Name: 7033_07_F14.02_GIS_GL

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Regional hydrogeology

Figure No: 14.2

Groundwater Discharge

Shallow alluvial aquifers are likely to discharge to the coast and into streams and estuaries (in particular the Calliope River and Auckland Creek) as base flow. Coastal groundwater is likely to discharge within intertidal zones, typically comprising sands and mudflats, whereas deeper aquifers discharge beyond the littoral zone further into the marine environment.

Discharge through evaporation may occur for shallow aquifers (where groundwater is less than 2 mbgl) particularly at near shore areas and mudflats at low tide. Discharge through plant transpiration is likely to occur from shallow aquifers within several metres of the surface where deep rooted phreatophytes grow. These plants obtain water from a permanent groundwater supply or from the watertable, and are likely to occur in estuarine wetland areas near the coast.

Groundwater Flow

Within the study area, groundwater flows are expected to occur through both porous media and fractured rock geologies. Groundwater flow in bedrock is expected to be predominantly through a network of fractures or joints. Wandilla Formation bedrock has limited groundwater development potential due to the generally low primary porosity. Secondary processes (faulting and fracturing) may have created zones of increased permeability within this formation at some locations.

Groundwater flow is expected to be influenced by topographic gradient, and groundwater elevations on the mainland are generally consistent with a groundwater flow direction from upland areas towards the coast (southwest to northeast). The irregular groundwater elevations across Curtis Island do not allow for a dominant groundwater flow direction to be defined. Topographic considerations and the constant head boundary at the coast would suggest that groundwater flow will be from upland recharge areas towards the coast (north to south). Local hydrological boundaries such as streams and estuaries are also likely to receive groundwater discharge and locally influence groundwater flow direction.

Hydraulic conductivity (the measure of the permeability of rocks and sediments to groundwater movement) within the study area is variable, although this variation is considered normal.

Previous studies on Curtis Island on and adjacent to the LNG plant project area have reported the following hydraulic conductivities (URS, 2009b):

- Alluvial/estuarine deposits (clay and sandy clay): 0.003 m/d to 0.06 m/d.
- Bedrock (Wandilla Formation): 0.006 m/d to 1.2 m/d.

Previous studies on the mainland within 4 km west and north of Fishermans Landing have reported the following hydraulic conductivities (GHD, 2009b):

- Alluvial/colluvial deposits (clay, silty clay and sandy clay): 0.00073 m/d to 0.05 m/d.
- Weathered siltstone: 0.003 m/d.

The overall mean and median hydraulic conductivity for the alluvial/colluvial deposits are 0.09 m/d and 0.04 m/d respectively; and for bedrock aquifers, 0.4 m/d and 0.5 m/d respectively. These values are consistent with lithology in the study area, and suggest that the bedrock has generally higher permeability than the alluvium/colluvium.

Groundwater Levels and Bore Yields

Previous studies have identified groundwater levels within the shallow aquifer system on Curtis Island within the project area between 0.01 and 3.2 mbgl (Coffey Geotechnics, 2009). Groundwater levels in the adjacent Gladstone LNG Project area range from 1.6 to 4.6 mbgl in the shallow alluvial/estuarine deposits and 2.4 to 22.5 mbgl in bedrock aquifers (URS, 2009b).

Previous studies have identified groundwater levels on the mainland (along a coastal strip to the northwest of the study area) between 0.7 and 2.8 mbgl (GHD, 2009b). Groundwater levels obtained from the DERM registered groundwater bores (2011f) further inland within the deeper aquifer system ranged from 0.6 to 28 mbgl.

Seasonal fluctuations in groundwater levels of between 0.4 to 1.0 m have been recorded for the shallow groundwater system on the mainland (GHD, 2009b). Seasonal fluctuations of greater than 1.0 m have also been recorded near coastal areas as a result of tidal influence (GHD, 2009b). Groundwater elevations on the mainland are generally consistent with a groundwater flow direction towards the coast.

Bores within the study area exhibit low sustainable yields (less than 3 L/s), which reflect the relatively low permeability and limited groundwater movement through the aquifer systems.

Aquifer depths and sustainable yields for selected representative bores are available in Appendix 7, Groundwater Impact Assessment. The locations of these bores are shown in Figure 14.2.

14.3.3 Groundwater Quality

The groundwater resources, as assessed from data for boreholes located in the vicinity of the study area, are limited and mainly of poor quality. The reported bore yields, static water levels and water quality were based on the available records at time of the study and may vary with time and spatially. Groundwater within the study area is generally of poor quality ranging from marginally fresh to brackish and saline water.

