APPENDIX 2

ARROW LNG PLANT

Geology, Landform and Soils Impact Assessment

arrow energy
go further

GEOLOGY, LANDFORM AND SOILS IMPACT ASSESSMENT ARROW LNG PLANT

Arrow CSG (Australia) Pty Ltd and

Coffey Environments Australia Pty Ltd

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EXECUTIVE SUMMARY

E1. INTRODUCTION AND STUDY BACKGROUND

Coffey Geotechnics' Geology, Landform and Soils Impact Assessment has been prepared as part of the Arrow LNG Plant Environmental Impact Statement. Arrow Energy proposes to develop an LNG plant on Curtis Island, adjacent to Gladstone, Queensland. The geology, landform and soils study provides an assessment of the areas of the landscape that could be directly or indirectly affected by the LNG plant and associated infrastructure. Coffey Geotechnics' report provides the following:

- Study background and legislative context, where relevant to the geology, landform and soils study (Section 1).
- Description of the Arrow LNG Plant project and project activities relevant to the geology, landform and soils study (Section 2).
- Method of assessment (Section 3).
- Description of the existing geology, landform and soils of the study area, including sites of environmental significance (geoheritage) (Section 4).
- Assessment of environmental values associated with the geology, landform and soils of the study area, and their sensitivity (i.e. susceptibility to change in response to disturbance) (Section 5).
- Assessment of environmental constraints and design considerations associated with the geology, landform and soils of the study area (Section 6).
- Assessment of potential impacts of the project on the geology, landform and soils of the study area prior to implementation of management and mitigation measures (Section 7).
- Management recommendations to mitigate against identified potential impacts, including inspection and maintenance programme recommendations (Section 8).
- Assessment of potential residual impacts following successful implementation of recommended management and mitigation measures (Section 9).
- Cumulative impact assessment (Section 10).
- Conclusion (Section 11).

The geology, landform and soils study has concentrated on the areas that will be physically disturbed by the project, and the potential indirect impacts that may result from this disturbance.

E2. GEOLOGY, LANDFORM AND SOILS ASSESSMENT METHOD

A phased approach to the geology, landform and soils study was adopted. Firstly, a preliminary desktop study was carried out to collate and assess available existing mapping, studies, data and relevant legislation from publically available sources, including information from several other EIS studies in the locality. Secondly, as soils mapping at a scale suitable for the study was not available, the findings of the desktop study were used to divide the study area into areas which have broadly similar characteristics, properties and environmental values, known as "terrain units" (TU). Thirdly, the terrain mapping was ground-truthed through observation of existing exposures of rock and soil during a field visit in June 2010. Finally, the findings of the desktop study and fieldwork were used to assess the significance of environmental impact, the residual impact (assuming successful implementation of management and mitigation measures) and the cumulative impact.

E3. EXISTING ENVIRONMENT

The study area was divided into 4 broad physiographic regions: the Mount Larcom Range, the Coastal Plains, Curtis Island and the Gladstone Urban Region. These regions have the following characteristics:

- Mount Larcom Range: Rugged peaks rising to over 650 mAHD, created by igneous intrusions into Permian sedimentary sequences. Soils are variable with texture contrast soils supporting some GQAL (Good Quality Agricultural Land) along the eastern slopes. Shallow, gravelly soils elsewhere.
- Coastal Plains: Low-relief coastal plain characterised by broad expanses of marine muds (hydrosols). Inland, alluvial and colluvial plains rise gently to the steeper ground of the Mount Larcom Range. Soils are variable gradational and texture contrast soils that are commonly ferruginised. Areas of major industrial development have caused large-scale land alteration (topographic and reclamation). The marine plains at the Calliope River estuary and the Targinie State Forest are considered to be key elements of the coastal landscape (EPA, 2003).
- Curtis Island: Steeply dipping Late Devonian/Carboniferous Curtis Island Group sedimentary sequences form steep-sided ridges (up to 173 mAHD), rising above steep, gullied valleys and coastal mudflats. Soils are gradational and gravelly, with texture contrast soils along valley bottoms. The marine plans and ridges of southwestern Curtis Island are considered to be key elements of the coastal landscape (EPA, 2003).
- Gladstone Urban Region: Largely altered due to industrial and residential development. Areas of topographic alteration and reclaimed land. Undisturbed land is generally characterised by low-lying coastal plains and mudflats.

E4. ENVIRONMENTAL VALUES, LANDSCAPE SENSITIVITY AND ENVIRONMENTAL CONSTRAINTS

Terrain unit mapping was used to define the environmental values of the study area which govern the way in which the landscape responds to disturbance. Seven broad units were defined, further sub-divided into 17 sub-units according to the intrinsic landscape properties and characteristic geomorphic processes. Seven of the sub-units will be affected by the project to some degree.

An assessment of sensitivity indicated that specific elements of the landscape were particularly sensitive to disturbance, as follows:

- Erodible soils associated with sodic texture contrast soils located on the valley floors of Curtis Island and along the foothills of the Mount Larcom Range; and reclaimed land comprising former ash pond material in the Gladstone Urban Region.
- Saline soils along coastal margins.
- Soft and/or waterlogged soils prone to compression and erosion associated with coastal marine muds and sodic texture contrast soils.

- Poor rehabilitation potential due to low fertility; shallow, gravelly soils and difficult soil profile reinstatement.
- Steep slopes causing local increases in landscape sensitivity.

The overall sensitivity of terrain units impacted by the project was assessed to be moderate. The combined environmental values of each unit were not sufficiently robust to warrant a low sensitivity classification, but equally, these values were not unstable enough to warrant a high sensitivity classification.

Environmental constraints to the project are largely related to soil characteristics and topography. The area is characterised by erodible, sometimes sodic, saline, compressible soils. These properties may cause erosion-related site damage, trafficability problems and slope instability. Localised steep slopes may increase the level of constraint. The variable rock strength may affect excavatability and sourcing of construction materials.

E5. IMPACT ASSESSMENT

The impact of the project on the geology, landform and soils is related to the environmental values and sensitivity to change. These environmental values will be present throughout the lifetime of the project and should, therefore, be a constant consideration.

Potential impacts of the project on the geology, landform and soils of the study area, without implementation of management and mitigation measures, indicated that land degradation would be a potential project-wide impact. This could involve erosion, resulting from vegetation clearance, soil compaction or flow concentration; creation of dust; reduced soil quality. Other potential impacts are related to activities associated with specific project components. The feed gas pipeline may result in disturbance of compressible, saline, waterlogged or acidic soils. Differential settlement of trench backfill may occur, possibly resulting in creation of preferential surface and subsurface pathways. Storage of spoil is likely to result in compression of coastal muds. Leakage or collapse of stored tunnel spoil could cause alteration of soil chemistry and down-system sedimentation. Construction of the LNG Plant will cause landform change, and large-scale removal of soils which could lead to slope instability, and down-system sedimentation. Impacts are likely to be exacerbated by the large spatial extent of disturbance (approximately 218 ha). TWAF 8 (the temporary workers accommodation facility option at the base of the Mount Larcom Range) will impact approximately 9.5ha of GQAL.

The significance of potential impacts is calculated by combining landscape sensitivity with magnitude of potential impact (the latter related to the severity, geographical extent and duration of the potential impact). The assessment found that, without implementation of management and mitigation measures, the LNG plant would have a high magnitude of impact on the environmental values of Curtis Island (both inland and at the coast), due to the large spatial extent of permanent topographic change in an area characterised by erodible soils. The feed gas pipeline will have a high impact magnitude on the coastal flats, due to the soft, waterlogged nature of soils and potential for chemical or sediment contamination. Therefore, the significance of impacts in these areas was also high. The feed gas pipeline on the coastal plains; heavy haul roads on Curtis Island; and TWAF 8 where it impacts GQAL were assessed to have a moderate magnitude (and significance) of impact.

E6. MANAGEMENT AND MITIGATION MEASURES

Management and mitigation measures have been proposed in accordance with National and State guidelines. Performance criteria for rehabilitation, along with an inspection and maintenance programme, should be developed to confirm successful implementation of these measures. The different project components often require similar construction, maintenance and rehabilitation techniques, although at differing scales. Therefore, generic management and mitigation measures have been recommended, largely related to mitigation of land degradation.

Land degradation management measures (including erosion control measures) typically involve control of water flow and maintenance/rapid re-establishment of vegetation cover to reduce erosion hazard. Measures should consider natural and constructed drainage patterns, slope steepness, rainfall frequency and intensity, potential flow magnitudes, ground cover, the presence of erodible soils and land-use impacts. The main aim of erosion control measures is to retard flow velocities, impound mobilised sediment and maintain protective ground cover (ultimately using self-sustaining native vegetation). Impacts can be reduced if works are timed to avoid periods of heavy or prolonged rainfall.

Soil management is also recommended to reduce impacts to valuable (and limited) soil resources. Measures should consider appropriate soil stripping, storage and replacement techniques, to avoid adverse impacts to the soil properties (i.e., chemistry (including salinity), profile and fertility).

Specific management measures have been recommended for the different project components, related to relevant project activities. In particular, measures to control sedimentation should be implemented where associated with large-scale earthworks, e.g., at the LNG Plant site and tunnel spoil storage site at the mainland tunnel launch site of the feed gas pipeline.

E7. RESIDUAL IMPACT ASSESSMENT

The residual significance of impact is controlled by the effect that implementation of management and mitigation measures have on the magnitude of impact, given that the sensitivity of the landscape is essentially a constant. Successful implementation of the recommended management and mitigation measures is anticipated to reduce the magnitude and, therefore, significance of impact to low levels for the majority of project components. The permanent alteration of the environmental values of southwestern Curtis Island and large scale of disturbance at the LNG Plant site will have a moderate magnitude (and significance) of impact. Rehabilitation will be targeted to produce a stable, safe, non-polluting landform with self-sustaining soil fertility, thus re-setting the baseline of the environmental values of the area.

E8. CUMULATIVE IMPACT ASSESSMENT

Several similar projects are ongoing or proposed within or adjacent to the study area. The Gladstone LNG (GLNG), Queensland Curtis LNG (QCLNG) and Australia Pacific LNG (APLNG) projects also involve major topographic alteration of southwestern Curtis Island. These projects are anticipated to increase land degradation impacts and result in permanent alteration of environmental values. Rehabilitation may be hampered by exhaustion of finite soil resources in the region. At a regional level, the Arrow LNG Plant project is anticipated to have a similar or lesser impact to other proponents' projects, due to the degree of topographic alteration proposed. The disturbance areas of these projects do not overlap and impacts are, therefore, not considered to be cumulative at the site level.

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ABBREVIATIONS

AHD	Australian Height Datum
APIA	Australian Pipeline Industry Association
ASCS	Australian Soil Classification System
DEM	Digital Elevation Model
DERM	Queensland Government Department of Environment and Resource Management
DSEWPC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
EC	Electrical Conductivity
EIS	Environmental Impact Statement
ESP	Exchangeable Sodium Percentage
KRA	Key Resource Area
QGEOP	Queensland Government Environmental Offsets Policy
GSDA	Gladstone State Development Area
GLS	Geology, Landform and Soils
GQAL	Good Quality Agricultural Land
LNG	Liquefied Natural Gas
MOF	Materials Offloading Facility
SPP	State Planning Policies
TU	Terrain Units

GLOSSARY

The following glossary provides a definition of technical terms used within this report. The definitions have been adapted from online glossaries and dictionaries, including webpages of: CSIRO "The Australian Soil Classification"; Department of Primary Industries (Victoria) and Department of Environment and Resource Management (Queensland).

A Horizon	*n.*	Surface soil horizons which contain organic material. This is also referred to as 'topsoil'.
Alluvium	*n.*	Detrital sediments that have been deposited by rivers or streams.
B Horizon	*n.*	Subsoil horizons differing from the overlying A horizon by either colour, mineralogy, organic content or structure. This is also referred to as 'subsoil'.
Clear or abrupt soil horizon change	*n.*	Horizon boundary less than 50 mm in thickness.
Colluvium	*n.*	Unconsolidated material at the base of slopes or cliffs that have been deposited by gravity.
Cuesta	*n.*	A ridge formed by erosion or faulting of gently dipping sedimentary rocks. The landform has a steep escarpment face, with a gently sloping dip slope.
Dip Slope	*n.*	A slope in the land surface that conforms with the inclination of underlying strata.
Escarpment	*n.*	A steep slope or cliff separating two relatively level areas of ground, resulting from erosion or faulting.
Felsic	*adj.*	Rocks that contain an abundance of light coloured silicate minerals (e.g. quartz, feldspars, feldspathoids).
Graben	*n.*	An elongated block of the earth's crust bounded on at least two sides by faults and displaced downward relative to the blocks on either side.
Hogsback	*n.*	A cuesta formed by steeply dipping rocks (over about 40°). The scarp and dip slopes are approximately symmetrical.
Horst	*n.*	An elongated block of the earth's crust bounded on at least two sides by faults and displaced upwards relative to the blocks on either side.
Incised Channel	*n.*	A stream or river channel which cuts through the bed of the valley floor.
Intertidal		The coastal strip of land that is above low tide but submerged during high tide.
Laterisation	*n.*	Weathering of a substance into laterite.
Laterite	*n.*	Residual soil comprised of secondary oxides of iron and/or aluminium with clay minerals and silica.
Mafic	*adj.*	Rocks that are generally dark, and are rich in magnesium and/or iron rich minerals (e.g. olivine, pyroxene, amphibole and biotite).

GLOSSARY

Metasedimentary Rock (Metasediments)	*n.*	A sediment or sedimentary rock that has been subjected to regional or contact metamorphism.
Ped	*n.*	A natural unit of soil structure formed by cracking along planes of weakness.
Piping	*vb.*	Subsurface geomorphological processes causing development of pipes or tunnels (sometimes referred to as tunnelling erosion). Pipes form through exploitation of cracks (particularly in dispersive material) and/or winnowing of fine grains through the soil matrix.
Plateau	*n.*	An elevated area of relatively level land, surrounded by steeper slopes or cliffs. Plateaux are larger in extent than mesas.
Project Area	*n.*	The area that will be disturbed or potentially disturbed by the proposed development, including a buffer that reflects the potential for activities to extend outside the area to be directly disturbed.
Project Footprint	*n.*	The actual area of disturbance.
Regolith	*n.*	Unconsolidated material overlying bedrock that has been formed by weathering, erosion, transport and/or deposition of older materials.
Relief	*n.*	The difference between the highest and lowest elevations in a given area.
Scarp Slope	*n.*	The surface of the steep slope of a cliff or escarpment.
Sedimentary Rock	*n.*	A rock formed by the consolidation and/or cementation of sediments that have been transported and deposited by wind, water, gravity or ice.
Soil Creep	*n.*	Slow gravitational movement of soil downslope.
Strait		A narrow passage of water connecting two larger water bodies.
Study Area	*n.*	The area studied, including an approximate 3km buffer around the Project Area, to allow an assessment of direct and indirect geology, landform and soils environmental impacts of the Arrow LNG Plant.
Subsoil	*n.*	See “B Horizon”.
Supratidal	*n.*	The coastal strip of land that is affected by spray from waves and is only submerged during storms.
Texture Contrast Soil	*n.*	Soils with a clear or abrupt change in texture between the A and B Horizons. A horizons are typically bleached.
Topsoil	*n.*	See “A Horizon”.

1 INTRODUCTION

This section of the report provides an overview of the Geology, Landform and Soils Study for the Arrow LNG Plant.

1.1 Project Overview

The project comprises the construction and operation of an LNG plant and feed gas pipeline, with associated temporary and permanent facilities and infrastructure. The project is located at the southern end of Curtis Island, incorporating the coastal strip between (and including) Gladstone and the Mount Larcom Range (see Figure 1.1). The project will pipe coal seam gas beneath Port Curtis to the LNG plant on Curtis Island. Section 2.2 provides a more detailed description of the project.

1.2 Geology, Landform and Soils Study Aims and Objectives

The aim of the geology, landform and soils study is to investigate areas of the landscape that could be directly or indirectly affected by the proposed LNG plant and associated infrastructure. An approximate 3km buffer around the EIS study area, hereafter collectively referred to as the study area, was used to allow assessment of both direct and indirect environmental impacts (see Section 3: Geology, Landform and Soils Assessment Method).

The objectives of the geology, landform and soils study are as follows:

- Fulfil the requirements of the project terms of reference, summarised in the Cross-Reference Table (see Appendix B).
- Address relevant issues raised by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC).
- Discuss the legislative context of the proposed project in terms of geology, landform and soils.
- Characterise the existing topography, soils, geology, geomorphology and landforms of the proposed study area.
- Identify the environmental values of the existing landscape.
- Assess the impact of the proposed project on the topography, soils, geology, geomorphology and landforms.
- Provide recommendations for management strategies to avoid significant impacts upon the geology, landforms and soils of the study area.

The study assessed the geology, landforms and soils of the study area, both in terms of the impact of the project on the environment and *vice versa*. The aim of the impact assessment was to gain a broad understanding of landscape sensitivity, constraints, impacts and issues associated with the geology, landforms and soils throughout the study area, and a site-specific understanding of these issues within known project activities areas, e.g., the LNG plant site.

1.3 Related Studies

This study provides reference to other Arrow LNG Plant EIS studies but does not provide specialist comments outside the scope of the geology, landform and soils impact assessment. The other EIS studies referenced and their relationship to the geology, landform and soils study are provided below:

- Groundwater Impact Assessment, including information regarding the deeper stratigraphy (Coffey Geotechnics, 2011a.).
- Surface Water Impact Assessment, including issues associated with surface water and erosion associated with creeks and rivers (Alluvium, 2011).
- Stage 1: Preliminary Site Investigation (Contaminated Land) and Acid Sulfate Soils Impact Assessment (Coffey Environments, 2011; Coffey Geotechnics, 2011b).
- Aquatic Ecology and Flora and Fauna Impact Assessments, including potential flora and fauna impacts (Aquateco, 2011; Ecosure, 2011).
- Landscape and Visual Impact Assessment, including potential impacts to the visual amenity of the landscape (AECOM, 2011).

1.4 Explanation of the Term “Soil”

The term “soil” is used by geotechnical engineers and soil scientists to mean different things. When used in a geotechnical engineering context, all material above bedrock is assessed, and should properly be termed “regolith”. When used in a soil science context, a recognisable profile must exist, i.e., several layers (horizons) sub-parallel to the ground surface, formed by physical, chemical and biological processes (Charman and Murphy, 2007). Engineering soil/regolith includes developed soils, but not all regolith is soil as defined by soil scientists. The common use of the term “soil” can be confusing, e.g., the widely accepted engineering term for compressible sediments is “soft soils”, despite the fact that this material may not have developed a soil profile. This report has attempted to provide clarity as to which definition is being referred to.

1.5 Legislative Context and Standards

The geology, landform and soils study considered key statutory regulations governing land management relevant to the project. These are listed below.

- Queensland *State Development and Public Works Organisation Act 1971*. The object of this Act is to coordinate whole-of-government assessment of environmental impacts for State significant projects and by creating State Development Areas. In 1997, the Gladstone State Development Area (GSDA), which encompasses the study area, was created pursuant to this Act.
- Queensland *Nature Conservation Act 1992.* The object of this Act is the conservation of nature, including ecosystems and their constituent parts, and all natural and physical resources. This Act is relevant to the Arrow LNG Plant project should the development impact upon the soils, geology and/or landforms within protected areas (listed under s14) that contribute to the biological diversity and integrity, or intrinsic or scientific value of that particular place.
- Queensland *Land Management Act 1994*. The object of this Act is to manage land for the benefit of the people of Queensland based on the principles of sustainability, evaluation, development and community purpose.

- Queensland *Vegetation Management Act 1999.* Objects of this Act considered relevant to the Arrow LNG Plant geology, landform and soils study include 1) ensuring that vegetation clearance does not cause land degradation, 2) and managing environmental effects associated with clearance.
- Queensland *Sustainable Planning Act 2009* (replacing the *Integrated Planning Act 1997)*. The objective of this Act is to seek to achieve ecological sustainability by managing development processes, associated environmental effects, and streamlining the coordination of planning and local, regional and State planning instruments. As the project site falls within the Gladstone State Development Area, MCU's (material change of use), including gas transportation infrastructure and infrastructure facilities, are not assessable under the *Sustainable Planning Act 2009*, rather falling under the jurisdiction of *the State Development and Public Works Organisation Act 1971*. However, several state planning policies which advance the purpose of this Act are considered relevant to the Arrow LNG Plant project and are discussed in detail below.
- State Planning Policies (SPP) and their associated Guidelines including:
  - SPP1/92 Development and Conservation of Good Quality Agricultural Land (GQAL). Discussed further in Section 1.5.1.
  - SPP 2/02: Planning and Managing Development Involving Acid Sulfate Soils. The purpose of which is to avoid the release of acid and associated metal contaminants into the environment associated with development. Several soil groups present along the coastal fringes of the development have acid sulfate soil potential. These are the subject of a separate Acid Sulfate Soils Impact Assessment (Coffey Geotechnics, 2011).
- *Curtis Coast Regional Coastal Management Plan 2003* (*Curtis Coast Plan*) (EPA, 2003). This plan outlines how the Curtis Coast Regional zone should be managed within the policy framework established by the *State Coastal Management Plan 2002*, and takes into consideration state and regional policies guiding the effective management and development of the Curtis Coast area. Several landscapes of state significance discussed within this plan fall within the study area and are considered relevant to the geology landform and soils study including the Mount Larcom Range and Curtis Island strike-ridge system; the coastal landforms of the Targinie State Forest; and the marine plains of Curtis Island and around the mouth of the Calliope River.

In addition, SPPs relevant to this study but not specifically mentioned in the terms of reference were considered, as follows:

- SPP 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide. This requires developments to minimise potential adverse impacts of flood, bushfire and landslide on people, property, economic activity and the environment. This policy is relevant to this study as direct or indirect modification to soils or landforms required for the development may adversely impact flood or landslide risk.
- SPP 2/07: Protection of Extractive Resources. This policy identifies areas of extractive resources of State or regional significance, and aims to protect these sites from developments that may prevent or severely constrain current of future extraction when the need for the resource arises. This has been achieved through the delineation of Key Resource Areas (KRAs) and associated transport routes, where land development must be compatible with existing or future extraction industries. KRA 20 (Yarwun KRA) in located approximately 1 km west of Yarwun, south of the study area. Quarried materials are transported west of this KRA along Quarry Road to Mount Larcom

Gladstone Road. This transport route does not cross through the study site and thus is considered unlikely to be impacted upon by the development.

1.5.1 Agricultural Land Legislation: GQAL Identification and Conservation

The terms of reference requires an assessment of agricultural land and its conservation, as stipulated in State Planning Policy SPP 1/92 and the associated guidelines (DPI and DHLGP, 1993; DIP, 1995). However, the study area largely falls within the Gladstone State Development Area (GSDA). The GSDA recognises the overriding need for orderly industrial development in the Gladstone/Curtis Island area (DIP, 2008). SPP 1/92 GQAL classification has, in this case, been superseded by industrial zonation. The small area of the study site that extends outside the GSDA is zoned industrial land therefore GQAL does not apply across the whole study area. However, in recognition of the requirements of the terms of reference and potential impacts to existing agricultural areas, this report provides an overview of GQAL classifications within the study site, giving additional information regarding potential impacts and suitable land management.

Four classes of agricultural land have been defined in Queensland, as follows:

Table 1.1 GQAL Descriptions

Class	Description
Class A	**Cropland** – Land that is suitable for current and potential crops with limitations to production which range from none to moderate levels. Considered to be GQAL in all areas.
Class B	**Limited cropland** – Land that is marginal for current and potential crops due to severe limitations; and suitable for pastures. Engineering and/or agronomic improvements may be required before the land is considered suitable for cropping. Considered to be GQAL in most areas.
Class C	**Pasture land** – Land that is suitable only for improved or native pastures due to limitations which preclude continuous cultivation for crop production; but some areas may tolerate a short period of ground disturbance for pasture establishment. Not considered to be GQAL.
Class D	**Non-agricultural land** – Land is not suitable for agricultural uses due to extreme limitations. This may be undisturbed land with significant habitat, conservation and/or catchment values or land that may be unsuitable because of very steep slopes, shallow soils, rock outcrop or poor drainage. Not considered to be GQAL.

1.5.2 Strategic Cropping Land Framework

Under the Sustainable Planning Act (SPA) 2009, a new statutory planning instrument will be implemented to guide planning for strategic cropping. This will subsume SPP 1/92, and aims to ensure that local government planning schemes and regional plans recognise and conserve areas of the best agricultural land (defined as “strategic cropping land”) under the Strategic Cropping Land policy framework (DERM, 2010).

DERM has released a series of draft trigger maps as part of the policy framework. These maps indicate areas where strategic cropping land is expected to exist, based on available soil, land and climate information. While the new laws are yet to be enacted, the Queensland Government expects proponents of new projects to take the framework principles into account when advancing their particular projects. These maps indicate that there is no strategic cropping land within the Arrow LNG Plant study area. Therefore, no further assessment has been conducted during this study.

2 PROJECT DESCRIPTION

This section provides an overview of the Arrow LNG Plant project and project activities relevant to the geology, landform and soils study.

2.1 Proponent

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited

2.2 Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland's central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of key infrastructure components: LNG plant, feed gas pipeline and dredging.

2.2.1 LNG Plant

Overview. The LNG plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision undertaken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see 'Liquefaction Process' below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110 m high flare stack, power generators (see 'LNG Plant Power' below), administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps (see 'Workforce Accommodation' below), a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations (see 'Marine Infrastructure' below).

Construction Schedule. The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between 120,000

m^3 and 180,000 m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

Construction Method. The LNG plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial stick-built component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll-on roll-off ferries or barges from the mainland launch site.

LNG Plant Power

Power for the LNG plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.
- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30-MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.
- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.
- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

Liquefaction Process

The coal seam gas enters the LNG plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gases are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove mercury. The coal seam gas is then ready for further cooling and liquefication.

A propane, precooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to -33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and precooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas from -33°C to approximately -157°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of - 163°C.

A small amount of off-gas is generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be regasified back into sales specification gas on shore at its destination location.

Workforce Accommodation

The LNG plant (Phase 1), tunnel, feed gas pipeline, and dredging components of the project each have their own workforces with peaks occurring at different stages during construction. The following peak workforces are estimated for the project:

- LNG plant Phase 1 peak workforce of 3,500, comprising 3,000 construction workers: 350 engineering, procurement and construction (EPC) management workers and 150 Arrow Energy employees.
- Tunnel peak workforce of up to 100.
- Feed gas pipeline (from the mainland to Curtis Island) peak workforce of up to 75.
- A dredging peak workforce of between 20 and 40.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF; in the vicinity of Gladstone city on the former Gladstone Power Station ash pond No.7

(TWAF7) or in the vicinity of Targinnie on a primarily cleared pastoral grazing lot (TWAF8). Both potential TWAF sites include sufficient space to accommodate camp infrastructure and construction laydown areas. The TWAF and its associated construction laydown areas will be decommissioned on completion of the Phase 1 works.

Of the 3,000 construction workers for the LNG plant, it is estimated that between 5% and 20% will be from the local community (and thus will not require accommodation) and that the remaining fly-in, fly-out workers will be accommodated in construction camps. The 350 EPC management and 150 Arrow Energy employees are expected to relocate to Gladstone with the majority housed in company facilitated accommodation.

The tunnel workforce of 100 people and gas pipeline workforce of 75 people are anticipated to be accommodated in the mainland in company facilitated accommodation. The dredging workforce of 20 to 40 workers will be housed onboard the dredge vessel.

Up to 2,500 people will be housed at Boatshed Point construction camp. Its establishment will be preceded by a pioneer camp at the same locality which will evolve into the completed construction camp.

Marine Infrastructure

Marine facilities include the LNG jetty, materials offloading facility (MOF), personnel jetty and mainland launch site.

LNG Jetty. LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF. Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the LNG plant site at the southern boundary. A quarantine area will be located south of the LNG plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

- South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG plant site. The quarantine area for this option will be located southwest of the LNG plant near the LNG storage tanks.
- North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of

construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty. During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site. Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll-on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

- Launch site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.
- Launch site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

2.2.2 Feed Gas Pipeline

An approximately 8-km long feed gas pipeline will supply gas to the LNG plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto's Yarwun alumina refinery. The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the tunnel launch shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40-m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the mainland tunnel launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.
- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG plant, parallel to the above ground cryogenic pipelines. This

section will be constructed using conventional open-cut trenching methods within a 30-m wide construction right of way. A permanent easement up to 30 m wide will be negotiated with the relevant land manager or owner.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the tunnel launch shaft, whereby Arrow Energy would construct a power cable within the tunnel to the LNG plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

2.2.3 Dredging

Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation's Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

- Dredge site 1 (dredge footprint for launch site 1): The dredging of this site would facilitate the construction and operation of launch site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting launch site 1, past Mud Island to the main shipping channel. The worst-case dredge volume estimated at this site is approximately 900,000 m^3.
- Dredge site 2 (dredge footprint for launch site 4N): The dredging of this site would facilitate the construction and operation of launch site 4N. This dredge site would abut launch site 4N and extend east from the launch site to the shipping channel. The worst-case dredge volume identified at this site is approximately 2,500 m^3.
- Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.
- Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.
- Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the jetty. The worst-case dredge volume identified is approximately 120,000 m^3.

The spoil generated by dredging activities will be placed and treated for acid sulfate soils (as required) in the Port of Gladstone Western Basin Dredging and Disposal Project reclamation area.

2.3 Project Activities Relevant to this Study

Details of the project components and activities discussed above that are specifically relevant to the geology, landform and soils study are as follows:

LNG Plant. The LNG plant covers a large area (approximately 218 ha) of southern Curtis Island. Structures are proposed to have shallow-engineered rock fill foundations, except for those with high loads or tall buildings, such as the flare located in low-lying soft ground, which will have pile foundations. Plant facilities will include a construction camp at Boatshed Point.

Feed Gas Pipeline. The feed gas pipeline from the mainland to Curtis Island will be tunnelled by a tunnel boring machine beneath Port Curtis. A short section of pipeline on the mainland leading to the mainland tunnel launch shaft will have a 40 m right of way. A track will provide access to the launch shaft from Gladstone-Mount Larcom Road Tunnel spoil from the mainland tunnel launch shaft will be placed adjacent to the tunnel entrance, within a bunded placement area on coastal mudflats. The feed gas pipeline will be open trenched from the tunnel receival shaft on Hamilton point to the LNG plant gas inlet. The right of way on Curtis Island will be 30 m wide.

Heavy Haul Roads. Roads capable of transporting overweight (up to 2,500 t) and oversize elements during construction will be constructed from the MOF at Hamilton Point South or Boatshed Point (depending on which MOF option is selected) to the LNG plant. These will be constructed from compacted crushed material with sand fill and no asphalt top layer. The road at Boatshed Point is likely to be built over the existing mud flats.

LNG Jetty and Materials Offloading Facility/Passenger Terminal (MOF) – The onshore components of these facilities were included in the LNG plant facilities assessment. The MOF option at North Hamilton point would be shared with the Gladstone LNG project (GLNG), and impacts have been addressed in the GLNG EIS.

Launch Site 1. Located partially on natural and partially on reclaimed land. The natural southern section of the site comprises mud flats, with the northern section of the site comprising reclaimed land (former Gladstone Power Station ash pond). Launch site 4N has not been assessed for this study, as it is located within Port Curtis and constructed from dredge material.

Temporary Worker's Accommodation Facilities: TWAF 7 is located off Blaine Drive, Gladstone on reclaimed land (former Gladstone Power Station Ash pond 7); and TWAF 8 off the Calliope–Targinie Road, is partially located on GQAL (but not Strategic Cropping Land).

Access tracks: are not considered separately, but assessed as part of the listed project components, as they are within the anticipated area of disturbance of these components.

This study focuses on impacts to terrestrial geology, landform and soils. Aspects of the project within the marine environment are assessed in other specialist studies (Coffey Environments, 2011b; BMT WBM, 2011). Therefore, the following project activities have not been assessed as part of the geology, landform and soils study.

- Dredging and disposal of dredging spoil (with the assumption that spoil will not be disposed of onshore, other than adjacent to the mainland tunnel launch shaft of the feed gas pipeline),
- Launch site 4N.
- Offshore components of facilities.

3 GEOLOGY, LANDFORM AND SOILS ASSESSMENT METHOD

Coffey undertook a phased approach to the geology, landform and soils study, involving the following:

- Existing Environment: baseline condition assessment, including:
  - Desktop study collation and assessment of available mapping, studies, data and relevant legislation. These are referenced where relevant through the report and listed in Section 12: References.
  - GIS geodatabase construction, including input of geospatial data from previous studies in the study area and environs, to help establish a framework to assess the significance of environmental values and any potential issues.
  - Preliminary sensitivity mapping, subject to change following the field reconnaissance.
  - Field reconnaissance to ground-truth the findings of our desktop study, including the sensitivity mapping, and provide additional background information.
- Environmental Values, Landscape Sensitivity and Landscape Constraints Assessments, based on the findings of the baseline condition assessment.
- Impact Assessment – Assessment of the significance of potential impacts, including:
  - The impact of the project, and extent of these impacts on the geology, landform and soils of the project area.
  - Potential changes in landform stability and erosion rates as a result of the project.
- Management and Mitigation Recommendations – Recommendations for management and mitigation strategies to reduce the significance of the impact of the project.
- Residual Impact Assessment – Assessment of the significance of potential residual impacts following successful implementation of management and mitigation recommendations.
- Monitoring Recommendations and Plans – Recommendations for monitoring the effectiveness of management and mitigation strategies.
- Cumulative Impact Assessment – Assessment of the combined effect of approved or proposed developments that could interact with the Arrow LNG Plant project.

3.1 Study Area

The GLS study area was based on an approximate 3km buffer around the defined EIS study area (see Figure 1.1). An assessment of the regional context was also carried out to enable better understanding of the landscape within the study area.

3.2 Geology Investigation Method

A largely desk-based approach was used to assess the study area geology, including the likely characteristics or constraints associated with the different rock types. Publicly available geology and geotechnical soils investigations which wholly or partially covered the study area were reviewed. Geotechnical soils investigations differ from the soil science approach (discussed in Section 3.4: Soil Assessment Method), in that the physical and mechanical properties of regolith are assessed; with particle size grading, plasticity and organic matter content classified using the Unified Soil Classification system.

This study has mainly used the detailed geological mapping and commentary of Donchak and Holmes (1991). Supplementary information was gained from the existing EIS geological studies prepared for other projects in the region. Additional geological information was obtained from the Queensland Department of Employment, Economic Development and Innovation (formerly the Department of Mines) 1:100,000 digital mapping and 1:250,000 hard copy maps (Geological Survey of Queensland, 1974); and site visit observations and mapping.

3.3 Landform Assessment Method

The landforms of the study area were assessed using a combination of satellite imagery and aerial photography, site visit observations and information from previous investigations. Contours were available at an interval of 10 m. These were used to create a Digital Elevation Model (DEM) of the study area. The DEM was used to create topographic and slope steepness maps, which aided in landform assessment and identification.

3.4 Soils Assessment Method

The soils of the study area were assessed using a soil science approach, as well as the geotechnical investigation approach discussed in Section 3.2: Geology Investigation Method. Soils have been described using the Australian Soil and Land Survey Field Handbook (National Committee on Soil and Terrain, 2009). Soil groups have been classified using the morphological and chemical properties of the soil profile, in accordance with the Australian Soil Classification (Isbell, 2002). At the time of this assessment many soil investigations had been completed on Curtis Island, while information on soils in the mainland portion of the study areas was scarce. The intrusive investigations from Curtis Island completed by other LNG proponents provided variable results, with soil interpretations ranging greatly within small areas.

Additional soils data was obtained from DERM Land Suitability and Land Systems Mapping (Gilles, 1978; DPI, 1995, 1997; Macnish, 1996; Ross, 1999). The DERM information is also patchy. Detailed soils mapping, at a scale of 1:75,000, is available for a narrow strip along the eastern flanks of the Mount Larcom Range. The remainder of the mainland is only covered by out-of-date 1:250,000 or 1:500,000 scale mapping. Curtis Island is only covered by 1:2 million scale Atlas of Australian Soils Mapping. Only the latter two map sets were considered to be suitable for background information for the purposes of this study.

Reliable GQAL mapping is only available for a small area along the eastern Mount Larcom foothills (Ross, 1999). However, given the landscape characteristics, it is unlikely that GQAL exists outside this corridor. GQAL has, therefore, only been included where mapped by external sources (specifically Ross, 1999).