Groundwater in the shallow alluvial/estuarine deposits on the mainland can be classified as sodium-chloride type. The measured electrical conductivity (EC) values ranged from 6,900 to 61,900 μS/cm (GHD 2009b) indicating brackish to saline groundwater. Measurements of pH ranged from neutral to slightly acidic. The high EC indicates that the groundwater in the alluvial/estuarine material on the mainland within the study area is generally unsuitable for drinking, stock watering and irrigation.

Groundwater on Curtis Island within the study area is sodium-chloride type. Data from groundwater bores indicate a broad range of salinity ranging from about 22,000 to 158,000 μS/cm, indicating a range of brackish and saline, to hypersaline (Coffey Geotechnics 2011; URS, 2009b).

The DERM registered groundwater bore database (2011f) indicates that the majority of the registered groundwater bores within the study area have salinity ranging between 500 and 5,000 mg/L The salinity data of 23 DERM registered bores within 2 km of the study area indicated groundwater quality ranging from fresh to brackish water types, except for the saline water (TDS of 17,000 mg/L) at bore 88464.

Elevated levels of dissolved chromium, cobalt, copper and zinc were observed for some shallow and deep groundwater systems. Concentrations of these metals exceed ANZECC/ARMCANZ (2000) guidelines for freshwater and marine ecosystems. The groundwater, from both shallow (less than 8 m) and some deep (greater than 20 m) bores, is recognised as unsuitable for discharge into the fresh or marine water environments and for domestic use due to elevated dissolved metals. GHD (2009b) reported a range of metals above the ANZECC/ARMCANZ (2000) guidelines for marine aquatic ecosystems at some locations on the mainland.

Some groundwater in the study area is of marginable potable quality (generally in areas where salinity is low, i.e., salinity of between 500 mg/L to 1,000 mg/L). Groundwater quality data and groundwater salinity mapping (Figure 14.2) indicate that groundwater of marginal potable quality exists within Mount Larcom Range to the west of the project area.

The water quality results from groundwater bores used in the assessment are available in Appendix 7, Groundwater Impact Assessment.

14.3.4 Groundwater Vulnerability

Most of the study area is classified as low to moderate groundwater vulnerability and some areas near the coast on the mainland are rated moderate to high (generally where groundwater is less saline). The feed gas pipeline mainland tunnel entrance and tunnel spoil disposal area and TWAF 8 sites are located partially within this moderate to high vulnerability zone. Regional groundwater vulnerability is shown in Figure 14.3.

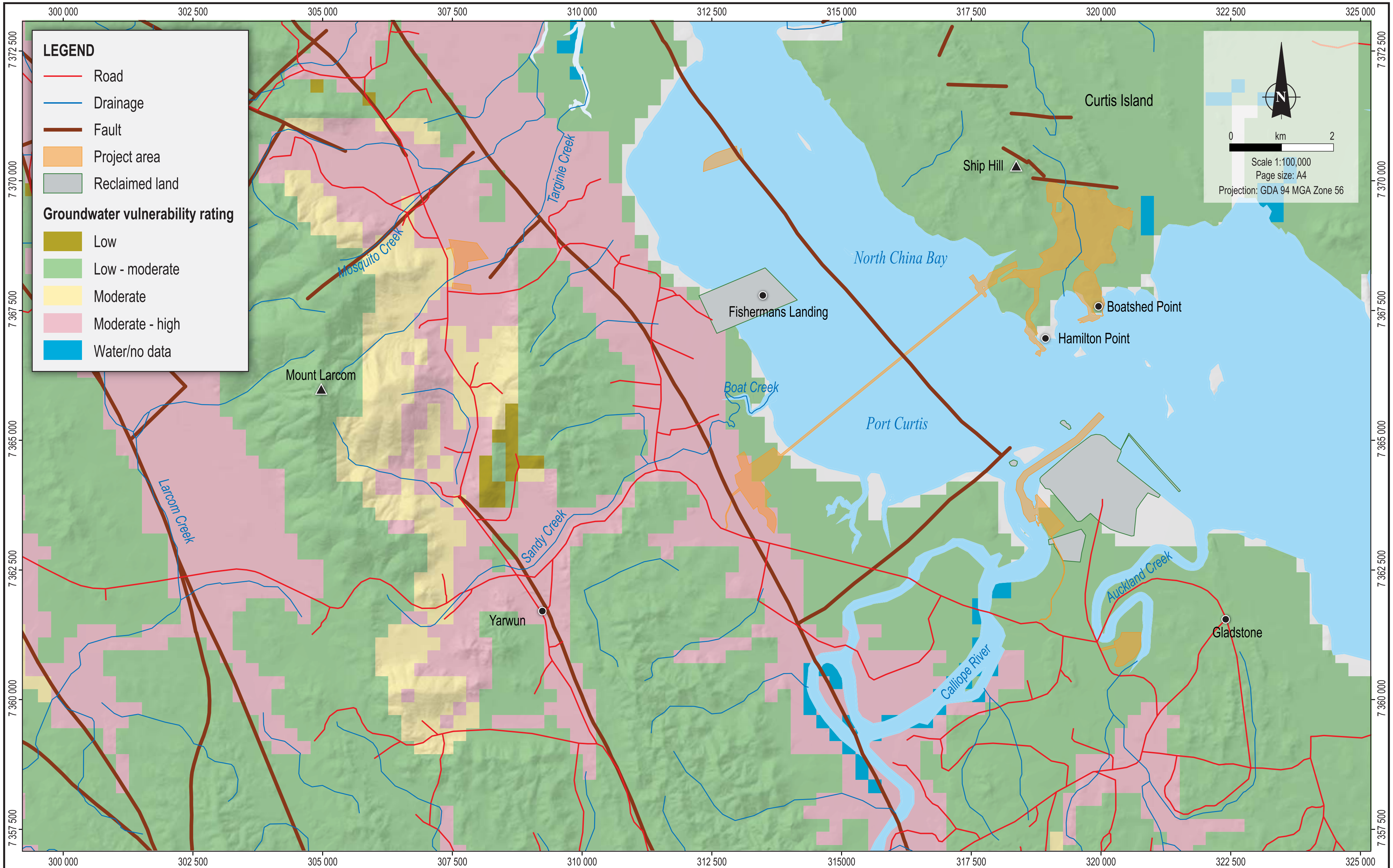
14.3.5 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems are defined as ecosystems that are dependent on groundwater for their existence and health (SKM, 2001). The following types of groundwater dependent ecosystems may potentially occur in the study area:

- Groundwater discharge wetlands. These estuarine ecosystems occur in the coastal/tidal parts of the study area and may be hydraulically connected to freshwater groundwater sources. Coastal wetlands are generally located below groundwater level and become natural groundwater discharge areas. Wetlands are discussed further in Chapter 13, Surface Water Hydrology and Water Quality, and Chapter 17, Terrestrial Ecology.
- Lakes, streams and estuaries. Groundwater systems that interact with surface ecosystems potentially have high ecological value. Deeper, confined and isolated groundwater systems that do not interact with surface water may have lower intrinsic ecological value. A range of groundwater/surface water interactions are expected to occur within the study area. In some cases, this will result in groundwater discharge (baseflow) to surface water features and biological features will require protection, depending on the ecological value of the groundwater system. Surface waterbodies and their ecology are discussed further in Chapter 13, Surface Water Hydrology and Water Quality, and Chapter 19, Marine and Estuarine Ecology.
- Phreatophytes. Plants that depend on permanent groundwater.
- Spring fed ecosystems. Discharge springs have not been identified within the study area, although it is possible that some minor springs are present in settings such as break of slope areas.

14.3.6 Groundwater Environmental Values

A search of the DERM Water Management System database for groundwater user entitlement data showed that there were no registered groundwater user entitlements allocated within the study area. The groundwater resources within the 2 km of the study area do not appear to be used for water supply (DERM, 2011). This is possibly a reflection of generally poor water quality and low yields (hence limited sustainability of supply).



Source:
Place names, roads, watercourses and faults from DME.
Project area and digital elevation model from Coffey Environments.
Groundwater vulnerability rating from DERM (optimum scale 1:500,000).
Coastline from GBRMPA.

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Regional groundwater vulnerability

Figure No: 14.3

Relevant EPP derived environmental values relevant to groundwater that are present in the study area include:

- Groundwater for biological uses. Waters of the study area are slightly to moderately disturbed due to the surrounding past and present land uses. Ecosystems supported by groundwater (including groundwater dependent ecosystems) may occur in low lying areas such as wetlands, streams (in particular the Calliope River and Auckland Creek on the mainland and the lower reaches of the ephemeral streams on Curtis Island) and estuarine areas where shallow groundwater is hydraulically linked to surface water. In these areas, shallow unconfined aquifers may discharge to these ecosystems. Species dependent on groundwater sources may include deep rooted phreatophytes in wetland areas.
- Groundwater for consumptive or productive uses:
  - Due to the generally poor quality (high salinity) of aquifers in the study area, groundwater is generally not suitable for drinking. The spatial variability of water quality means that the suitability of groundwater for potable supply would be location specific. Although groundwater quality varies greatly, there are some areas where groundwater could be sourced for potable use (following treatment). Based on the topographic and geological setting, the most likely areas for potential potable groundwater would be those further from the coast in deep confined bedrock aquifers where salinity is lower; and may include the TWAF 8 site.
  - A significant portion of the non-potable groundwater in the region may be suitable for irrigation and stock purposes. Potential is limited by the saline nature of water and low sustainable yield.
  - Groundwater may be suitable for industrial processes including cooling water, process water, utility water and wash water. These processes require particular water quality, and specific hydrochemical data is normally required to evaluate suitability for a specific industrial use. Groundwater has limited potential for industrial use at any project area owing to its low sustainable yield and saline water.