The geology and soils desktop study findings were ground-truthed during the site visit, through observation of existing rock and soil exposures.

3.5 Terrain Mapping and Environmental Values Assessment Method

The information collated during the baseline condition assessment was amalgamated, interpreted and mapped. The study area was divided into terrain units, representing areas of the landscape which have broadly similar characteristics, properties and behaviour – i.e., environmental values. The terrain units were checked using aerial photographs, satellite imagery (including that accessible through Google Earth) and in the field.

The terrain unit mapping is at an appropriate scale for the study area. This mapping gives an indication of the likely geology, landform and soils characteristics that will be encountered. The maps are designed to enable manageable and useable outputs given the large study area and diverse landscape features. Consideration should be given to the variability of conditions which can occur within a mapping unit. Within a terrain unit, localised areas may have markedly different properties and response to disturbance to the broadly defined characteristics.

Site-specific assessments of the landscape characteristics and properties should, therefore, be carried out prior to detailed design and construction.

3.6 Landscape Sensitivity and Constraints Assessments Method

The sensitivity of the environmental values of the landscape (i.e., the terrain units) was assessed within the context of the anticipated project activities. This indicates the susceptibility of the landscape to change in response to disturbance. Sensitivity is related to both the intrinsic properties of the landscape and the geomorphic processes acting.

The potential landscape constraints on the project were also assessed. These constraints are strongly related to sensitivity, as this governs natural landscape behaviours that could affect project components or activities.

3.7 Impact Assessment Method – Significance of Impacts

The impact assessment method involved a multi-step process. The first step was to define the landscape environmental values and sensitivity outlined in Sections 3.5 and 3.6, as follows:

- Identification of the potential impacts of the project on the geology, landform and soils environmental values within the study area. As many project activities have similar impacts, this phase of the assessment was split into generic and project-activity specific impacts.
- Assessment of the likely geographical extent, duration and severity of impact (i.e., impact magnitude).
- Assessment of the significance of the potential impacts on the environmental values; defined as the product of the sensitivity of the receptor (terrain unit) and the impact magnitude.

3.8 Management and Mitigation Recommendations

Appropriate industry-standard management guidelines were reviewed, in particular the International Erosion Control Association (IECA) Best Practice Erosion and Sediment Control Manual (2008; the standard guideline for Queensland) and the Australian Pipeline Industry Association (APIA) Code of Environmental Practice for Onshore Pipelines (2009) and other relevant guidelines (as discussed in Section 1.5: Legislative Context and Standards). Relevant management and mitigation measures are recommended in accordance with these guidelines and legislation.

3.9 Residual Impact Assessment Method

The residual impact was assessed using the same multi-step process as the impact assessment, but assuming successful implementation of the recommended management and mitigation measures.

3.10 Cumulative Impact Assessment Method

The aim of the cumulative impact assessment is to assess the combined effect of approved or proposed developments that could interact with the Arrow LNG Plant, including the degree to which these projects contribute to the overall impact on the relevant environmental values.

The baseline for assessment of cumulative impacts includes existing developments constructed and operating in the Gladstone region, and those projects that have taken a financial investment decision at the time of writing. The cumulative impact assessment only includes projects that have been approved by the Queensland Coordinator-General or have sufficient information in the public domain (i.e., EIS) to enable an assessment of the potential impacts. Projects to be included in the cumulative impact assessment must meet the following criteria:

- The project is located in the Gladstone region.
- The project is being assessed by one of the following:
    - The *State Development and Public Works Organisation Act 1971* (Qld) and has been declared by the Queensland Coordinator-General as a ‘project of state significance’ for which the status of the EIS is either complete or, as a minimum, has an Initial Advice Statement published on the Department of Infrastructure and Planning (DIP) website.
    - The *Environmental Protection Act 1994* (Qld) and has completed an EIS or has an Initial Advice Statement (or similar) listed on the Department of Environment and Resource Management (DERM) website.
- The project is envisaged in statutory planning documentation.

Projects are only included in the cumulative impact assessment if they could potentially impact the environmental values relevant to the geology, landform and soils study. Projects considered to have no additional impact are not included and the reasons for the exclusion given.

4 EXISTING ENVIRONMENT

This section describes the geological evolution, and the existing surficial geology landforms and soils of the study area and environs. The study area is situated within 4 different physiographic regions, associated with landform formed by different rock types and geomorphological processes. These are summarised in Table 4.1 and described in the following sections.

Table 4.1 Summary of Environmental Characteristics of the Study Area

Landscape Characteristics	Physiographic Area			
	Mount Larcom Range	**Coastal Plains**	**Curtis Island**	**Gladstone Urban Region**
Surface Geology (see Section 4.1, and Figures 4.1 and 4.2)	Felsic to intermediate igneous intrusions (e.g., Targinie Granite and trachyte) into Berserker Group sedimentary sequences.	Superficial alluvial, colluvial and marine sediments overlying sedimentary Wandilla Formation and sedimentary/ volcanic rocks of the Doonside Formation.	Steeply dipping sedimentary sequences of the Wandilla Formation.	Largely underlain by coastal muds overlying Wandilla Formation sediments with areas of reclaimed land.
Rainfall (See Figure 4.3)	Over 1000 mm/yr.	800-900 mm/yr, with higher rainfall along the margins of the uplands.	Around 900mm/yr, with higher rainfall over higher ground.	Around 800 mm/year, with lower rainfall near the coast.
Relief (See Section 4.2 and Figure 4.4)	Relief is strongly linked to geology (rock type and structure): steep slopes and higher elevations are associated with resistant igneous and sedimentary rock, and upthrust horst blocks. Low-lying areas are associated with low-strength rocks, fault zones and downthrust graben features. Younger sedimentary rocks have typically accumulated within the low-lying areas.			
	Rising from around 50 mAHD at the base of the foothills to Mount Larcom peak, at 658 mAHD, the highest point in the region.	Below 50 mAHD, with the majority of the area below 20 mAHD.	Highly undulating, rising from sea level to 173mAHD along The Spine.	Generally below 20 mAHD, with some small remnant hills rising to around 50 mAHD.
Landform (See Section 4.2, and Figures 4.4 and 4.5)	Rugged, craggy peaks surrounded by steep, undulating hills.	Broad coastal plains interspersed with minor remnant bedrock hills. Broad mudflats and mangrove swamps along coastal margins.	Northwest-trending hogsback ridges and rounded remnant hills, rising above steep, gullied valleys and coastal mudflats.	Low-lying coastal plains and mudflats with isolated rounded hills. Areas of reclaimed land.
Soils (see Section 4.3)	Variable. Generally texture contrast soils on lower eastern slopes, with shallow, gravelly gradational soils elsewhere. Skeletal soils at higher elevations.	Variable. Gradational and texture contrast soils. Ferruginisation common. Mudflats classified as Hydrosols.	Variable. Generally gravelly gradational soils of variable depth, with some ferruginisation. Texture contrast soils in broader valley bottoms.	Largely artificially altered.
Land-Use	Largely forested, with some cleared grazing land on the foothills. Moderate intensity plantations along the eastern flanks.	Pockets of heavy industry within natural forest and cleared grazing land.	Small pockets of cleared grazing within forest.	Urban.
Erosion (See Section 4.2.1)	Gullying and rilling of cleared or disturbed areas, particularly in areas of sodic/dispersive soils.		Gullying of disturbed, sodic/dispersive soils, particularly in the LNG plant area.	Dependent on degree of alteration and success of erosion management measures.

4.1 Geology

This section discusses the processes of geological formation within the study area, and the tectonic (i.e., faulting and seismic activity) and geomorphic processes (i.e. erosion, transport of material, sedimentation and *in situ* weathering) that have combined to produce the geological sequence that exists today. The contemporary surface geology is described, along with the geotechnical properties of the rocks and soils likely to be encountered.

4.1.1 Geological Evolution

The central Queensland coast represents an area of complex structural geology (see Figures 4.1 and 4.2). The strait separating Curtis Island from mainland Queensland is known as “the Narrows” to the north of the study area, and Port Curtis within the study area. This strait follows a northwest to southeast alignment of a major fault zone, dividing the Coastal Block tectonic unit, which includes the Narrows Graben, from the mainland Berserker Block.

The Curtis Island Group sedimentary rocks dominate the Coastal Block. Within this group, the Wandilla Formation conformably overlies the older Doonside Formation. The Group comprises Devonian to Carboniferous age clastics (weakly metamorphosed conglomerate to quartzitic and greywacke sandstone and mudstone) that were deposited on a continental slope that formed the margin of the Australian land mass. Parts of the sequence are typified by deep trench deposits (radioloarian chert and pelagic mudstone is found), whilst the Group is dominated by series’ of fining upward clastic sequences. These deposits are characteristic of turbidite deposits (coastal shelf landslides). The rocks were contemporaneously thrust against the continent at a destructive tectonic boundary; the sequences are intensely folded. The accreted sediments were consequently severely faulted, representing compressional and partly strike-slip movement.

The mudstones of the Wandilla Formation are characteristically dark grey, weathering to pale brown (see photograph P3 in Appendix A). Thin quartz veinlets and localised thick veins penetrate the rocks parallel to foliation. The sequences are locally interspersed with muddy limestone and volcanic rock. The Doonside formation is essentially similar, although observation reveals extensive weathered mudstone, distinctive chert and, possibly, volcanic rocks.

The Rockhampton Group is the mainland analogy to the Wandilla Formation (i.e., Carboniferous age), separated by the Yarrol Fault (previously known as the Boyne River Fault). The group is dominated by dark grey mudstone, some muddy limestone and sandstone or conglomerate derived from volcanics. These sedimentary rocks are interspersed with crystalline rhyolite rocks.

During the early Permian, the region was subjected to tectonism (large scale extrusive, volcanic flow). The resultant block faulting created the Coastal and Berserker regional, fault-bounded Blocks, which can be identified today.

The Permian Berserker Group dominates the adjacent tectonic unit to the west of the Coastal Block, separated by the Yarrol Fault. This group was observed to comprise predominantly mudstone interspersed with pyroclastic (volcanic) tuff and agglomerate, and some reworked conglomerate. In the Mount Larcom area, the Permian aged Berserker Group Rhyolite outcrops. Permo-Triassic Targinie Granite, which makes up the eastern foothills of the Mount Larcom Range was intruded as a pluton into the older sediments during the late Permian to early Triassic periods. Low-grade contact metamorphism has altered the country rock adjacent to the pluton.

Igneous activity was also associated with further tectonic instability during the Cretaceous and Tertiary periods. This included intrusions of granite and trachyte, which now form the higher peaks of the Mount Larcom Range, inland. More recently, during the Oligocene aged, olivine basalt was extruded in the Scrubby Mountain area.

The Narrows fault-controlled basin (graben) developed during the Tertiary, possibly along the alignment of pre-existing faults. This basin filled with fining-upwards clastic sequences, including the Worthington, Rundle and Curlew Formations (see Figure 4.2). The graben has been identified as asymmetric with a series of extensional faults marking its western margin. Accumulations of the Tertiary aged formations created distinct depositional sub-basins. It is probable that the sequences underlie much of the coastal area and Port Curtis to its eastern side. The Rundle Formation, typically deeper than 120 m beneath Port Curtis, incorporates biogenic sediments, including the Stuart Oil Shale (Henstridge and Missen, 1982). Along the western coastal margins of Port Curtis, the oil shales crop out where they have been faulted upwards.

During later Tertiary times (e.g., Pliocene) tectonic stability resulted in deep lateritic weathering. Observations of outcrops in creeks or intertidal zones during the site visit indicated that soils are typically laterised (see photographs P9 and P12, Appendix A).

Quaternary aged estuarine deposits include tidal and mangrove flats, supratidal flats and coastal grasslands. These comprise mud or muddy sand that, on the mangrove flats, has a high organic content (see photograph P9 and P12, Appendix A).

4.1.2 Geological Structure, Faulting and Seismic Activity

The major northwest trending Yarrol Fault (Boyne River Fault) divides the study area between the two distinct tectonic blocks, the Coastal and the Berserker Blocks.

Distinct sub-parallel faulting within the Coastal Block resulted in development of the downthrust Narrows Graben, now partially infilled by thick sedimentary sequences. In the centre of the Graben, it is possible that up to 1000 m of sedimentary rock may be present above the Wandilla Formation. However, the overall thickness of strata varies across the subbasins due to the tectonic regime of deposition. A series of extensional faults marking the western margin of the graben have produced a high degree of rock type variability and, possibly, depths to rockhead. The location of major basement faults may not be well-defined by the geological mapping, as their surface expressions are masked by the drape of Tertiary and Quaternary aged sediments.

Curtis Island Group sediments are typically folded and faulted. Minor faulting occurs throughout the study site, both sub-parallel to the major northwest structural trend and orthogonal to this trend.

The study area is also one of the most tectonically active in Australia (URS, 2008; Worley Parsons, 2010), and the most active area in Queensland (Granger and Michael-Leiber, 2001). The region has been subject to earthquakes strong enough to cause damage to buildings and infrastructure. URS (2008) report that, earthquakes of this magnitude have occurred, on average, every 5 years over the last century. The project commissioned a specific seismic hazard study (Ove Arup, 2009a; 2009b). This study concluded that the study area was generally considered to be at low risk of fault movement, liquefaction or earthquake-induced slope instability. However, liquefaction was considered to be a risk within the coastal and marine muds (terrain unit Ib: Contemporary intertidal and supratidal flats). TWAF 7 and the northern section of launch site 1 are located on reclaimed land formed from ash from the coal-fired Gladstone Power Station. This material may be highly susceptible to liquefaction.

4.1.3 Contemporary Surface Geology

The study area is geologically complex, if observed from a structure and rock-type context (see Figures 4.1 and 4.2 for distribution of rock types and map symbols referred to below). However, the pattern of outcropping rocks is simpler than might appear from the geological map; the near-surface geology is consistently variable.

The study area is characterised by folded, steeply-dipping, well-jointed, low-strength, variably weathered mudstone and siltstone outcrops. These sedimentary sequences are characteristic of the following formations (the geological age is given for guidance, as the exact age of many formations is uncertain (Donchak and Holmes, 1991):

- Permian Berserker Group (maximum age of around 277 Million years ago (Ma); Geoscience Australia, 2011)), comprising the Lakes Creek Formation (Pkl) and Chalmers Formation (Pkc).
- Carboniferous Rockhampton Group (Cr) (maximum age of around 351 Ma (Geoscience Australia, 2011)).
- Early Carboniferous Mount Alma Formation (DCy) (maximum age of around 361 Ma (Geoscience Australia, 2011)).
- Late Devonian/Carboniferous Wandilla Formation (DCcw); and Doonside Formation (DCcd) (maximum age of approximately 370 Ma).

The following geological variations are found within the study area:

- Sandstone (including highly resistant greywacke), conglomerate and breccia layers within the Curtis Island Group (Wandilla Formation and Doonside Formation), particularly on Curtis Island. Sandstone forms the higher elevation areas of Curtis Island; remnant corestones can dominate ridges and summits, with surface cobbles and boulders also found overlying mudstone on the steeper and lower slopes (representing sequences of the Wandilla Formation);
- Occasional limestone layers and conglomerate clasts within the Wandilla Formation on Curtis Island, although limestone was not specifically observed during field visits.
- Contact metamorphic rocks and weakly metamorphosed quartzose mudstone and sandstone (not mapped in detail), located close to the igneous intrusions, discussed next.
- Igneous intrusions or unconformable flows, ranging from:
  - Mafic, e.g., a Triassic olivine basalt plug (Tib, of uncertain age) just to the northeast of the Mount Larcom Range.
  - Intermediate, e.g., Late Devonian Balnagowan Volcanics (DCcd/b) (of variable composition, but largely mafic to intermediate, and with an approximate age of 370 Ma) associated with the Doonside Formation, to the east of Mount Larcom; and Triassic andesitic Targinie Granite (PRgta; maximum age of approximately 250 Ma) along the eastern flanks of the Mount Larcom Range.
  - Felsic e.g., a granitic pluton forming the eastern foothills of the Mount Larcom Range (PRgta, probably intruded during the early Triassic, around 250 Ma); trachyte (PTgta/a) forming the Mount Larcom peaks; Rhyolite, including rhyolitic tuff, has intruded into the Berserker Group sedimentary sequences (Pkc, with a maximum age of about 276 Ma (Geosciences Australia, 2011)), and is common on the northwest flanks of the Mount

Larcom Range. Felsic dykes are found intruded into the Wandilla Formation at Boatshed Point on Curtis Island and are possibly associated with other higher elevation ridges.

Observations during the site visit did not indicate large expanses of volcanic outcrop. These rocks tend to be interbedded with sedimentary sequences. The published geological maps of the area, if not assessed in conjunction with accompanying notes (e.g., Donchak and Holmes, 1991), can give a misleading impression of broad areas of bedrock homogeneity when, in reality, variability is the main characteristic.

Lower-lying areas are blanketed by geologically recent material associated with fluvial and hillslope processes. This includes Tertiary and Quaternary aged alluvium (TQa and Qa, respectively); Holocene aged creek material and terraces (Qha) and Pleistocene aged river terraces (Qpa). Colluvium of Tertiary and Quaternary age has accumulated along the lower slopes of hills throughout the study area (TQr and Qr\s). Recent marine muds (Qhe/m) are found along the coastal fringes, extending further inland within bays and close to the Calliope River estuary.

LNG Plant Site Geology

An assessment of the facilities area geology has been carried out as part of a detailed investigation of the site (Coffey, 2010). In summary, the site comprises variably thick, cyclic sequences of clastic rocks (predominantly conglomerate, sandstone and siltstone) which dip steeply to the east. In general, more resistant, quartzose sandstones form the core of ridgelines and hilltops, with weaker, thinly inter-bedded finer grained rocks, including mudstones, forming valleys.

4.1.4 Geotechnical Properties

Coffey Geotechnics has undertaken preliminary geotechnical and engineering geological assessments of the LNG plant area and sections of the feed gas pipeline area (Coffey Geotechnics, 2009a; 2009b; 2010). This information, combined with information from other EIS studies and field observations has formed the basis for this section.

Rock Properties

The study area is characterised by geological variability, in particular in terms of rock strength and depth to rockhead. There may be little surface expression of changes in rock strength characteristics.