Groundwater Systems

The study area has been categorised into four broad groundwater systems on which sensitivity has been assessed:

- Unconfined alluvial/colluvial systems.
- Confined alluvial/colluvial systems.
- Unconfined bedrock systems.
- Confined bedrock systems.

Alluvial/colluvial groundwater systems are considered to have the following general characteristics:

- May occur at all project sites.
- Range from marginally potable to saline water quality.
- Of regional extent. These aquifers are common in many areas.
- Shallow systems that are recharged regularly, predominantly through rainfall processes, and are resilient to groundwater drawdown.

- Dynamic processes such as diffuse rainfall recharge are likely to enable rapid groundwater level recovery in the event of drawdown.
- Where unconfined, rehabilitation can be achieved readily when impacts are removed.
- Where confined, groundwater systems are at lower risk of contaminant impact from surface processes.

Bedrock groundwater systems are considered to have the following general characteristics:

- May occur at all project sites.
- Range from marginally potable to saline water quality.
- Of regional extent. These aquifers are common in many areas.
- Shallow systems are recharged regularly predominantly through rainfall processes, and are resilient to groundwater drawdown.
- Deeper bedrock groundwater systems are recharged regularly, predominantly through rainfall processes in upland outcrop areas or inter-aquifer leakage, and can be resilient to groundwater drawdown depending on parameters.
- Dynamic processes such as diffuse rainfall recharge (where shallow) are likely to enable rapid groundwater level recoveries where drawdown occurs.
- Where unconfined, rehabilitation can be achieved readily when impacts are removed.
- Where confined, groundwater systems are at lower risk of contaminant impact from surface processes.

The sensitivity of these groundwater systems is shown in Table 14.3.

Table 14.3 Sensitivity of groundwater systems

	Likely Project Sites	Conservation Status (Biological Uses)	Conservation Status (Consumptive and Productive Uses)	Rarity	Resilience	Dynamicism	Rehabilitation Potential	Sensitivity
Unconfined Alluvial/ Colluvial Systems	All project sites	Very High	Very Low	Very Low	Very Low	Very low	Very Low	**Low**
Confined Alluvial/ Colluvial Systems	All project sites	Low	Low	Very Low	Low	Low	Moderate	**Low**
Unconfined Bedrock Systems	All project sites	Low	Moderate	Very Low	Low	Very Low	Low	**Low**
Confined Bedrock Systems	Curtis Island	Low	High	Very Low	Low	Low	Moderate	**Moderate**

A sensitivity of moderate was adopted for the LNG plant site on Curtis Island as confined bedrock systems are known to occur in the site vicinity based on groundwater data from existing Curtis Island bores. For the remaining sites, a sensitivity of low was adopted as these areas are unlikely to impact confined bedrock systems.

14.4 Issues and Potential Impacts

This section describes the issues and potential impacts on groundwater and issues arising during construction, operations and decommissioning of the project. The groundwater system will respond to disturbance based on characteristics (for example water chemistry, transmissivity, storativity and extent) and the hydrogeologic processes acting on the groundwater systems (for example recharge and discharge).

14.4.1 Construction and Operation

The following impacts are expected to occur during construction and operation.

Ground Disturbance and Dewatering – Reduced Aquifer Recharge

Clearing of vegetation, resurfacing with impermeable materials and ground compaction during construction of all project areas may reduce infiltration rates and recharge to shallow unconfined groundwater systems on Curtis Island and the mainland. Clearing of land can also reduce transpiration losses, increasing net recharge, although this is likely to be offset by a reduction in infiltration caused by development cover from buildings, concrete and hardstand.

Any changes to overall groundwater recharge will be small due to the relatively small area of aquifer affected, compared with aquifer extent. On Curtis Island, the bulk of aquifer recharge most likely occurs in upland locations outside the LNG plant footprint. At the LNG plant site, the magnitude of impact will be very low. Combined with moderate sensitivity of groundwater systems in this area, the significance of impact is **low**.

On the mainland, the bulk of aquifer recharge is likely to occur in upland locations beyond the project area. At the feed gas pipeline mainland tunnel entrance, TWAF and launch site, the magnitude of impact will be very low. Groundwater systems in these areas are of low sensitivity, and the significance of impact is **very low**.

Dewatering may be required at the feed gas pipeline mainland tunnel entrance. The alteration of recharge (increased) along the trench would be localised within the area of activity and the magnitude of impact would be low. Sensitivity of groundwater systems at this site is low and the resulting significance of impact is **low**.

Ground Compaction, Tunnelling and Dewatering – Altered Aquifer Level, Flow and Gradient

Reduced groundwater flows due to changes in aquifer characteristics could affect groundwater dependant ecosystems. Auckland Creek, the Calliope River and estuaries are close to the proposed TWAF 7 and launch site 1. Groundwater in shallow alluvial aquifers at these sites would be expected to discharge at the coast and estuaries and into streams as baseflow. Groundwater at TWAF 8 may flow through the subsurface off site, and baseflow discharge to the local stream is feasible. The full nature of groundwater/surface water interaction is not known for this site.

Potential impacts on phreatophytes may occur at the LNG plant from groundwater dewatering (lowering watertables) or reduced recharge (also leading to lowering watertables). Groundwater extraction is not planned and the likely location of lowered watertables (should they occur) is limited to down-gradient of the LNG plant where phreatophytes may not occur.

Construction of the LNG plant, TWAF and launch site 1 may compact underlying unconfined shallow aquifers and alter hydrogeological characteristics (i.e., porosity, permeability, structure) affecting groundwater flow, levels and gradients. Compaction will be limited as the extent of the area affected is small in comparison to the aquifer. The magnitude of impact from compaction at the LNG plant is very low. The sensitivity of this site is moderate, and the significance of impact is **low**.

Temporary reduction of groundwater levels by dewatering may be experienced during the installation of the feed gas pipeline. The pipeline depth is unlikely to impact groundwater flow directions due to the shallow emplacement depth where land traverses occur. The tunnel (and pipeline within it) will run under Port Curtis, and will mainly be within subsea groundwater conditions. The area and depth of disturbance is limited, and the extent of the area affected is small in comparison to the aquifer. Impacts on shallow coastal groundwater systems are unlikely. The magnitude of impact will be very low. In this area, the sensitivity of groundwater systems is low and the significance of impact is **very low**.

Alterations in shallow groundwater flow patterns localised along the trench, and temporary reduction of groundwater levels during installation of pipe (within or near to the area of activity) are anticipated to have a low magnitude of impact. Combined with the low sensitivity of the feed gas pipeline mainland tunnel entrance, the significance of impact is **low**.

During operation, the tunnel will be designed and constructed to be largely dry, and volumes of dewatering water very low. As such, this impact is not considered further.

Saline Intrusion from High-salinity Aquifers to Lower-salinity Aquifers

Intrusion of saline water to deeper aquifers with lower salinity could occur during activities that intersect these groundwater systems, impacting groundwater values at those sites. Construction of the tunnel launch and tunnel reception shafts may intersect shallow and deep groundwater systems. Proposed construction methods employ a bentonite or grout curtain to seal the geological strata as the shaft is excavated, minimising the potential for groundwater ingress and leakage to other aquifers.

On Curtis Island, the sensitivity of the groundwater systems is moderate. The magnitude of the impact will be low when this method is employed, resulting in a **low** significance of impact

At the tunnel launch shaft on the mainland, the magnitude of impact will be low when this method is employed. Sensitivity in this area is low and the resulting significance of impact is **negligible**. It is noted that any groundwater in the tunnel launch site area may have little or no practical beneficial use.

Contamination by Leaks, Spills and Discharge of Hazardous or Detrimental Materials

Disturbance of contaminated land resulting in contamination of groundwater is discussed in Chapter 12, Contaminated Land and Acid Sulfate Soils.

Shallow groundwater quality could be degraded through unintentional spills and leaks of hazardous materials. These leaks may originate through poor storage and handling of petroleum based fuels and lubricants, chemicals used on the site, and waste water generated by project activities.

Contaminants entering the groundwater system can migrate to deeper groundwater systems vertically and horizontally though the aquifer. Contaminated shallow groundwater could migrate to deeper groundwater systems and impact groundwater dependent ecosystems.