Regolith Properties

Much of the study area is characterised by shallow, gravelly soils, with inconsistent depth to bedrock. Regolith (i.e., engineering soil) within the study area (other than coastal sediments) typically has the following engineering properties:

- Relatively low shrink-swell potential, although clay in low-lying areas (typically below 5 mAHD) may be highly reactive, with high shrink-swell potential.
- Deep, soft soils are present in the low lying bays and supratidal flats along the coastal margins. This material is low in strength, with a high compressibility.
- Moderate to high dispersivity, evident from deep gully and rilling erosion.

- Former ash pond material may comprise poorly graded silts (i.e., with little variability in grain size). Material in these areas is, therefore, likely to be friable, and susceptible to rill and wind erosion. This material frequently has poor rehabilitation potential.

4.2 Landform

4.2.1 Study-Specific Landform Features and Geomorphological Processes

Hogsback Ridges

Cuestas are formed by the erosion of gently tilted sedimentary rocks: the dip slope parallel to the dip of the strata and the steep escarpment representing the eroded face. When the angle of tilt becomes more extreme, the landforms are referred to as hogsbacks (also known as “hog’s backs” or “hogbacks”), which are formed by bedrock dipping at greater than about 40°. The dip slope is, therefore, approximately symmetrical to the scarp slope. The steeply dipping Wandilla and Doonside Formation rocks have formed hogsback ridges. Southern Curtis Island is dominated by the hogsback landform known as The Spine (see photograph P1 in Appendix A).

Landsliding and Slope Instability

Slope stability is strongly affected by the geological characteristics (including the dip of the rock, relative permeability of adjacent layers and regolith thickness), slope steepness, moisture content and artificial alteration (placement of fill at the head of a slope or excavation at the toe). These contributing factors can bring a slope to the threshold of failure. Landslides are typically triggered by prolonged and/or intense rainfall. Earthquakes may also trigger failures on susceptible slopes.

No evidence of large-scale slope instability was found within the study area, either within the desktop study or from field observations. Some areas of soil creep (i.e., slow, steady downhill movement of material) were observed on steeper hillsides. Springlines were observed at the boundary of permeable (sandstone) and less permeable (mudstone) rocks on Curtis Island during the field visit. These conditions increase landslide susceptibility. However, in the Gladstone area (exact location is not recorded), several slope failures have been triggered by prolonged or intense rainfall, particularly associated with inappropriately managed earthworks (Granger and Michael-Leiber, 2001).

Runoff (Sheetwash), Rill and Gully Erosion: Erosion Hazard

Erosion is related to vegetation cover, rainfall characteristics, soil characteristics (i.e., soil erodibility), slope steepness and length; and artificial influences. Runoff erosion, or sheetwash, occurs when unconfined flow over bare or sparsely vegetated ground strips the surface soil layers. In the Gladstone region, intense, prolonged rainfall occurs during the summer months and is associated with tropical cyclones (Granger and Michael-Leiber, 2001). Over 50% of the total annual rainfall occurs during between December and February (Bureau of Meteorology, 2010).

Rills are small channels (defined as minor trenches that can be ploughed out, generally less than 300 m in depth) formed from concentration of runoff flows. Rills can develop into larger gully features. Gullies are narrow deep trenches, forming either along incised watercourses or as a result of erosion into previously intact ground. Upstream erosion of gully headcuts can cause expanding incised networks to form. Once initiated, the incised gully system sets up a positive feedback, whereby water gains energy when flowing over gully headcuts (the upstream limit of the gully), increasing erosivity and causing the headcut to retreat upstream. Piping and rilling can occur upstream of gully headcuts, accelerating the gullying process. Sediment from the eroding gully systems can be transported downstream into creeks and rivers. Deposition of this material (typically where channel slopes become shallower) can cause sedimentation problems.

Prevention of gullying is considerably easier than its rehabilitation. Gullies have a natural course of evolution which, over decades, results in self-stabilisation (assuming no further disturbance). Given sufficient time and appropriate circumstances, gullies may naturally re-fill to pre-disturbance levels. However, this process may take many decades (or even centuries) and, in some cases, pre-disturbance landforms may never be restored.

These processes are exacerbated in dispersive, highly erodible sodic texture contrast soils. The structure and chemical composition of this type of soil makes them susceptible to subsurface piping/tunnelling; and surface rill and gully erosion, particularly once the vegetation cover is removed. Once initiated, rills and gullies promote flow concentration and are difficult to remediate successfully.

Landscape changes which can lead to increased erosion and gully formation are as follows:

- Loss of protective surface vegetation, whether through natural causes or human intervention.
- Flow concentration, increasing the energy available for erosion, e.g., along tracks or along existing rills and gullies.

Within the study area, runoff, rill and gully erosion are characteristic of erodible soils on Curtis Island (see Section 4.3.2: Sodic and Dispersive Soils), particularly where flows have become concentrated (e.g., along access tracks, see photographs P2, P6, P7, P8 and P13, Appendix A). Field observations within the proposed LNG plant site indicated that access tracks become preferential pathways for overland flows. Along many tracks, surface soils had been eroded, exposing hardpans. These hardpans can reduce subsoil erosion. However, areas with discontinuous pans can allow flows to reach the subsoil. Gullies up to 1m deep were observed in these areas during the site visit.

On the mainland, preferential flow pathways were observed to have exploited buried infrastructure where backfilling and compaction had not been appropriately completed. During the site visit, adjacent to The Narrows Road, it was observed that erosion had exposed cables originally buried approximately 0.5 m deep.

Wind Erosion

Wind erosion is not generally problematic over the majority of the study area, as the soils typically have a cohesive surface. However, along the coastal margins, wind erosion of susceptible soils can occur: texture contrast soils with a fine sandy surface are particularly vulnerable to wind erosion, especially where surface cover has been removed (Ross, 1999). Tropical cyclones and severe thunderstorms may create localised strong winds, resulting in wind erosion of these susceptible soils (Granger and Michael-Leiber, 2001).

4.2.2 Physiography, Topography and Geomorphology

The study area landforms are strongly linked to the underlying geology, particularly rock type and geological structure, and geomorphological evolution of the area (see Figure 4.4). Along the coastline, landforms are strongly fault-controlled, with fault-bounded, uplifted zones (horst blocks) forming upland areas, e.g., The Spine, and downthrown zones (graben blocks) forming low elevation areas, e.g., The Narrows.

The landscape within the study area is characterised by 4 different physiographic regions, which have appreciably different characteristics (see Figure 4.4):

- Mount Larcom Range – steep, largely forested uplands (largely outside the study area). TWAF 8 is located at the foot of the Mount Larcom Range.
- Coastal Plains – found along the margins of The Narrows strait separating Curtis Island and the mainland, comprising marine sediment mudflats with mangroves and patches of laterised regolith. The feed gas pipeline crosses to Curtis Island from the coastal plains.
- Curtis Island – to the east of the study area, comprising steep rounded ridges and remnant rounded hills rising above broad, gullied valleys. The LNG plant is situated in the southwest corner of Curtis Island.
- Gladstone Urban Region – to the southeast of the study site, comprising a largely artificially altered landscape, including reclaimed land and large-scale earthworks. TWAF 7 is located within the Gladstone Urban Region. The reclaimed areas of the launch 1 and 4N sites are also included in this region.

The following sections provide a more detailed description of the four physiographic regions.

Mount Larcom Range

Mount Larcom is the highest elevation point in the locality of the study area, rising to 658 mAHD (see Figure 4.4). The Mount Larcom Range comprises felsic igneous intrusions and sedimentary rocks, which have been metamorphosed in places. A resistant trachyte plug forms the steepest peak of the Range. The steep eastern flanks comprise resistant andesitic and granitic rocks. Near-vertical rockfaces outcrop along these sections. The western flanks, comprising sedimentary, metamorphic and volcanic rocks, have been dissected by watercourses to the northwest.

The majority of the Mount Larcom Range is characterised by open to dense forest. The northeastern foothills of the range and the adjacent Targinie Valley are home to the most intensive farming in the region. The deeper soils in this area support plantation cropping and grazing.

TWAF 8 is located at the foot of the Mount Larcom Range, at the northern end of the Targinie Valley.

Coastal Plains

A low-relief coastal plain is located to the east of the Scrubby Mountain Range and Mount Larcom Range. This land is generally below 20 mAHD, with slopes of below 5° (see Figures 4.4 and 4.5). The costal margins are characterised by broad expanses of marine muds, with mangrove swamps fringing Port Curtis. Further inland, alluvial and colluvial plains rise gently towards the steeper ground inland. The coastal plains are traversed by several watercourses, including the Calliope River.

The presence of oil shale and ore deposits, combined with flat, relatively undeveloped land of the coastal plains has resulted in considerable industrial development along this strip. Since the recognition of the Gladstone area as a nationally significant industrial zone over the last few years, the scale and rapidity of development has accelerated. Major industries, other than LNG projects, include Orica chemical manufacturing and TransPacific Industry’s waste management and recycling plant.

In several places, significant modification to the natural landscape has occurred, including the following:

- Creation of Fishermans Landing Wharf, a large area of reclaimed land protruding into the Port Curtis.

- Removal of several small hills during site levelling and for construction material located west of the Calliope River Estuary and along the foothills of the range of hills dominated by the Doonside Formation rocks.
- Cutting and filling of hillsides to create level facilities areas located along foothills of the Doonside Formation range.

Industrial areas aside, the remaining landscape supports moderately dense vegetation.

The feed gas pipeline to the LNG plant will be tunnelled beneath Port Curtis, with short trenched or thrust-bored sections to the mainland tunnel launch site just south of Fishermans Landing and from the receival shaft of Hamilton Point to the LNG plant on Curtis Island.

Curtis Island

The southern portion of Curtis Island is characterised by a series of north-northwest-trending steep-sided rounded ridges and remnant hills rising above broad, gullied valleys. The island is densely forested, with hardy dry eucalypt species suited to thin soils. The coastline is characterised by rocky headlands separated by broad inter-tidal mudflats. As with the mainland coastal zone, mangroves fringe the low-lying edge of the coastline.

The dominating landform of southern Curtis Island is the hogsback ridge known as The Spine. This ridge has scarp/dip slopes of well over 30° and rises to 173 mAHD at Ship Hill. Associated remnant hills can rise up to 100 m above the surrounding valleys, with side slopes occasionally over 30°. The higher elevation areas represent more resistant layers of the Wandilla Formation, generally containing quartzitic sandstone and possibly chert.

A lower-angled slope is located at the base of The Spine. This slope is deeply dissected by gullies in places, forming steeply undulating terrain. This rugged relief is not apparent on the topographic maps, despite the undulations being in excess of 10 m in places. Here, bedrock is close to the surface and superficial cover is thin, even in gully bottoms (rarely observed at depths of over 2 m).

Curtis Island is the focus for several other LNG project activities; namely Gladstone LNG (GLNG), Queensland Curtis LNG (QCLNG) and Australia Pacific LNG (APLNG). GLNG and QCLNG are, at the time of writing, underway and will result in significant, permanent landscape change.

The LNG plant site is characterised by gently sloping land rising to a rounded hill over 40mAHD in height in the northern third of the site. Slopes are generally shallow, up to 7°, but with hillside slopes of up to approximately 15°. During February 2010, storm events caused significant gullying of tracks, cleared areas and valley bottoms, particularly along steeper sections.

Gladstone Urban Region

The Gladstone urban region is located on the mainland to the south of the LNG plant site, in the southeast corner of the study area. This region is characterised by large-scale artificial alteration associated with rapid recent industrial development. Land reclamation has been achieved through placement of ash from the nearby NRG Gladstone Power Station). Levelling during the construction of various developments and roads has significantly altered the former natural landscape, with disturbance, alteration and removal of soils and landforms.

TWAF 7 is located on a former NRG Gladstone Power Station ash pond, bounded on 3 sides (west, north and east) by a large river (estuary) bend. Launch site 1 is located on the east bank of the Calliope River estuary, adjacent to the existing RG Tanna coal export terminal.

4.3 Soils

4.3.1 Soil Types and Characteristics within the Study Area

Soil characteristics are strongly related to parent material, formation process and relief (National Committee on Soil and Terrain, 2009). The complex geology along the Central Queensland coast means that several types of soil parent material exist within a relatively small area. Parent material in the study area includes the following (Locations discussed in Section 4.1.3: Contemporary Surface Geology):

- Felsic (Acidic), Intermediate and Mafic (Basic) Igneous Rocks.
- Sedimentary Rocks and Metasediments, including minor Limestone outcrops.
- Alluvium and Colluvium.

In addition, the undulating, occasionally rugged, relief has resulted in small pockets of variable soil types. As discussed in Section 3.4, soils mapping at an appropriate scale for the study was not publically available at the time of writing. Therefore, soils within the study area were assessed using a combination of available Land Systems Mapping (in particular Ross, 1999), other relevant reports and site visit observations. A summary of soil types in relation to various landscape components is included in Section 4.1: Terrain Unit Mapping.

The soils in the study area have been separated into five broad groups. These groups along with their typical characteristics, constraints and properties (interpreted from other proponent's reports) have been summarised below. The broad soil types (1-5) are listed from most to least clay content as follows:

Soil Type 1 – Marine clays

- Formed from marine sediments in saline and wet conditions at elevations of less than 5 mAHD.
- Generally have a uniform sandy clay content, although can have sand lenses.
- Often colonised by mangroves. Can have high organic content due to mangrove debris.
- Commonly grey or 'gley' in colour due to reduction and oxidation.
- Commonly have a pH of less than 4, due to oxidation of sulphides. These soils can be Acid Sulfate Soils or Potential Acid Sulfate Soils (Coffey Geotechnics, 2011).
- Found in intertidal flats that experience regular saline tidal inundation or infrequent tidal inundation with a saline water table at shallow depths: on the west and south coast of Curtis Island and on the east coast of the mainland.
- See Photographs P9 and P12 in Appendix A.
- Classified as Intertidal Hydrosols and Supratidal Hydrosols using the Australian Soil Classification System (ASCS; Isbell, 2002).

Soil Type 2 – Gradational Soils

Gradational soils are common in the study area. Two distinct types have been identified, based on particle size:

Soil Type 2.1 – Clays

- Soil depth varies across the study area and is related to landscape position. Generally soils are between 0.5 m and 1.5 m in depth.
- Soil textures are generally silty clay loams to clays with a gradual increase in clay content with depth.
- Soils have weakly structured subsoils.
- Generally red or brown in colour.
- pH is slightly acidic with a range of broadly 5.5 - 6.5.
- Subsoils can be sodic with an exchangeable sodium percentage (ESP) > 6%. However this is highly variable across the study area.
- High amount of free iron oxide is present in these soils to the east of the Mount Larcom Range, indicated by a strong red hue. These iron-rich soils are suitable for agricultural production (Ross, 1999).
- Generally associated with volcanic rocks and alluvium.
- Formed from mafic igneous rocks or metamorphic equivalents.
- Found in isolated areas of the low-lying coastal plains (including on Curtis Island; see photographs P4 and P11 in Appendix A) and along the base of the Mount Larcom Range.
- Includes Dermosols and Ferrosols (ASCS; Isbell, 2002).

Soil Type 2.2 – Loams

- Generally less than 1m deep. However, on steep slopes and ridges these soils can be very shallow with depths of less than 0.5 m.
- Generally loamy sand or sandy loam surface soils with clay content gradually increasing with depth to loam or sand clay loam.
- Commonly have a high mixed-sized angular gravel content.
- Weak pedological organisation, apart from topsoil, with some profiles containing hard pans or unconsolidated mineral materials.
- Generally yellow or brown in colour.
- pH is strongly to slightly acidic, 4.5 – 6.5.
- Found on mid-slopes of Curtis Island.
- Includes Kandosols and Tenosols (ASCS; Isbell, 2002).

Soil Type 3 – Texture Contrast Soils

- Distinct texture contrast between the surface horizon and the subsoil, generally with a change from sandy loam to a clay; although the change can also be from a sand to a loam.
- Boundaries between horizons are clear, abrupt or sharp.
- Commonly have sodic subsoils (exchangeable sodium percentage greater than 6%), indicated by profiles with a conspicuously bleached A horizon and a B horizon with a columnar or prismatic structure.
- Subsoils may also have a strongly acid pH (i.e., less than 5.5).
- Found on lower slopes near alluvium on both Curtis Island (see photographs P2, P5, P6, P7 and P8 in Appendix A) and the mainland; and on undulating land on the flanks on Mount Larcom.
- Formed from sedimentary rocks, felsic igneous rocks, and alluvium.
- Includes Sodosols, Chromosols and Kurosols (ASCS; Isbell, 2002).

Soil Type 4 – Alluvial Sands

- Mostly massive structure and very shallow (less than 0.5 m).
- Generally sandy to loamy sand soils.
- Can be overlain by organic brown-stained sand which supports vegetation.
- May contain water-worn rounded gravels and cobbles.
- Occur in isolated areas along creek lines and some creek terraces.
- Includes Rudosols and Tenosols (ASCS; Isbell, 2002).

Soil Type 5 – Rocky Skeletal Soils

- Shallow soils with negligible pedological organisation.
- Texture of soil can vary based on parent material and weathering rates.
- Generally brown or grey in colour with no colour change with depth.
- pH values range depend of parent material, however these soils are generally slightly acidic (pH between 5.5 – 6.5).
- Occur on steep slopes or tops of ridges, hills and mountains throughout the study area, where soil is eroded at a greater rate than it can form.
- Classified as Rudosols (ASCS; Isbell, 2002).

4.3.2 Sodic and Dispersive Soils

Sodic soils (with an exchangeable sodium percentage greater than six percent) contain enough sodium to affect the structural stability of the soil. When the soil becomes wet, the clay particles lose their sodium bonds and disperse. Hence, sodic soils are frequently dispersive. Erosion of dispersive soils occurs along existing cracks within the soil mass, with material entrained by flowing water (US Bureau of Reclamation, 1991). Many sodic clay soils are highly reactive (i.e., with a high expansion ratio) and prone to cracking. Subsurface piping (tunnelling) erosion is, therefore, a characteristic of sodic, dispersive soils.

Surface erosion of sodic, dispersive soils tends to occur in response to sudden, intense rainfall events, rather than gradual wetting (US Bureau of Reclamation, 1991). Rainfall in the study area typically falls as intense deluges. Sodic soils are prone to sheetwash, rilling and gully erosion under intense rainfall conditions.

Structures constructed from sodic soils, e.g., dams and fill platforms, are prone to failure, particularly on first wetting (US Bureau of Reclamation, 1991). Cracks in the structures (e.g., due to soil reactivity or differential settlement) are exploited by flowing water, which can result piping erosion and sudden, catastrophic structural failure. Failures are also triggered by a change in groundwater chemistry: the lower the percentage of dissolved salts in water affecting the structure, the greater the susceptibility to dispersion (US Bureau of Reclamation, 1991).

Texture contrast soils on Curtis Island and along the flanks of the Mount Larcom Range are typically sodic, dispersive and erodible.

4.4 Salinity

Saline soils are those containing soluble salts in the soil water. The main salt involved in salinity is sodium chloride, but sulfates, carbonate and magnesium salts can also contribute. Saline soils are related to geology, catchment hydrology (in particular, groundwater flow) and terrain.

Salinity is associated with coastal and marine areas subject to current or past marine inundation. Salinity can also occur from natural rock weathering. Vegetation clearance can case saline groundwater to rise in recharge areas, as water uptake from vegetation is reduced. Additionally, salinity can be caused by excess application of water to soils with poor drainage (e.g., compacted and/or clay soils). This can cause groundwater levels to rise, bringing subsurface salts to the surface (commonly referred to as dryland salinity).

There is little evidence of salinity in the study area other than in tidal areas (Ross, 1999). Within the study area, salinity may occur in areas of texture contrast soils with impeded drainage. These soils occur as isolated pockets along drainage lines of the coastal plains (Ross, 1999), but available records indicate that these soils are outside the project footprint.

4.5 GQAL in the Study Area

The dominant agricultural land-use of the study area is native pasture, used for grazing beef cattle (Ross, 1999). Scattered horticulture is present along the coastal fringe, generally small-scale tropical fruit plantations. The major constraints to broadacre horticulture expansion include landform, water supply, soil and frost (the latter more common at inland and at higher elevations; Ross, 1999).

The focus on industrial activities and the introduction of the GSDA has resulted in a change from agricultural to industrial land use.

The study area generally has low soil fertility, with grazing occurring on shallow and texture contrast soils. Horticulture is located in the Targinie Valley, to the east of the Mount Larcom Range. Soils in this area are generally deep, well-drained, red in colour and have a clay loam to clay texture (Ross, 1999).

The variability of soils in the study area has resulted in generally Class C or Class D agricultural land, with pockets of areas of Class A and Class B (see Figure 4.7). GQAL in the study area is typically concentrated along the lower slopes of igneous upland areas, e.g., along the eastern flanks of the Mount Larcom Range; along the flanks of the Balnagowan Volcanics (a member of the Doonside Formation) and (just to the south of the study area) along the flanks of Mount Sugarloaf.

GQAL (i.e., Class A or B agricultural land) is only found in the locality of TWAF 8 (see Figure 4.7), and occupies approximately 9.5 ha (roughly 20%) of this site.

4.6 Specific Sites of Environmental Significance – Geoheritage

Within the study area, there are no sites listed by DSEWPC as being of geoheritage value. However, similar principals to those used to formally define geoheritage sites have been applied to identify significant areas within the study area, based on the regional assessment of geology, landform and soils characteristics.

4.6.1 Port Curtis Strait

The strait of Port Curtis forms the southern extension of The Narrows, a DSEWPC-listed site (outside the project study area). Many of the features of The Narrows are also found along Port Curtis, including:

- Geological setting: both Port Curtis and The Narrows are flooded half-graben features, separating rocky Curtis Island from the mainland. The surface features are underlain by the Rundle Formation, in particular the Rundle and Stuart oil shale deposits have a diverse fossil assemblage.
- Geomorphological processes: both landforms contain examples of tropical intertidal estuarine sedimentation features (Cook *et al*., 1997). The landforms also represent modern analogies to many of the rock headlands in Queensland that have already joined to the mainland by sedimentation processes occurring along both The Narrows and Port Curtis today.
- Ecological diversity: both landforms are characterised by an ecologically diverse set of intertidal channels (Cook *et al*., 1997). The marine muds support the distinctive ecology of the Port Curtis Wetlands.

The Curtis Coast Regional Coastal Management Plan identifies the marine plains of Curtis Island and around the mouth of the Calliope River as key coastal sites, as they support a range of critically important ecosystems (EPA, 2003). Developments within/around such landforms are considered to be a coastal management issue as they have the potential to expose acid sulfate soils; change natural rates of sedimentation; and affect natural drainage and tidal patterns. The Curtis Coast Plan recommends that such impacts be avoided by maintaining appropriate vegetation buffer zones around such ecosystems.

The LNG plant, launch site 1, and feed gas pipeline encroach onto coastal mudflats.

4.6.2 Hogsback Ridges, Southwest Curtis Island

The unique geological structure has strongly influenced the landforms along the coastal strip of the study area. Steeply dipping, faulted, folded rocks with very variable rock strengths have been differentially eroded to form distinctive steep-sided hogsback ridges (a strike-ridge system). These landforms record Permian tectonism and provide a striking example of the influence of geology on landform. These ridges form a significant part of the coastal landscape, as identified in the Curtis Coast Regional Coastal Management Plan (EPA, 2003). The Plan recommends that any development within these areas is limited to below ridgelines; any scarring of the landscape be avoided or appropriately screened; and that rehabilitation planting is encouraged in denuded areas.

The LNG plant is located at the southeastern end of the main hogsback ridge, known as “the Spine” (see photograph P1 in Appendix A), and the plant footprint covers several hills that are remnants of the larger ridgeline.

4.6.3 Mount Larcom and the Mount Larcom Range

Mount Larcom is a spectacular landscape feature; the pale trachyte plug peaks and crags loom above the forested surrounding area. The Mount Larcom Range, along the Calliope–Targinie Road, Yarwun, is listed as an indicative place on the Register of the National Estate, as identified in the Curtis Coast Regional Coastal Management Plan (EPA, 2003).

The Mount Larcom peaks themselves are just outside the study area, but TWAF 8 is located at the foot of the uplands.

4.6.4 Targinie Remnant Vegetation Coastal Landforms

The Targinie key coastal site (which includes the Targinie State Forest) is characterised by coastal landforms that support examples of remnant vegetation and act as a wildlife corridor. The Curtis Coast Regional Coastal Management Plan indicates that development within this area is considered a coastal management issue, as secondary impacts of any earthworks, such as increased erosion and sedimentation rates, may have the potential to adversely impact upon these values (EPA, 2003).

Although the Targinie remnant vegetation site and Targinie State Forest are within the study area, no facilities sites are located within the Forest.

5 ENVIRONMENTAL VALUES AND LANDSCAPE SENSITIVITY

This section discusses the environmental values of the study area and the sensitivity, or susceptibility to change in response to disturbance, of these values.

The broadly similar geological, landform and soil characteristics have been compiled into broad terrain units which represent the environmental values of the landscape, and govern the way in which the landscape responds to disturbance, i.e., its sensitivity. This is controlled by a combination of:

- Intrinsic properties of the geology, topography and soils, e.g., resistance to erosion, soil texture/profile/ chemistry, vegetation cover and slope steepness.
- Geomorphic processes acting on the landscape, e.g., *in situ* weathering, mass movement (landslides), water or wind erosion.

Intrinsic landscape properties and geomorphic processes are not static: landscape evolution and landscape properties/process form a two-way relationship, whereby processes are affected by intrinsic properties, and *vice versa*. For example, if vegetation cover is removed, water flows can become more erosive as their velocities increase. The contemporary landscape is the end product of centuries to millennia of the interaction between intrinsic properties and process. Future landscape evolution is also controlled by this interaction. The landscape is, therefore, in a constant state of flux, with some areas being more susceptible to change then others. This study has focussed on those attributes which could adversely affect landform change, sensitivity or potential impact.

In some cases, the attributes of a landscape are such that the site is considered to be of geoheritage value, i.e., of importance within the context of Australia's natural history in terms of influence, rarity, understanding, unique characterisation and aesthetic value (Cook *et al*., 1997). Geoheritage is the only environmental value that is not directly related to landscape characteristics: although geoheritage sites are unique as a result of their characteristics, they are only placed within the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) Australian Heritage Database following assessment by the Australian Heritage Council and the Minister for Sustainability, Environment, Water, Population and Communities. No heritage-listed sites are located within the study area at the time of writing (as discussed in Section 4.6).

5.1 Terrain Unit Mapping and Environmental Values

The study area was divided into seven broad terrain units, representing the environmental values of the study area, based on the findings of the existing environment assessment (see Section 4: Existing Environment). The terrain units were defined and subdivided based on the following variables (see Section 3.5: Terrain Mapping and Environmental Values Assessment Method, Figure 5.1 and Figure 5.1a):

- Landform: slope steepness and topography.
- Geology: bedrock outcropping and engineering properties.
- Soils: physical, chemical and engineering properties, including GQAL.
- Properties: characteristics of the landscape that may cause adverse response to disturbance.
- Geomorphological Processes: Geomorphological processes that may cause adverse landscape change.

Table 5.1 summarises the terrain unit characteristics, properties and processes that represent the environmental values of the study area.

Table 5.1 Environmental Values of the Study Area: Terrain Unit (TU) Characteristics, Properties and Processes

TU	P*	Landform	Geology	Soils			Intrinsic landscape Properties	Geomorphological Processes of Landscape Change
				Typical Soil Type	ASC Classification	GQAL		
Clay Alluvial or Marine Plains								
Ia		Contemporary floodplains	Quaternary Alluvium	Clay loamy surface over sodic clays or shallow rock	Shallow Dermosols or texture contrast soils	C	• Erodible soils • Variable soil depths	• Flooding
Ib	✓	Contemporary intertidal and supratidal flats	Modern Coastal Muds	Clays, inundated, saline	Grey, gleyed Hydrosols	D	• Acid sulfate soils • Salinity • Soft soils • Waterlogging • Rapid landform change • Key coastal sites on Curtis Island and around the mouth of the Calliope River	• Tidal inundation
Ic		Older alluvial plains and terraces	Pleistocene Alluvium	Not Assessed	Not Assessed	C	• Salinity	
Undifferentiated Colluvial/Alluvial Plains								
IIa		Remnant laterised soils	Tertiary Laterised Regolith	Red gradational clay loams and uniform clays, with occasional bleached surface soils	Ferrosols or Red Dermosols, occasional Chromosols	C	• Erodible soils • Salinity • Soft soils • Waterlogging	
IIb	✓	Gently undulating coastal rises and plains	Undifferentiated colluvium/alluvium derived from Curtis Island Group bedrock and Mt Alma Formation	Brown and red loams/clay loams, possibly with a wash of bleached sand/loam.	Ferrosols, red or brown Dermosols/Kandosols. Chromosols or Sodosols in places.	C	• Probably sodic, erodible and hard-crusting soils • Salinity • Waterlogging of texture contrast soils • Variable soil type/depth • Targinie State Forest	
Curtis Island Group Forests								
IIIa	✓	Gently undulating rises and plains, in places dissected by deep, active gullies	Undifferentiated colluvium/alluvium derived from Wandilla Formation	Gravelly/stony brown/red brown loams/clay loams with wash of sand/loam on valley floors in broader low-lying areas	Rudosols and Kandosols in the narrow valleys of the north study area. Chromosols and Sodosols in valley bottoms in the south. Ferrosols possible depending on degree of weathering.	C	• Variable colluvial/alluvial sodic soils • Salinity near coastline • Very variable depth to rock • Undulating terrain	• Rill and gully erosion • Flash flooding (particularly in narrow valleys)
IIIb	✓	Steeply undulating hills and rises	Wandilla Formation	Gravelly/stony brown/red brown loams/clay loams. Depth of soils variable depending on location on slope.	Kandosols, Tenosols and Rudosols	C	• Sodic, erodible subsoils • Very variable depth to variable strength rock • Steeply undulating relief • Hogsback ridges	• Rill and gully erosion

TU	P*	Landform	Geology	Soils			Intrinsic landscape Properties	Geomorphological Processes of Landscape Change
				Typical Soil Type	ASC Classification	GQAL		
Curtis Island Group Forests (ctd.)								
IIIc		Steep ridges and isolated hills	Wandilla Formation	Shallow, gravelly, skeletal soils	Rudosols with some Kandosols and Tenosols	C	• Sodic soils • Shallow soils overlying variable strength rock • Steep slopes (other than ridge crests) • Hogsback ridges	• Rill and gully erosion
IIId		Gently undulating rises and plains	Undifferentiated colluvium/alluvium derived from Doonside Formation	Brown/red gravelly loams/clay loams with occasional wash of sand/loam	Gradational soils, largely ferruginised	C	• Possible sodic, erodible soils • Variable soil depth	• Rill and gully erosion
IIIe		Undulating hills and rises	Undifferentiated colluvium/alluvium derived from Doonside Formation	Gravelly loams & clay loams	Gradational soils	A to C	• GQAL along flanks of Mount Larcom Range • Possible sodic, erodible soils • Very variable depth to variable strength rock • Undulating terrain	• Rill and gully erosion
IIIf		Steeply undulating hills and rises	Doonside Formation /Balnagowan Volcanics	Gravelly loams & clay loams	Gradational soils	C	• Possible sodic, erodible soils • Very variable depth to variable strength rock • Steep slopes	• Rill and gully erosion
Undifferentiated Sedimentary/Volcanic Uplands								
IVa		Steeply undulating hills and rises	Beserker Group Undifferentiated Sedimentary/Volcanic Sequences	Silty loam topsoils with loamy clay subsoils. Possible bleached sandy surface	Rudosols, Tenosols, texture contrast soils in places.	C	• Sodic, erodible subsoils • Very variable depth to variable strength rock • Steep and undulating slopes • Mount Larcom Range	• Rill and gully erosion
Mafic Igneous (Gabbro and Basalt) Uplands								
Va		Isolated hills	Basalt intrusion into sedimentary rocks	Cobbly clayey surface with red clay subsoil	Red Dermosols with patches of texture contrast soils	C	• Shallow soils	
Felsic Igneous (Trachyte and Rhyolite) Uplands								
VIa	✓	Undulating hills and rises	Colluvium from Felsic Igneous hills	Clay subsoil with sandy loam topsoils that are often bleached	Kurosols, Chromosols or Sodosols	C	• Acidic and sodic, erodible soils • Waterlogging • Mount Larcom Range	• Rill and gully erosion
VIb	✓	Steeply undulating hills and rises	Felsic Igneous intrusions: Trachyte and Rhyolite	Gradational soils becoming more clay-rich with depth and with sand throughout	Tenosols or Kandosols	A/C	• GQAL along flanks of igneous uplands • Can be acidic • Variable depth to variable strength rock but generally shallow soils • Mount Larcom Range	

TU	P*	Landform	Geology	Soils			Intrinsic landscape Properties	Geomorphological Processes of Landscape Change
				Typical Soil Type	ASC Classification	GQAL		
Felsic Igneous (Trachyte and Rhyolite) Uplands (ctd.)								
VIc		Steep hills and mountains	Felsic Igneous intrusions: Trachyte and Rhyolite; Adamelite and Granite	Stony, loamy, gradational soils	Rudosols and shallow Tenosols	D	• Shallow, gravelly soils • Mount Larcom Range	
Artificially Altered Area								
VIIa	✓	Large areas of reclaimed land and earthworks	Curtis Island Group and overlying colluvium and alluvium		Anthroposols	D	• Large-scale land reclamation • Large-scale earthworks • Possible uncontrolled fill (i.e. fill of unknown origin and type) • Poor rehabilitation potential on ashponds	• Sheetwash, rill and wind erosion of former ash ponds

P* ✓ indicates terrain units that are located in the project area of disturbance

NOTE: ASC soil classifications are based on the findings of relevant, publicly available studies and field observations of soil exposures. Invasive field investigations were not carried out for the soil study. If ASCs are described as generic texture contrast soils or gradational soils, soils types were too variable or there was insufficient laboratory data for classification.

5.2 Landscape Sensitivity Assessment

This section of the report assesses the sensitivity of the environmental values of the study area. The environmental values of the mapped terrain units have been used to assess the likely response of the landscape to the project. The variability of geology, landforms and soils means that environmental value sensitivity will not generally be consistent across the entire unit (see Section 3.5: Terrain Mapping and Environmental Values Assessment Method). To gain an understanding of the regional landscape sensitivity and for comparative purposes, the susceptibility to disturbance of geology, landforms and soils of all terrain units within the study area were assessed (see Sections 5.2.1 – 5.2.7). The sensitivity of environmental values and overall sensitivity of terrain units associated with specific project components is then discussed in Section 5.3: Sensitivity Ranking Summary and Overall Terrain Unit Sensitivity.

The sensitivity of a terrain unit is controlled by the sensitivity of its attributes. These are broadly defined by a combination of the criteria given in Table 5.2:

Table 5.2 Landscape Sensitivity Classification Criteria

<table>
<tr><th>Sensitivity
Criteria</th><th colspan="2">Low Sensitivity
(Ls)</th><th colspan="2">Moderate Sensitivity
(Ms)</th><th colspan="2">High Sensitivity
(Hs)</th></tr>
<tr><td>Conservation or geoheritage status of elements of the terrain unit</td><td colspan="2">No features within the terrain unit are listed assets or equivalent</td><td colspan="2">Features have similar attributes to those officially listed or are being assessed by the Australian Heritage Commission</td><td colspan="2">Features of the terrain unit are listed by DSEWPC as geoheritage assets</td></tr>
<tr><td>Rarity of occurrence, abundance or distribution of geology, landform or soil types and availability of equivalent or representative alternatives</td><td colspan="2">Landscape features which are common locally, regionally and nationally and which, therefore, have locally available alternatives</td><td colspan="2">Landscape features which are locally unique, but which have regionally available alternatives</td><td colspan="2">Features of the landscape which are regionally or nationally unique (typically recognised as geoheritage sites). GQAL or strategic cropping land</td></tr>
<tr><td>Resilience to change (i.e., landscape properties)</td><td>Soils and outcropping rocks resistant to erosion, weathering or mass movement</td><td rowspan="3">Shallow slopes</td><td>Soils and outcropping rocks where erosion, weathering and landslides are possible but not common</td><td rowspan="3">Moderate slopes</td><td>Soils or outcropping rocks are erodible and prone to landsliding or weathering</td><td rowspan="3">Steep slopes</td></tr>
<tr><td>Dynamicism of the existing environment (i.e., landscape processes)</td><td>Low energy systems that are slow to change with short recovery periods</td><td>Landscapes which are moderately dynamic with medium-term recovery periods</td><td>Landscape systems are dynamic and prone to rapid change and long recovery periods</td></tr>
<tr><td>Rehabilitation potential[1]</td><td>Rehabilitation can be successfully achieved</td><td>Slow or only partially successful rehabilitation</td><td>Limited rehabilitation potential</td></tr>
</table>

1 Rehabilitation potential describes the probable success of re-establishing the soil profile and vegetation supported by this soil. This is related to soil fertility, profile complexity and structure.