Contamination impacts at project sites are discussed below:

- LNG Plant. Leaks from the reverse osmosis plant (brine water) and the sanitation and domestic wastewater systems (construction and operation) could contaminate groundwater systems. Contaminated groundwater due to spills and leaks could migrate off site, persist over time and affect groundwater dependent ecosystems in discharge wetlands, streams and estuaries in the lower lying areas of the LNG plant. The expected magnitude of impact from spills at the LNG plant is moderate. This area has a moderate sensitivity and the resulting significance of impact is **moderate**.
- Feed Gas Pipeline. Unintentional spills and leaks of drilling fluids, chemicals and hydrocarbons (fuels and lubricants) used during construction of the tunnel and pipeline could contaminate shallow groundwater systems and could persist over time. Any contamination in shallow aquifers could migrate off site through the groundwater system. No groundwater dependent ecosystems are likely to be impacted in this area.

  The expected magnitude of impact from spills at the feed gas pipeline sites is moderate. This area has a low sensitivity and the resulting significance of impact is **moderate**.
- TWAFs and Launch Site 1. Unintentional spills and leaks from petroleum based fuels from excavators and construction machinery, chemicals and wastewater could reach shallow groundwater and degrade its quality in the vicinity of the TWAFs and launch site 1. Potential spills during the management of waste from sanitation and domestic waste systems could degrade groundwater quality in shallow aquifers.

  At TWAF 8, groundwater dependent ecosystems downstream along Targinie Creek could be impacted if a chemicals spill, leak or discharge were to occur. At TWAF 8, groundwater may flow through the subsurface off site, although baseflow discharge to the local stream is feasible.

  At TWAF 7 and launch site 1, the topography and position in the landscape indicate that groundwater in shallow alluvial aquifers discharge at the coast and estuaries and into streams as baseflow, feeding groundwater dependent ecosystems.

  At launch site 1, the limited area of site operation indicates that any impacts would be localised and lower in magnitude than for the TWAF areas, however launch site 1 has a longer operational duration.

  At launch site 1, TWAF 7 and TWAF 8 migration impacts could occur both on site and off site and across-aquifers impacts could persist over time. At TWAF 7, TWAF 8 and launch site 1, impacts are moderate in magnitude. Sensitivity at these sites is low, and the significance of impact is **moderate**.

Degradation of Groundwater Quality through Disturbance to Acid Sulfate Soils

Disturbance of potential acid sulfate soils during earthworks in low lying coastal areas and subsequent acidic leachate migration to groundwater are discussed further in Chapter 12, Land Contamination and Acid Sulfate Soils.

The construction of marine infrastructure and haul roads on Curtis Island will involve excavation in low lying areas where marine/estuarine sediments may generate acid from oxidation of sulfide minerals in the potential acid sulfate soils. This may cause the acidification and degradation of shallow groundwater quality. The resultant low pH conditions could lead to the mobilisation of metals in groundwater and subsequent discharge to the sea. The magnitude of impact at this site is moderate. The sensitivity of this site is moderate and the significance of impact is **moderate**.

At the feed gas pipeline mainland tunnel entrance, excavation activities have the potential to cause deterioration in groundwater quality due to the exposure of acid sulfate soils where they occur. The magnitude of impact at this site is high. The sensitivity of this area is low and the significance of impact is **moderate**.

The construction of TWAF 7 and launch site 1 near low lying areas along Auckland Creek may generate acid groundwater conditions due to exposure of acid sulfate soils. The magnitude of impact at this site is moderate. The sensitivity of this area is low and the significance of impact is **moderate**.

Impact Summary

A summary of construction and operation impacts on groundwater across the project area is shown in Table 14.4.

Table 14.4 Summary of construction and operation groundwater impacts

Impact	Location	Sensitivity	Magnitude	Significance
Reduced aquifer recharge	LNG plant	Moderate	Very low	Low
	TWAF 7, TWAF 8, launch site 1, mainland tunnel entrance	Low	Very low	Very low
Altered aquifer characteristics	LNG plant	Moderate	Very low	Low
	TWAF 7, TWAF 8, launch site 1, mainland tunnel entrance	Low	Very low	Very low
Altered groundwater flow due to tunnelling, causing saline intrusion	Feed gas pipeline and mainland tunnel entrance	Low	Low	Negligible
	LNG plant	Moderate	Low	Low
Contamination by leaks, spills and discharge of hazardous or detrimental materials	LNG plant	Moderate	Moderate	Moderate
	Feed gas pipe, TWAF 7, TWAF 8, launch site 1	Low	Moderate	Moderate
Degradation of groundwater quality through disturbance to acid sulfate soils	LNG plant	Moderate	Moderate	Moderate
	Feed gas pipeline and mainland tunnel entrance	Low	High	Moderate
	TWAF 7, TWAF 8, launch site 1	Low	Moderate	Moderate

14.4.2 Decommissioning

All facilities will be decommissioned at some undetermined future time. The potential impacts on groundwater values caused by the decommissioning will be similar to the construction and operation impacts. Impacts on groundwater values during decommissioning include contamination from the management and handling of waste and materials during this phase. Onsite monitoring wells and bores will require decommissioning. Impacts of decommissioning on groundwater will be largely confined to the LNG plant site. The sensitivity of the LNG plant site is moderate and the significance of impact is **moderate**. The sensitivity of all other areas is low and the significance of impact is **moderate**.

Mitigation measures have been developed for impacts on the groundwater values in the study area with a significance of moderate or higher.

14.5 Avoidance, Mitigation and Management Measures

The following mitigation measures will be undertaken during project design, construction, operation and decommissioning.

Design

- Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system. [C14.01]

- Prepare a materials handling and waste management plan to manage any potential contaminants, soils or materials that might result in impacts on shallow groundwater through either short term or long term leaching. [C14.02]

Construction and Operation

- Minimise the extent and duration of construction dewatering required. [C14.03]

- Develop an ASS management plan prior to construction work. In the plan, specify how onsite ASS disturbances should be managed in accordance with SPP 2/02 and the methods set out in Queensland acid sulfate soil technical manual soil management guidelines (Dear et al., 2002). [C12.17]

- Store fuels, chemicals and hazardous wastes in appropriately sized, bunded storage facilities (in leak proof sealed containers). [C14.04]

- Where fuel or oil is contained in above ground storage facilities, ensure they are constructed with suitable secondary containment in accordance with Australian standards. [C14.05]

- Maintain accurate records of fuels and oils stored in underground storage tanks to enable leak detection through quantity auditing. [C14.06]

- Develop appropriate spill prevention and response plans to cover project activities and the types and quantities of fuel, oil and chemicals held at each site. [C13.12]

- Minimise site storage of brine products. [C14.07]

- Collect sewage and greywater generated from the pioneer camp in portable disposal units or other mobile collection facilities. Use a licensed waste contractor to service the sewage facilities and dispose of effluent at a licensed waste management facility. Dispose of sewage from the mainland TWAF through a connection to the local sewerage network or ensure that it is collected in portable disposal units or other mobile collection facilities. [C14.08]

- Implement engineering controls to minimise the extent of aquifer drawdown and saline water encroachment such as sheet piling of excavations or groundwater reinjection. [C14.09]

Decommissioning

- Prepare a materials handling and waste management plan to manage any potential contaminants, soils or materials that might result in impacts to shallow groundwater through either short term or long term leaching. [C14.02]

- Follow standard guidelines for decommissioning of all monitoring bores including the Manual of Water Well Construction Practices (US EPA, 1977) and Minimum Construction Requirements for Water Bores in Australia (DNRME, 2003). [C14.10]

14.6 Residual Impacts

Residual impacts for the mainland sites range from very low to low significance, assuming implementation of the design and mitigation measures proposed. Project activities are unlikely to adversely impact the mainland groundwater environment.

Residual impacts for the LNG plant site on Curtis Island range from low to moderate significance. Impacts that remain of moderate significance include disturbance to acid sulfate soils at the LNG plant and potential contamination of groundwater systems from leaks and spills. Confined (bedrock) aquifers on Curtis Island are unlikely to be affected by project activities as the actual risk of contamination from surface activities is low and acid sulfate soils are assumed to be managed effectively, in accordance with the acid sulfate soil management plan.

14.7 Inspection and Monitoring

The following inspection and monitoring activities will be undertaken during construction and operation.

14.7.1 Inspection

Regular inspections will be undertaken to assess the integrity of groundwater protection controls. Where potential impacts are identified during inspections, controls will be rectified or optimised accordingly.

Arrow Energy will undertake routine inspections (during construction and operations) of the handling, storage and disposal of chemicals, fuels and hydrocarbons for compliance with applicable Australian standards such as AS1940-2004: Australian standard for the storage and handling of flammable and combustible liquids, and AS 3780-2008: Australian standard for the storage and handling of corrosive substances.

14.7.2 Monitoring

A groundwater monitoring program will be established prior to construction, which will:

- Include a network of existing and new monitoring bores to provide base level of groundwater quality data as well as the level of groundwater present at each bore location.
- Target shallow unconfined and deeper confined aquifers in the vicinity of the LNG plant, TWAF and launch site 1.
- Describe the parameters to be monitored.
- Relocate preconstruction monitoring bores that are likely to be damaged by project construction activities so monitoring can continue during operations.

A construction groundwater management plan will be prepared prior to construction commencing and will include monitoring requirements.