Given the variability of environmental values and associated sensitivity across a terrain unit, the sensitivity classification may also vary, as indicated in the following sections and accompanying figures. Thus, in some cases, the sensitivity classification is split, as some areas of a terrain unit have a different sensitivity to other areas.

In some cases, landscape sensitivity may be such that adverse landscape change would result in a fundamental alteration of the environmental values of the terrain unit. These areas would generally be classified as “No Go” areas. The assessment of the existing environment of the study area (discussed in Section 4: Existing Environment) does not indicate sensitivity to this degree associated with geology, landscape or soils within the study area.

The general landscape sensitivity classification criteria in Table 5.2 has been used to inform specific sensitivity criteria for project relevant processes and attributes that relate to the study area environmental values. The sections below detail the specific criteria that have been carried forward into the impact assessment.

5.2.1 Conservation Status and Geoheritage Assets

The sensitivity classification combines geoheritage status and rarity of occurrence, defined as follows:

- Low – Geology, landform and soils may be found abundantly elsewhere within Australia.
- Moderate – Sites classified by this study as being of importance from a geology, landform or soils perspective – terrain unit Ib is associated with the marine plains of Port Curtis; terrain units IIIb and IIIc are associated with Hogsback ridges in southwestern Curtis Island; Mount Larcom and the Mount Larcom Range are associated with terrain units IVa and VIa-VIc; and the Targinie State Forest is located within terrain unit IIb.
- High – Geoheritage sites listed by DSEWPC – Not found within the study area.

5.2.2 GQAL

Within the study area, deep, fertile soils are found along the flanks of igneous upland areas. These soils are classified as GQAL under SPP 1/92 (see Sections 1.5.1: Agricultural Land Legislation and 4.5: GQAL in the Study Area). Areas of GQAL class A and B are ranked as having a high sensitivity to change, whereas areas classed as C or D are ranked as having a low sensitivity; disturbance of the soil structure in GQAL areas will have a greater impact on the landscape than in non-GQAL areas. The GQAL ranking gives an indication of the rehabilitation potential of the terrain unit: much of the study area is agricultural class C or D land, comprising shallow or gravelly soils with poor fertility and rehabilitation potential.

GQAL is found within terrain units IIIe and VIb. Approximately 20% (9.5Ha) of TWAF 8 comprises GQAL, associated with terrain unit VIb. These areas are likely to have high rehabilitation potential, unless adversely impacted given their sensitivity to change.

5.2.3 Landscape Sensitivity to Erosion (Erodibility) and Erosion Hazard

Susceptibility to Water Erosion – Soil Erodibility

The erodibility of a material indicates its potential to erode i.e., it is not related to the erosion processes that actually instigate the erosion – but these processes must act before erosion occurs. Erodibility is related to the soil/rock physical/chemical properties (particularly soil sodicity).

Within the study area, sodic soils are prone to both surface (sheetwash, rilling and gullying) and subsurface (piping or tunnelling) erosion in response to minor disturbances. This is particularly the case in soils formed from Curtis Island Group parent material. Sodic texture contrast soils were observed within terrain unit IIIa on Curtis Island and within the LNG plant site.

The sensitivity ranking for erodibility is as follows (after Charman and Murphy, 2007) see Figure 5.2:

- Low – High organic matter; well-structured, coarse sandy soils – no soils within the study area are considered to have low erosion hazard sensitivity.
- Moderate – Moderate organic matter, sandy or loamy soils or non-dispersive clays - terrain unit Ia-Ib, IIb and areas of VIb and lower relief or shallow soil areas of terrain unit IIb, IVa, Va and VIa-VIb.
- High – Low or very low organic matter, friable silty soils or dispersive subsoils – terrain units IIIa-IIIf; fining upwards sequences (sands to silts to clays) of terrain unit Ic; areas with sodic texture contrast soils in terrain units IIc, IVa, Vc and VIa; former ash pond sites within terrain unit VIIa.

Water Erosion Hazard

The properties of a soil affect its erodibility, but this can be significantly affected by slope steepness and length; vegetation coverage, rainfall characteristics and artificial influences. The presence of landforms which increase the potential for erosion or artificial modification of topography or drainage can result in erosion in areas classified as being of low susceptibility to erosion.

The study area is characterised by undulating relief, influenced by the variable underlying geology (see Figure 4.1). Steep slopes are associated with resistant geological outcrops and structure, including the Curtis Island hogsback ridges.

Low-lying land on Curtis Island is prone to gullying, with evidence of rapid channel avulsion observed during the field visit. This area also has higher relief and gullying is, therefore, more likely. Gully sides and artificial batter slopes can also form localised, small-scale steep slopes.

Sodic, dispersive soils become more susceptible to erosion if they are used for construction (e.g., dams or other earthworks). These soils are also more susceptible to erosion if ground salinity decreases, e.g., following a rise in the water table.

Susceptibility to Wind Erosion

Soils with fine, loose surface material are prone to wind erosion, particularly if cleared of vegetation or mechanically disturbed (see Figure 5.3). In general, soils are not considered to be susceptible to wind erosion within the study area, other than along coastal margins (see Section 4.2.1: Landform Features). This is due to the prevalence of shallow, gravelly soils within the study area. The sensitivity classification for wind erosion is as follows:

- Low – Cohesive, dense soils – terrain units Ia-Ic, IIa, IIIb-IIIc, IIIf, IVa, Va, VIa-VIb and areas of terrain units IIb, IIIa, IIIb, IIId and IIIe.
- Moderate – Texture contrast soils with fine sandy loam topsoils – areas of terrain units IIb, IIIa-IIIb and IIId-IIIe. Lower-lying areas of terrain units IIb, IIIa and former ash pond sites within terrain unit VIIa are considered to be most sensitive with regard to wind erosion and dust production.
- High – Sandy topsoils. No soils within the study area are considered to have a high sensitivity to wind erosion.

5.2.4 Landscape Sensitivity from Salinity

Terrain units which include saline soils may be sensitive to adverse change following groundwater level rise, soil compaction or soil profile inversion (exposure of saline subsoils). Salinity can result in a terrain unit which is susceptible to:

- Vegetation scalding and die-off.
- Erosion (generally a secondary affect, typically related to increased sodicity from sodium salts).
- Poor rehabilitation potential.

Terrain units have been assessed as having the following sensitivity to salinity following disturbance:

- Low – Inland units and transition zones between saline and non-saline soils – areas of terrain unit IIIa and inland terrain units.
- Moderate – Possible saline soils, located within low-lying coastal plain or texture contrast soils with sodic subsoils – terrain unit Ic and areas of terrain units IIa-IIb, IIIa and VIIa.
- High – Saline marine muds; terrain units Ib and areas of terrain units IIb, IIIa and VIIa.

5.2.5 Landscape Sensitivity from Soft Soils and Waterlogging

Areas of the landscape prone to soft soils or waterlogging may be susceptible to localised compaction, wheel rutting and erosion from concentration of water throughout the project. Marine muds are subject to both issues. Waterlogging is a seasonal problem in the region. Sodic soils on Curtis Island, and elsewhere, can become very soft and prone to compaction when wet and can be hardsetting (i.e., prone to water puddling following rain due to impaired infiltration. Over the remainder of the site, soils are generally shallow with a high gravel content and fewer soft soil issues.

The sensitivity of the terrain units to adverse impacts from soft soils and waterlogging reflects the anticipated worst-case conditions following prolonged or intense rainfall, classified as follows (see Figure 5.4):

- Low – Shallow, dense, gravelly soils – terrain unit Va.
- Moderate – Moderate to deep uniform or gradational soils which are less prone to waterlogging – terrain units IIa-IIb, IIIb-IIIf, VIb and higher elevation areas of terrain unit IIIa.
- High – Moderate to deep texture contrast soils which are prone to waterlogging within terrain unit VIa, or deep waterlogged mud – terrain unit Ia and low-lying areas of terrain unit IIIa; deep, waterlogged, soft mud – terrain unit Ib; waterlogging and wet soft soils of ash pond material within terrain unit VIIa.

5.2.6 Rehabilitation Potential

The rehabilitation potential of soils in the study area reflects the susceptibility of the terrain unit to revegetation and reinstatement of the soil profile following disturbance. This is related to soil fertility and characteristics (particularly structure and textural profile) and slope steepness. Texture contrast soils with sodic subsoils and thin topsoils are particularly susceptible to poor rehabilitation success, as topsoils are thin, with unfavourable subsoils. Therefore, stripping of topsoils without causing soil profile mixing may prove difficult.

The susceptibility to disturbance of the rehabilitation potential of a terrain unit is assessed as follows:

- Low (i.e., straightforward soil profile reinstatement and revegetation) – moderate to high fertility, weakly structured soils with a deep, uniform profile on shallow slopes (<5°) – lower slopes of terrain unit VIb.
- Moderate – moderate fertility, well-structured gradational soils on moderate slopes (5°-20°) – All other terrain units; terrain unit Ib has shallow slopes and organic-rich soils, but rehabilitation will be constrained by salinity and waterlogging.
- High (i.e., difficult soil profile reinstatement and revegetation) – low fertility texture contrast soils, particularly those with sodic subsoils; compacted soils; or shallow soils, especially those with thin topsoils; steep slopes (>20°) – terrain units Ia, III;V and VIa, and areas of VIb; former ash pond sites within terrain unit VIIa.

5.2.7 Effect of Slope Steepness on Landscape Susceptibility

The characteristics of slopes within a terrain unit, while not a measurable sensitivity, directly influence the sensitivity of the landscape, particularly with regard to erosion, landslide susceptibility and rehabilitation potential. Localised effects of slope steepness include the following:

- Increased likelihood of erosion: water on steeper slopes tends to have higher velocity and, therefore, erosive energy.
- Increased likelihood of slope instability: steeper slopes are more prone to landsliding.
- Steeper slopes are likely to have shallow soils, with reduced revegetation potential and, therefore, rehabilitation success.

Therefore, steep slopes may locally increase landscape sensitivity within a low sensitivity area, and shallow slopes may locally decrease sensitivity. Artificial steepening of slopes is likely to locally increase the susceptibility of a terrain unit to erosion, landsliding and poor rehabilitation success.

5.3 Sensitivity Ranking Summary and Overall Terrain Unit Sensitivity

A summary of the environmental values identified within each terrain unit is given in Table 5.3. Only those terrain units which will be impacted be project activities have been summarised in this table and given an overall sensitivity classification, following the criteria outlined in Table 5.2: Landscape Sensitivity Classification Criteria and Sections 5.2.1 – 5.2.7.

The overall sensitivity was assessed as follows:

5.3.1 Sensitivity of Terrain Unit Ib – Contemporary Coastal Flats

- Port Curtis marine plains, which are key regional coastal sites.
- Soft, saline marine muds which are prone to compression and waterlogging, and which are moderately susceptible to erosion.
- Rehabilitation constrained by salinity and water logging.

The construction of the LNG plant site and the mainland section of the feed gas pipeline will disturb areas of terrain unit Ib, which has a **moderate** overall sensitivity.

5.3.2 Sensitivity of Terrain Unit IIb – Coastal Rises and Plains

- Targinie remnant vegetation and Targinie State Forest key coastal site, no DSEWPC heritage-listed sites.
- Loamy soils are moderately susceptible to erosion, compaction and waterlogging.
- Moderate rehabilitation potential.

TWAF 8 and mainland section of the feed gas pipeline will disturb areas of terrain unit IIb, which has **moderate** overall sensitivity

5.3.3 Sensitivity of Terrain Unit IIIa – Undulating Rises and Plains – Wandilla Formation

- Southwest Curtis Island/hogsback ridges key coastal site, no DSEWPC heritage-listed sites.
- Soft, compressible texture contrast soils which can be shallow with thin topsoils and sodic subsoils that are prone to waterlogging, highly susceptible to water erosion, moderately susceptible to wind erosion, and prone to rapid gullying.
- Soil profile and poor fertility reduces rehabilitation potential.

The LNG plant and the Curtis Island section of the feed gas pipeline will disturb areas of IIIa, which has a **moderate** overall sensitivity.

5.3.4 Sensitivity of Terrain Unit IIIb – Steeply Undulating Hills and Rises – Wandilla Formation

- Southwest Curtis Island/hogsback ridges key coastal site, no DSEWPC heritage-listed sites.
- Texture contrast soils which are highly susceptible to erosion, exacerbated by steep slopes in places.
- Poor rehabilitation potential due to low fertility soils and steep slopes.

The LNG plant will disturb areas of IIIb, which has a **moderate** overall sensitivity.

5.3.5 Sensitivity of Terrain Unit VIa – Undulating Hills and Rises – Felsic Igneous Uplands

- Mount Larcom Range key coastal site, no DSEWPC heritage-listed sites.
- Sodic texture contrast soils which are susceptible to water erosion, particularly on steeper slopes, and prone to waterlogging.
- Rehabilitation potential constrained by poor soil fertility and soil profile.

TWAF 8 will disturb areas of terrain unit VIa, which has a **moderate** overall sensitivity.

5.3.6 Sensitivity of Terrain Unit VIb – Steeply Undulating Hills and Rises – Felsic Igneous Uplands

- Mount Larcom Range key coastal site, no DSEWPC heritage-listed sites.
- GQAL where deep, gradational soils are present.
- Soils are moderately erodible, particularly associated with steeper slopes, and moderately susceptible to waterlogging.

- Rehabilitation potential constrained in areas of shallow soils or areas with steeper slopes.

TWAF 8 will disturb areas of terrain unit VIb, which has a **moderate** overall sensitivity.

5.3.7 Sensitivity of Terrain Unit VIIa – Artificially Altered Areas

The sensitivity of terrain unit VIIa has been assessed for TWAF 7 and launch site 1 only, assuming the sites are partially or entirely characterised by typical ash pond material.

- No key coastal sites or DSEWPC geoheritage-listed sites.
- Ash fill which is highly susceptible to water and wind erosion; prone to compaction and waterlogging; and is likely to be saline.
- Low rehabilitation potential due to poor soil fertility.

TWAF 7 and launch site 1 will disturb areas of terrain unit VIIa, which has a **moderate** overall sensitivity. The southern section of launch site 1 comprises coastal plains analogous to terrain unit Ib, which also has a moderate overall sensitivity.

Table 5.3 Summary of Geology, Landform and Soils Sensitivity within the Study Area and Environs

Terrain Unit	Geoheritage[1]	GQAL	Susceptibility to Erosion		Salinity	Soft Soils/ Waterlogging	Sensitivity of Rehabilitation Potential [2]	Overall Sensitivity
			Water Erosion	Wind Erosion				
Clay Alluvial or Marine Plains								
Ib	M	L	M	L	H	H	H	M_s
Undifferentiated Alluvial/Colluvial Plains								
IIb	M	L	M	L/M	M/H	M	H	M_s
Curtis Island Group Forests								
IIIa	L	L	H	L/M	M/H	M/H	H	M_s
IIIb	M	L	H	L	L	M	H	M_s
Felsic Igneous (Trachyte and Rhyolite) Uplands								
VIa	M	L	M/H	L	L	H	H	M_s
VIb	M	H	M	L	L	M	L/M	M_s
Artificially Altered Areas								
VIIa[3]	L	L	H	M	M/H	H	H	M_s

1. Geoheritage sites represent small areas within the broader terrain unit extent. The sensitivity classification is for the specific site only.
2. Sensitivity of rehabilitation potential indicates the susceptibility to disturbance of the rehabilitation potential of a terrain unit: units which are highly sensitive are those which will be difficult to rehabilitate following disturbance.
3. Unit VIIa only ranked for former ash pond sites, as the extent and impact of other alterations is unknown.

All the identified terrain units within the study area are considered to be moderately sensitive to disturbance given the presence of regionally important heritage sites; soils that are prone to salinity, compaction, waterlogging and erosion; and the generally poor rehabilitation potential.

6 ENVIRONMENTAL CONSTRAINTS AND DESIGN CONSIDERATIONS

This section of the report assesses environmental constraints within the study area i.e., the impact of the environment on the project. It is anticipated that these constraints will be considered during the detailed design phase of the project. The mapped terrain units have been used to provide a general overview of the likely characteristics, constraints and likely impacts on the project activities. The variability of geology, landforms and soils within each terrain unit means that constraints will not generally apply across the entire unit.

6.1 Erosion and Sedimentation

Both erosion and sedimentation can have a negative impact on project assets. Surface erosion can cause exposure or undermining of structures, potentially leading to failure. Rill and gully erosion may also result in access track or site damage. The sodic, dispersive soils in the study area, particularly those associated with terrain unit IIIa on Curtis Island, are prone to subsurface erosion, particularly if disturbed. Subsurface erosion can cause voids to form which have little or no surface expression. Void collapse can then result in structural or site damage.

Downslope, downstream or downwind deposition of eroded sediment may bury project components, in particular those which are located within topographic depressions or within low-lying areas of the study area (e.g., valley floors or coastal margins).

6.2 Salinity Constraints

Salinity can have the following effects on the project:

- Salt-affected soil retards plant growth, reducing vegetation cover and, in extreme, cases can cause land to be completely unproductive. This may affect rehabilitation attempts in saline soil areas.
- Saline land can be susceptible to wind and water erosion if vegetation cover is reduced.
- Soils with high salinity as a result of sodium chloride (i.e., sodic soils) have a tendency to disperse in water due to weak sodium bonds between clay particles. This increases the risk of subsurface erosion.
- At high concentrations, soil salinity can cause corrosion of footings and other susceptible surface infrastructure.

Salinity constraints are likely to be associated with marine sediments, particularly the saline marine muds of terrain unit Ib and areas of terrain units IIb and IIIa. Salinity problems may also occur in estuarine and coastal deposits within the low-lying coastal plain, i.e., areas of terrain units IIb-IIc and IIIa.

6.3 Topographic Constraints

The study area is characterised by undulating relief, influenced by the highly variable underlying geology (see Figure 4.1). Steep slopes (over 20°) contribute to the level of dynamicism of a landform, resulting in high energy geomorphological processes (such as gully erosion), landslide susceptibility and reduction of rehabilitation potential. Within the study area, steep slopes are associated with resistant geological outcrops and structure, including the Curtis Island Hogsback Ridges. The majority of naturally steep slopes will be removed during construction of the LNG plant. However, artificial batter slopes will create localised, small-scale steep slopes.

6.4 Landsliding and Slope Instability

Design for constructions on colluvium, in particular deep colluvium on steep slopes (>20°), should take account of the potential for slope instability. Failures are more likely along low shear strength zones associated with pre-existing shear surfaces. Failures are also possible where earthworks intercept a relatively competent/impermeable layer underlying a relatively competent/permeable layer; or where rock defects dip towards the artificial cut.

6.5 Faults and Seismic Hazard Constraints

There are a number of faults, which cross the study area, including major regional faults and minor joint sets (see Figure 4.1). The study area is also one of the most tectonically active in Australia (URS, 2008; Worley Parsons, 2010), and the most active area in Queensland (Granger and Michael-Leiber, 2001). The region has been subject to earthquakes strong enough to cause damage to buildings and infrastructure. URS (2008) report that earthquakes of this magnitude have occurred, on average, every 5 years over the last century. A specific seismic hazard study was, therefore, commissioned (Ove Arup, 2009a; 2009b). This study concluded that the study area was generally considered to be at low risk of fault movement, liquefaction or earthquake-induced slope instability. However, the study did consider liquefaction to be a risk within the coastal and marine muds (terrain unit Ib). Liquefaction is also a risk on reclaimed land formed from ash (TWAF 7 and the northern section of launch site 1).

The feed gas pipeline between the mainland and Curtis Island crosses through the major fault zone of the Narrows Graben. Should seismic activity result in fault reactivation, movement will propagate through the overlying Tertiary and Quaternary sediments, potentially leading to pipeline breach.

6.6 Trafficability Constraints

Trafficability problems in the study area can be caused by soft and/or slippery soils or waterlogging. Marine muds, within terrain unit Ib, are subject to both issues. Waterlogging is a seasonal problem in the region. Sodic soils on Curtis Island, and elsewhere, can become very soft and/or slippery when wet. Over the remainder of the site, soils are generally shallow with a high gravel content and fewer trafficability issues.

The relative trafficability constraint posed by different soils is comparable to the sensitivity of terrain units to soft soils and waterlogging (see Section 5.2.5: Landscape Sensitivity from Soft Soils and Waterlogging and Figure 5.4).

6.7 Soft Soils Constraints

Marine muds along the Coastal Plains present specific construction problems (terrain unit Ib). In areas where these soils occur, high magnitude and long timescale consolidation settlement beneath earthworks or footing loads is expected and will require careful management. In contrast, the soft soils of the coastal flats present different trenching problems. Without appropriate management measures, such as shoring, the feed gas pipeline trench is likely to be unstable and prone to collapse. The feed gas pipeline may need to be weighted and buried deeply, below the likely depth of natural or artificial disturbance. Disturbance and oxidisation of the marine muds is likely to result in acidification through oxidisation of sulphides, if not appropriately managed (Coffey Geotechnics, 2011b).

6.8 Rock Excavatability Constraints

Within the LNG plant site there are typically sharp contrasts in rock strength characteristics between adjacent units. Therefore, it is possible that rocks which can be easily excavated will be adjacent to rocks which are likely to require ripping or blasting: at the LNG plant site, steeply dipping low strength mudstones are interbedded with higher strength quartzose sandstones (including greywacke), weakly metamorphosed and igneous rocks (the latter in the form of dykes).

6.9 Construction Material Constraints

The variable geology of the study area may present problems when sourcing construction materials, including backfill and fill. Higher strength rocks, including sandstone and igneous/volcanic rocks, may be suited to crushing for aggregate, potentially providing robust, angular, granular fill. Low strength feldspathic sandstone and mudstone could probably be reworked as general fill, potentially requiring substantial moisture conditioning. Colluvium and alluvium within the site is predominantly clayey and does not represent a gravel resource. The material could be suited for use as general ('stony cohesive') fill. Colluvium and (reworked) alluvium, comprising gravelly stiff sandy clay, are likely to represent a challenge for the support of footings, particularly footings supporting critical structures. Footings for these buildings may require extending to bedrock.

The interbedded nature and strength variability of rocks within the study area may present issues when sourcing aggregate for tracks or roads. Mudstone is susceptible to breakdown under such usage. Coarse-grained sandstone and slightly metamorphosed rocks should crush to the appropriate size. Therefore, higher quality aggregate is likely to be retrieved from higher elevation areas.

7 ENVIRONMENTAL IMPACT ASSESSMENT

This section of the report assesses the potential impact of the project on the environment without implementation of management or mitigation measures. The recommended management and mitigation measures to reduce these potential impacts are discussed in Section 8. Inspection and maintenance programmes to check that measures have been successfully implemented are discussed in Section 8.4. The residual potential impact, assuming successful implementation of the recommended management and mitigation measures, is discussed in Section 9.

The greatest impacts are likely to occur during the construction phase, when the disturbance footprint is the largest. Following construction, partial rehabilitation of sites will reduce impact during the operation and maintenance phase. Rehabilitation will be carried out following decommissioning.

The impact that the project activities have on the geology, landform and soils is related to the susceptibility to change of the landscape element. This is related to the environmental values and sensitivity of the element (see Section 5: Environmental Values and Landscape Sensitivity). The environmental values associated with each terrain unit are present throughout the study area and for the lifetime of the project. Therefore, they should be a constant consideration.

Project components (and their associated project activities) that are anticipated to impact the landscape include:

- Feed gas pipeline and tunnel beneath Port Curtis (including the tunnel launch shaft).
- Various components of the project on Curtis Island, including the LNG plant, LNG jetty, materials offloading facility/passenger terminal (MOF) and Boatshed Point construction camp.
- Road infrastructure: Heavy Haul Roads.
- Mainland temporary construction camps, TWAF 7 and TWAF 8.
- Launch Site 1.

Many project components have similar impacts, since they involve similar activities. For example, most construction activities involve ground disturbance. These types of impacts have been termed as “generic impacts”. The distinguishing factors in assessing impact in these cases are generally the spatial and temporal extent of disturbance. Temporary lay-down areas disturbed during construction will impact the environment significantly less than the large LNG plant that will remain standing for several decades. Invasive activities, such as borrow pits and benching, will have a permanent impact on the landscape.

In addition to the generic impacts, there are also likely to be activity-based impacts. These will occur when a specific activity related to a project component is undertaken, e.g., large scale cut and fill in the LNG plant area. The impact of these activities is only related to these specific components.

7.1 Generic Environmental Impacts – Land Degradation

Any project activity which involves ground disturbance and/or vegetation removal has the potential to trigger or exacerbate erosion. Project-wide potential impacts are, therefore, largely associated with ground disturbance leading to land degradation, i.e., erosion. Erosion may be exacerbated by removal of protective vegetation coverage; soil compaction or disturbed soil which has been left uncompacted;

and activities which introduce pathways for surface runoff. Down-system deposition of eroded material may result in adverse sedimentation. Ground disturbance may also result in generation of dust. Soil quality can be reduced if the soil profile is inverted, incompatible material is imported or due to stockpiling. Potential impacts associated with land degradation are discussed in Sections 7.1.1 – 7.1.8.

7.1.1 Erosion

Any project activity which involves ground disturbance and/or vegetation removal has the potential to trigger or exacerbate erosion (see Section 4.2.1: Landform Features). The impact of an activity will be controlled by a combination of the erodibility of the affected materials, as well as the actual process of erosion.

Sections 7.1.2 – 7.1.4 discuss project tasks which may exacerbate erosion.

7.1.2 Reduced Vegetation Coverage

The erosion potential of project sites may be increased as a result of vegetation clearing in any part of the study area. Where vegetative groundcover is less than about 70%, the risk of erosion is anticipated to increase appreciably. Soil loss from bare areas can be an order of magnitude greater than from mulched or vegetated areas (Ross, 1999). Vegetation removal is likely to have the following effect:

- Removal of surface coverage: reducing protection from rainsplash erosion and leading to an increase in surface flow velocities and erosivity.
- Removal of root structures, which generally stabilise the ground and near-surface soils.

Field observations within the proposed LNG plant site indicated that erosion had occurred in areas cleared of vegetation.

7.1.3 Soil Compaction

Project activities which subject the ground to loading, such as access tracks, lay-down areas, spoil placement and LNG plant facilities, can cause soil compaction. Once compacted, it can be difficult to return the material to its original compactive state. Soft, compressible soils can occur in most terrain units, but are typical of terrain unit Ib, areas of terrain units Ia, IIa-b, IIIa, VIa and ash pond material in terrain unit VIIa.

At the other end of the scale, material which has been disturbed and left uncompacted (generally during construction) is also prone to erosion, e.g., new spoil heaps which have not settled to an equilibrium consolidation state.

7.1.4 Introduction of Preferential Pathways for Water Flow

Project activities which create surface depressions could form preferential paths for runoff, e.g., wheel rutting of access tracks, poorly compacted pipeline routes and foundation pads. This is particularly problematic on slopes which cause acceleration of runoff. Uncontrolled concentration of flow can cause erosion, or flows away from dams and water collection points.

Rill or gully erosion is more likely to occur within erodible soils, particularly the sodic texture contrast soils on Curtis Island, although flow concentration may result in erosion of any soil type.

7.1.5 Increased Sedimentation

Sedimentation may cause burial of vegetation, and reduce revegetation success (Alluvium, 2011). Increased sedimentation is likely downslope, downstream or down-wind of any area where erosion has been exacerbated by project activities.

7.1.6 Land Degradation Process Interaction

The processes and project activities discussed in Sections 7.1.1 – 7.1.5 often occur in combination causing exacerbation of adverse impacts. For example, loose materials that have been cleared of vegetation are particularly prone to erosion. Often, rills are initiated on bare surfaces, such as new spoil heaps. This concentrates surface runoff, increasing the likelihood of further erosion and gullying. Eroded soil is then deposited down-system (i.e., downslope or downstream).

7.1.7 Dust

Dust can be generated when surface soils lose cohesion due to surface disturbance in dry conditions. Project activities likely to cause dust generation include clearing vegetation, topsoil stripping, vehicle traffic, pipeline trenching, earthworks and if necessary blasting. Once soil loses structure and turns to dust, it is difficult to manage and is generally unsuitable for use in rehabilitation. Dust can have similar impacts to sedimentation, and may adversely affect rehabilitation success.

Soils with a fine silty surface are most prone to dust generation, in particular Soil Type 2.2 – Gradational Loams and Soil Type 3 – Texture contrast soils. These soils are dominant on Curtis Island (associated with terrain units IIIa and IIIb), especially in the proposed facilities area; on the mainland along the coast (within terrain unit IIb); and to the east of the Mount Larcom Range (associated with terrain unit VIa). Disturbance of this type of soil is likely within the LNG Plant site; TWAF 8; and the access track to the mainland tunnel launch site of the feed gas pipeline. Silty ash pond material at TWAF7 and northern section of launch site 1 is also prone to dust generation when disturbed.

7.1.8 Reduced Soil Quality

There are several activities which can cause a reduction in soil quality:

- Inversion of the soil profile and backfill materials during reinstatement can cause patchy exposure of sodic and saline sub-soils, leading to increased erodibility and irregular vegetation growth.
- Some project components will require construction materials to be imported, e.g., road base. This material is considered poor quality material for plant growth, and is likely to adversely affect rehabilitation.
- Soils within the study area are typically shallow and gravelly, with low fertility. Therefore, limited quantities of topsoil and/or subsoil may be available for rehabilitation. Stockpiling of these limited resources may further reduce their quality, particularly if not intensively managed.

7.2 Use of Rock Resources in Construction Activities

Project activities that involve construction may have an environmental impact due to the removal of rock resources. The project will require construction materials e.g., crushed rock for road pavements. These materials are a plentiful, although finite, resource within the project development area. Where construction materials have been removed, steep batter slopes are often created around the borrow pit margins, and shallow, remnant soils within the borrow areas can make revegetation difficult. The steep, bare batter slopes are likely to be prone to rill erosion and may be susceptible to landsliding.

7.3 Feed Gas Pipeline Impacts

The feed gas pipeline will be open-trenched or under bored a short distance through terrain units Ib and IIb, just south of Fishermans Landing, tunnelled under Port Curtis, and then trenched a short section from the exit pad to the LNG plant within terrain unit IIIa. Project activities and tasks specific to the construction of the feed gas pipeline may result in impacts not covered in the above generic or construction impacts. Pipeline specific tasks include:

- Trenching and under boring.
- Construction of a permanent access track to the mainland tunnel launch site.
- Use of large temporary lay down areas and tunnel entry and exit pads.
- Tunnelling beneath Port Curtis.
- Tunnel spoil disposal adjacent to the tunnel launch pad.

The feed gas pipeline may result in disturbance of compressible, saline, waterlogged or acidic soils. Differential settlement of trench backfill may occur, possibly resulting in creation of preferential surface and subsurface pathways. Storage of spoil is likely to result in compression of coastal muds. Leakage or collapse of stored tunnel spoil could cause alteration of soil chemistry and down-system sedimentation. These issues are discussed in Sections 7.3.1 – 7.3.4.

7.3.1 Disturbance of Unfavourable Soils

The coastal muds of terrain unit Ib are compressible, saline and prone to waterlogging. Tunnelling and associated activities are likely to cause significant, but localised, impact. Disturbance and oxidisation of the marine muds is likely to result in acidification through oxidisation of sulfides (Coffey Geotechnics, 2011).

7.3.2 Differential Settlement

It is likely that backfilled and filled areas will not be returned to original compaction levels, particularly as the soils in this area are compressible (soft) and prone to waterlogging. Differential settlement of fill could cause depressions or mounds to form which could potentially lead to drainage concentration and gullying or waterlogging.

7.3.3 Activation of Preferential Pathways in Subsoil

Burying a pipeline in subsoil may create a preferential pathway for subsurface flow. Water which accumulates and flows alongside the buried pipeline pathway may result in piping (tunnelling) erosion. Collapse of the subsurface void may lead to pipeline exposure.

This process may present a hazard for construction through Soil Types 2 (Clay or Loam Gradational Soils), 3 (Texture Contrast Soils) on Curtis Island, particularly where sodic conditions are encountered.

7.3.4 Tunnel Spoil Disposal

Tunnel spoil from tunnelling will be placed on the mudflats adjacent to the tunnel entrance pad, within terrain unit Ib. The coastal muds in this area are compressible and likely to be waterlogged. In addition, the spoil itself is likely to be waterlogged, and with different geotechnical and physical/chemical properties than the muds. Careful management of spoil and tail water will be required to avoid leakage causing alteration of soil chemistry; and destabilisation of spoil heaps. Spoil heap collapse could result in adverse sedimentation of adjacent mudflat areas. Potential impacts from Acid Sulfate Soils are discussed in Coffey Geotechnics (2011b).

7.4 LNG Plant Impacts

Specific tasks associated with construction of the LNG plant and associated facilities (including the construction camp) include:

- Large scale cut and fill.
- Large disturbance area.

Impacts associated with these activity-specific tasks include landform change, potential slope instability, large-scale removal of soils and down-system sedimentation. Impacts are likely to be exacerbated by the large spatial extent of disturbance. These issues are discussed in Sections 7.4.1 – 7.4.2.

7.4.1 Large-Scale Cut and Fill

Landform Change

The LNG plant design incorporates cut platforms of different elevations (between 10 mAHD and 18 mAHD) to reduce the topographic impact and spatial extent of benching and filling required.

The earthworks will result in alteration of the following landforms:

- Complete or partial removal of 5 isolated remnant hills, including most of the hill adjacent to Boatshed Point;
- Alteration of ridgelines: partial removal of ridgelines and infill of saddles.
- Infill of a large gully system and 2 large bay heads (above the intertidal zone).

The impact on the geology, landforms and soils of south-western Curtis Island will be considerable and irreversible.

Infilling of the gully system and bay heads is discussed further by Alluvium, 2011.

Slope Instability

The large area of cut required to construct the LNG plant may result in instability during and after the project (at any time following construction of cut slopes). Surficial unconsolidated deposits in the study area tend to be thin, typically with maximum depths of 1.5 m on valley floors and in gullies. Bedrock conditions are such that larger scale rock landslides (topple, side or wedge-type failures) are possible. Failures are more likely to occur under the following conditions:

- Where a relatively competent/impermeable layer underlies a relatively competent/permeable layer allowing an increase of pore-water pressures, which could trigger failure.

- Where rock defects dip towards the artificial cut, which may increase the likelihood of failure along existing weakness along foliations (bedding planes or joints). Consideration should be given to the orientation of cut batters compared with the orientation of bedrock defects.

Failure of the shallow colluvial and alluvial deposits is possible, but unlikely. Soil failures which do occur are likely to be small-scale.

Landslides, should they occur, are likely to be triggered by the prolonged, intense rainfall characteristic of the Gladstone region, with artificial over-steepening being a critical destabilising factor.

Soil Removal

The LNG plant construction will result in wholesale removal of the entire soil profile over the entire area of earthworks. Partial rehabilitation following construction and rehabilitation following decommissioning will require stockpiling of considerable quantities of material for extended periods of time and/or importing of suitable soil.

Sedimentation

The large-scale earthworks are likely to generate appreciable quantities of erodible sediment, both from existing soil and also from the finer fraction of blasting rock waste. Unless controlled by successful erosion control measures, this sediment will work down-system (downslope and downstream) until it is discharged into Port Curtis.

7.4.2 Spatial Extent

The LNG plant will disturb a large area of approximately 218 ha. It is anticipated that the localised spatial extent of disturbance and potential severity of impact is likely to be proportionately greater than other project activities.

7.5 Temporary and Permanent Infrastructure Impacts (Access Tracks)

Infrastructure is not generally anticipated to cause environmental impacts other than those outlined in Section 7.1: Generic Impacts. Specific infrastructure-related impacts will generally be related to ground disturbance, in particular erosion caused by vegetation clearance, soil compaction, drainage concentration and creation of dust. Impacts may result from earthworks required to level road corridors and lack of surface protection (particularly on temporary tracks). If haul road are located along mangrove swamps or mudflats, the soft, waterlogged mud may be compacted. These issues are discussed in Sections 7.5.1 – 7.5.3.

7.5.1 Landform Change

Where earthworks (benching or filling) are required to level road or access track corridors, impacts will be similar to those in Section 7.4.1: Large-Scale Cut and Fill, but affecting a lesser spatial extent.