During operation, groundwater level monitoring will be undertaken on a quarterly basis. Parameters to be monitored will be described in the groundwater monitoring plan.

Table 14.5 identifies indicative groundwater baseline monitoring activities which will be refined through the development of the groundwater monitoring program.

The groundwater monitoring program will be reviewed after three years with any changes and ongoing requirements agreed with the relevant authority.

Table 14.5 Indicative groundwater baseline monitoring

Activity	Frequency	Monitoring Bores	Parameters
Preconstruction			
Level monitoring	Monthly	A representative selection of available bores on the mainland and Curtis Island.	Groundwater level measurement.
Field parameters	Monthly	A representative selection of available bores on the mainland and Curtis Island.	pH, electrical conductivity, temperature, dissolved oxygen, redox potential (Eh).
Laboratory analytes	Once preconstruction	A representative selection of available bores on the mainland and Curtis Island.	• TDS, pH, total acidity, total alkalinity. • Major cations (calcium, magnesium, sodium, potassium) and major anions (chloride, sulfate, bicarbonate). • Total metals and dissolved metals (arsenic, cadmium, chromium, copper, nickel, lead, zinc, aluminium, manganese, selenium, iron, mercury). • Ferrous iron: filtered and unfiltered. • Nutrients: total nitrogen, nitrate, TKN, reactive phosphorous, total phosphorus. • Total petroleum hydrocarbons and volatile organic compounds.
Construction and Operation			
Level monitoring	Quarterly	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores.	Groundwater level measurement.
Field parameters	Quarterly	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores.	pH, electrical conductivity, temperature, dissolved oxygen, redox potential (Eh).
Laboratory analytes	Annually	A representative selection of available bores on the mainland and Curtis Island and newly installed targeted monitoring bores.	• TDS, pH, total acidity, total alkalinity. • Major cations (calcium, magnesium, sodium, potassium) and major anions (chloride, sulfate, bicarbonate). • Total metals and dissolved metals (arsenic, cadmium, chromium, copper, nickel, lead, zinc, aluminium, manganese, selenium, iron, mercury). • Ferrous Iron: filtered and unfiltered. • Nutrients: total nitrogen, nitrate, TKN, reactive phosphorous, total phosphorus. • Total petroleum hydrocarbons and volatile organic compounds.

14.8 Commitments

The measures (commitments) that Arrow Energy will implement to manage impacts on groundwater are set out in Table 14.6.

Table 14.6 Commitments: Groundwater

ID	Commitment
C14.01	Design the facility drainage system such that accidental releases of hazardous substances are collected to reduce the chance of contamination seeping into the groundwater system.
C14.02	Prepare a materials handling and waste management plan to manage any potential contaminants, soils or materials that might result in impacts to shallow groundwater through either short term or long term leaching.
C14.03	Minimise the extent and duration of construction dewatering required.
C12.17	Develop an ASS management plan prior to construction work. In the plan, specify how onsite ASS disturbances should be managed in accordance with SPP 2/02 and the methods set out in Queensland acid sulfate soil technical manual soil management guidelines (Dear et al., 2002). Common with Chapter 12, Contaminated Land and Acid Sulfate Soils.
C14.04	Store fuels, chemicals and hazardous wastes in appropriately sized, bunded storage facilities (in leak proof sealed containers). Common with Chapter 31, Waste Management.
C14.05	Where fuel or oil is contained in above ground storage facilities, ensure they are constructed with suitable secondary containment in accordance with Australian standards.
C14.06	Maintain accurate records of fuels and oils stored in underground storage tanks to enable leak detection through quantity auditing.
C13.12	Develop appropriate spill prevention and response plans to cover project activities and the types and quantities of fuel, oil and chemicals held at each site. Common with Chapter 13, Surface Water Hydrology and Water Quality, and Chapter 31, Waste Management.
C14.07	Minimise site storage of brine products.
C14.08	Collect sewage and greywater generated from the pioneer camp in portable disposal units or other mobile collection facilities. Use a licensed waste contractor to service the sewage facilities and dispose of effluent at a licensed waste management facility. Dispose of sewage from the mainland TWAF through a connection to the local sewerage network or ensure that it is collected in portable disposal units or other mobile collection facilities. Common with Chapter 31, Waste Management.
C14.09	Implement engineering controls to minimise the extent of aquifer drawdown and saline water encroachment such as sheet piling of excavations or groundwater reinjection.
C14.10	Follow standard guidelines for decommissioning of all monitoring bores including the Manual of Water Well Construction Practices (US EPA, 1977) and Minimum Construction Requirements for Water Bores in Australia (DNRME, 2003).