Landform change may include:

- Limited modification of landforms.
- Localised dust generation.
- Possible slope destabilisation.

7.5.2 Potential Impacts from Temporary Infrastructure

Temporary infrastructure refers to access tracks built for the construction phase of the project. Temporary tracks may not have as robust a design as the permanent infrastructure, and could result in erosion if inappropriately managed.

7.5.3 Potential Impacts from Permanent Infrastructure

Permanent infrastructure refers to tracks and roads constructed for the lifetime of the project. These are generally within the footprint of the area of disturbance of project components. This includes the heavy haul roads at Boatshed Point and Hamilton Point. It is anticipated that, although permanent infrastructure will have a greater spatial and temporal influence, the surface treatment is likely to be engineered to reduce damage, as a sealed surface is proposed.

The haul road at Boatshed Point is likely to impact the coastline along the western side of the road, and could be built over the mangrove swamps and mud flats (terrain unit Ib). Should the haul road be feed built over mudflats, it is likely to have a similar impact to the tunnel launch site (see Section 7.3: Feed Gas Pipeline Impacts), with potential impacts including compaction of soft, waterlogged mud.

The access track to the feed gas pipeline mainland tunnel launch site traverses erodible soils of terrain unit IIb. This track may cause land degradation, including soil compaction, drainage concentration and creation of dust.

7.6 Temporary Workers Accommodation Facility Sites

The Temporary Worker’s Accommodation Facilities’ options are located in landscapes with markedly different characteristics. As such, the impacts to the landscape will be different. It has been assumed that no major earthworks will be required for either TWAF option.

7.6.1 TWAF 7 - Use of Reclaimed Land

TWAF 7 is located on reclaimed land within the Gladstone Urban Region. During construction and operations phases, impacts are likely to be limited to the general impacts listed in Section 5.1. However, following decommissioning, effective rehabilitation could improve the environmental values of the site, i.e., landscaping and revegetation sympathetic with natural landscapes in the locality, thus having a positive impact.

7.6.2 TWAF 8 – GQAL Impacts

Approximately 20% (9.5Ha) of TWAF 8 comprises GQAL. This site is located at the foothills of the Mount Larcom Range and does not appear to be farmed at present. However, as noted in Section 4.5: GQAL in the Study Area, the extent of GQAL is locally limited and, therefore, represents an important resource. Construction of the TWAF will temporarily remove 9.5 ha of GQAL from potential agricultural production.

The soils in the GQAL area (terrain unit VIb) are gradational, with an increase in clay content with depth. Compaction of clay soils can significantly impact long-term crop productivity. Topsoil disturbance during construction (i.e., through excavation, erosion or trafficking) is likely to result in a long-term reduction in fertility levels within footprint area.

7.7 Magnitude of Impact

The magnitude of potential impacts due to specific project activities, associated with the different project components, has been assessed by considering the following:

- Severity of Impact – considers the scale or degree of change from the existing situation as a result of the impact.
- Geographical Extent – considers if the effect is widespread, regional, local or limited.
- Duration – considers the timescale of the effect, i.e., if it is temporary, short or long term.

This section discusses the magnitude of potential impact prior to implementation of the management and mitigation measures discussed in Section 8. Table 7.1 shows the description and classifications of each of the above considerations used to assess the magnitude of impact.

Table 7.1 Impact Magnitude Descriptors and Categories

Description	Anticipated Magnitude of Impact
• Impact to the landscape either unlikely to be detectable or detectable but small-scale and unlikely to be severe. • Damage is limited in spatial extent, i.e., limited to the project activities with restricted footprint areas. • Recovery short-term, i.e., up to 3 years.	Low (L_m)
• Impact to the landscape detectable but not severe. • Damage is locally significant: project activities may have large footprints, or the impact may extend outside the project activity footprint. • Recovery is medium-term, i.e. up to 10 years.	Moderate (M_m)
• Impact to the landscape is severe, e.g., major land degradation. • Impact is regional and may be detected up to 10km or over from the project activity. • Full landscape recovery may take up to 25 years or not be possible	High (H_m)

Different project components are anticipated to have a different magnitude of impact, related to the specific environmental values of the terrain units of the study area. Sections 7.7.1 – 7.7.4 discuss the magnitude of potential impacts in relation to the different terrain units. Section 7.7.5 provides a summary of the magnitude of impact for the various project components.

7.7.1 Magnitude of Impacts from Feed Gas Pipeline

Construction of the feed gas pipeline will disturb areas of terrain unit Ib and IIb on the mainland and terrain unit IIIa on Curtis Island.

Magnitude of Impact of Feed Gas Pipeline on Terrain Unit Ib– Contemporary Coastal Flats

- Pipeline laying is likely to locally impact the soils supporting the unique coastal/marine flora and fauna of Port Curtis.

- Although the above-ground pipeline corridor is relatively limited in extent, localised disturbance is likely. In addition, stockpiled trenching and tunnelling spoil could be eroded or transported by tail water and re-deposited many kilometres away.
- Vegetation and ecosystems supported by the landscape could take many years – if not decades – to recover. Localised land degradation is, therefore, likely.

It is anticipated that the feed gas pipeline will have a **high** impact magnitude on the environmental values of terrain unit Ib. Soils which are waterlogged, compressible and saline will be disturbed. Tunnel spoil material with different properties may cause sediment or chemical contamination. The extent of disturbance will be limited. However, impacts may extend outside the project footprint and are likely to have a long-term effect on the landscape.

Magnitude of Impact of Feed Gas Pipeline on Terrain Unit IIb– Coastal Rises and Plains

- Impacts are likely to be localised, although erosion (rilling and gullying) could be triggered.
- Impacts could extend outside the site, but are likely to be minor.
- Localised land degradation is likely but is anticipated to recover within a few years.
- Recovery is anticipated to be medium term.

It is anticipated that the feed gas pipeline will have a **moderate** impact magnitude on the environmental values of terrain unit IIb. Soils which are sensitive to erosion, compression and dust generation will be disturbed, but the extent of disturbance is limited.

Magnitude of Impact of Feed Gas Pipeline on Terrain Unit IIIa – Wandilla Formation Undulating Rises and Plains

- On Curtis Island, disturbance will be limited to the feed gas pipeline right of way and associated areas (e.g., laydown areas). Impacts are not anticipated to be significant, especially when compared with the much greater impact of the LNG plant and heavy haul roads.
- Terrain unit IIIa is characterised by highly erodible sodic texture contrast soils. Although excavation will only occur along the feed gas pipeline trench, erosion could extend outside the right of way.
- Recovery is anticipated to be medium-term.

It is anticipated that the feed gas pipeline will have a **low** impact magnitude on the environmental values of terrain unit IIIa. Soils which are sensitive to erosion, compaction and dust generation will be affected, and recovery is likely to take several years, but the extent of disturbance is limited.

7.7.2 Magnitude of Impacts from LNG Plant

The LNG plant will affect terrain units Ib, IIIa and IIIb on Curtis Island. The assessment of the magnitude of impact of the LNG plant incorporates the Boatshed Point construction camp, the MOFs and laydown areas. These project components, including the LNG Plant, combine to form a single, large area of disturbance with similar impacts over the disturbed area.

Magnitude of Impact of LNG Plant on Terrain Unit Ib– Contemporary Coastal Flats

- During construction of the LNG plant, large-scale filling of two bay heads (above the intertidal zone) is proposed. This will have a major impact on the local topography, sediment dynamics and soils. The bays represent the downsystem (i.e., downslope or downstream) limits of land-based processes, which will be irreversibly altered.
- The proposed area of disturbance is large (approximately 218 ha) and impacts could extend outside this footprint.
- Full rehabilitation will not be possible: it will not be possible for the landscape to be returned to its original topography and condition.

It is anticipated that the LNG plant will have a **high** impact magnitude on the environmental values of terrain unit Ib. Activities will result in localised permanent topographic change, burial of existing soils and removal of vegetation. Full recovery will not be possible.

Magnitude of Impact of LNG Plant on Terrain Unit IIIa – Wandilla Formation Undulating Rises and Plains and Terrain Unit IIIb – Wandilla Formation Steeply Undulating Hills and Rises

- Large-scale cut-and-fill is proposed during construction of the LNG plant, involving cut and fill within lower lying Wandilla Formation areas: ridges are being cut into; saddles and gullies infilled. Over much of the site, the entire soil profile will be removed. Gullying could be triggered. Landsliding and gullying could be triggered, particularly along steep slopes (greater than 20°) of terrain unit IIIb.
- The proposed area of disturbance is large (approximately 218 ha) and impacts could extend outside this footprint, as eroded sediment could enter watercourses or be washed into bays and the marine environment of Port Curtis.
- Full rehabilitation will not be possible: it will not be possible for the impacted landscape to be returned to its original topography and condition.

It is anticipated that the LNG plant will have a **high** impact magnitude on the environmental values of terrain units IIIa and IIIb. Levelling of the site requires permanent, large scale topographic change, even in areas only used during construction (e.g., the construction camp and laydown areas). The site is characterised by erodible soils, which are prone to gullying and slope instability is possible. Eroded or disturbed sediment could enter watercourses or be washed into Port Curtis.

7.7.3 Magnitude of Impacts from Heavy Haul Roads

This section concentrated on assessing the magnitude of impact of the Boatshed Point haul road, as it may extend into terrain unit Ib. Other heavy haul road options run within terrain unit IIIa and along the fringes of terrain unit IIIb (e.g., the South Hamilton Point haul road), and are anticipated to have a lower impact. The Boatshed Point haul road will mainly impact the coastal margins of terrain unit IIIa and possibly terrain unit Ib, along the edge of Boatshed Point Construction Camp.

Magnitude of Impact of Heavy Haul Roads on Terrain Unit Ib– Contemporary Coastal Flats

- Impacts on the coastal muds and mangrove swamps are not anticipated to be significant, largely due to the limited spatial extent of disturbance, particularly when compared with the large-scale extent of the LNG plant disturbance.

- The proposed road corridor of limited spatial extent (less than 100 m wide and 0.5 km long) and impacts could extend outside the footprint.
- Full rehabilitation will not be possible: it will not be possible for the landscape to be returned to its original topography and condition.

Despite the longevity of anticipated impacts and the possibility that impacts may extend outside the road corridor, given the limited spatial extent, it is anticipated that the Boatshed Point heavy haul road will have a **low** impact magnitude on the environmental values of terrain unit Ib.

Magnitude of Impact of Heavy Haul Roads on Terrain Unit IIIa – Wandilla Formation Undulating Rises and Plains and Terrain Unit IIIb – Wandilla Formation Steeply Undulating Hills and Rises

- Some earthworks are likely, but limited to the coastal margins of 2 remnant hills (Boatshed Point and Hamilton Point). Landsliding and gullying could be triggered, particularly along steep slopes (greater than 20°) of terrain unit IIIb.
- The proposed road corridor of limited spatial extent (less than 100 m wide and 0.5 km long) and impacts could extend outside the footprint.
- Full rehabilitation will not be possible: it will not be possible for the impacted landscape to be returned to its original topography and condition.

It is anticipated that heavy haul roads will have a **moderate** impact magnitude on the environmental values of terrain units IIIa and IIIb. Permanent, but small-scale topographic change is likely to be required. The route traverses erodible soils, occasionally on steep slopes, which are prone to gullying and slope instability is possible.

7.7.4 Magnitude of Impacts from TWAF

TWAF 7 is located within terrain unit VIIa. TWAF 8 will impact small areas of terrain unit IIb, VIa and VIb.

Magnitude of Impact of TWAF 7 on Terrain Unit VIIa – Reclaimed Land and Earthworks

- Site is already artificially modified; disturbance is not anticipated to significantly increase this impact.
- Impacts could extend outside the site. However, given the rapid industrial development of the Gladstone Urban Region, adverse impacts are not anticipated to be of local significance.
- Sensitive rehabilitation following decommissioning of the TWAF could improve the environmental values of the site compared its current condition.

It is anticipated that TWAF 7 will have a **low** impact magnitude on the environmental values of terrain unit VIIa, given that the site is already significantly modified and environmental values could be improved with sensitive rehabilitation.

Magnitude of Impact of TWAF 8 on Terrain Unit IIb – Coastal Rises and Plains and VIa – Mount Larcom Undulating Hills and Rises

- Impacts are likely to be localised. The site only impacts a small area of terrain unit IIb. Erosion (rilling and gullying) could be triggered, particularly in terrain unit VIa.

- Impacts could extend outside the site, particularly in terrain unit VIa as soils can be erodible and prone to compaction and waterlogging. Impacts are likely to be minor, as slopes are shallow and it is not anticipated that steep artificial batters will be constructed. The greatest impacts are likely to be associated with trafficking of access tracks.
- Localised land degradation is likely but is anticipated to recover within a few years, as soils are not likely to require excavation (and hence reinstatement of texture contrast or gradational profiles).

It is anticipated that TWAF 8 will have a **low** impact magnitude on the environmental values of terrain units IIb and VIa. Although the soils of terrain unit IVa are erodible, impacts will be limited by shallow slopes, surface works and the small area of disturbance. Recovery is expected to be short-term.

Magnitude of Impact of TWAF 8 on Terrain Unit VIb – Mount Larcom Steeply Undulating Hills and Rises

- The facility will disturb 9.5 ha of the already limited supply of GQAL within the study area.
- Impacts are anticipated to be limited to the site, but could extend beyond the site boundaries as soils are moderately erodible.
- Localised land degradation is likely, but recovery is likely to be medium-term: although the GQAL indicates fertile soils, disturbance of soil profiles and compaction could impact recovery.

It is anticipated that TWAF 8 will have a **moderate** impact magnitude on the environmental values of terrain unit VIb. 9.5 ha of the limited GQAL in the region will be disturbed. Soils are moderately erodible and recovery is expected to be medium term.

7.7.5 Magnitude of Impacts of Launch Site 1

Launch site 1 is partially located on a former ash pond and will also impact an area of contemporary coastal flats within terrain unit VIIa.

Magnitude of Impact of Launch Site 1 on Terrain Unit VIIa – Reclaimed Land and Earthworks

- Site is already largely artificially modified; disturbance is not anticipated to significantly increase this impact. Where the site is still unmodified, impacts on the coastal muds and mangrove swamps are not anticipated to be significant, largely due to the limited spatial extent of disturbance.
- Impacts could extend outside the footprint of the site, as the area is characterised by erodible, saline soils which are prone to waterlogging and compression. However, given the rapid industrial development of the Gladstone Urban Region, adverse impacts are not anticipated to be of local significance.
- Sensitive rehabilitation following decommissioning of the launch site could improve the environmental values of the site compared its current condition.

It is anticipated that launch site 1 will have a **low** impact magnitude on the environmental values of terrain unit VIIa. Although the area is characterised by erodible, saline soils which are prone to waterlogging and compression, significant disturbance has already occurred and sensitive rehabilitation could improve the environmental values of the site.

7.7.6 Summary of Impact Magnitudes

Table 7.2 summarises the findings of the magnitude of impacts on the environmental values of the terrain units.

Table 7.2 Summary of Magnitude of Potential Impacts on Environmental Values

Anticipated Magnitude of Impact / Terrain Unit	Feed Gas Pipeline	LNG Plant	Heavy Haul Roads[1]	TWAF	Launch Site 1
Ib – Contemporary Coastal Flats	H_m	H_m	L_m	-	-
IIb – Coastal Rises and Plains	M_m	-	-	L_m[2]	-
IIIa – Wandilla Formation Undulating Rises and Plains	L_m	H_m	M_m	-	-
IIIb – Wandilla Formation Steeply Undulating Hills and Rises	-	H_m	M_m	-	-
VIa – Mount Larcom Undulating Hills and Rises	-	-	-	L_m[3]	-
VIb – Mount Larcom Steeply Undulating Hills and Rises	-	-	-	M_m[2]	-
VIIa – Reclaimed Land and Earthworks	-	-	-	L_m[3]	L_m

Notes:

1. The magnitude of impact of other road infrastructure is assessed as part of the larger project component.
2. Impact magnitude refers to TWAF 8
3. Impact magnitude refers to TWAF 7
4. "-" indicates that project activities are not proposed in the terrain unit specified.

7.8 Significance of Potential Impacts on Environmental Values

The significance of potential impacts of the LNG plant project on the geology, landform and soils environmental values of the study area has been calculated by combining the landscape sensitivity summarised in Table 5.2 with the impact magnitude summarised in Table 7.1. The product of sensitivity and magnitude given the significance of the potential impact is as per the matrix given in Table 7.3.

Table 7.3 Matrix of Significance of Potential Impacts

Magnitude of Impact	Sensitivity of Environmental Value		
	Low (L_s)	Moderate (M_s)	High (H_s)
Low (L_m)	Negligible (N)	Low (L)	Moderate (M)
Moderate (M_m)	Low (L)	Moderate (M)	High (H)
High (H_m)	Moderate (M)	High (H)	Very High (VH)

The assessment of significance of potential impacts on the environmental values of the study area has indicated that the overall sensitivity for the environmental values of all terrain units is moderate. The magnitude of potential impact for the different project components is variable, depending on the anticipated scale and extent of disturbance, and landscape characteristics of the impacted terrain unit. Therefore, the significance of potential impacts is also variable, as indicated in Table 7.4.

Table 7.4 Summary of Significance of Potential Impacts on Environmental Values

Significance of Impact / **Terrain Unit**	**Feed Gas Pipeline**	**LNG Plant**	**Heavy Haul Roads[1]**	**TWAF**	**Launch Site 1**
Ib – Contemporary Coastal Flats	M_sxH_m=H	M_sxH_m=H	M_sxL_m=L	-	-
IIb – Coastal Rises and Plains	M_sxM_m=M	-	-	M_sxL_m=L[2]	-
IIIa – Wandilla Formation Undulating Rises and Plains	M_sxL_m=L	M_sxH_m=H	M_sxM_m=M	-	-
IIIb – Wandilla Formation Steeply Undulating Hills and Rises	-	M_sxH_m=H	M_sxM_m=M	-	-
VIa – Mount Larcom Undulating Hills and Rises	-	-	-	M_sxL_m=L[2]	-
VIb – Mount Larcom Steeply Undulating Hills and Rises	-	-	-	M_sxM_m=M[2]	-
VIIa – Reclaimed Land and Earthworks	-	-	-	M_sxL_m=L[3]	M_sxL_m=L[3]

Notes:

1. The magnitude of impact of other road infrastructure is assessed as part of the larger project component.
2. Impact magnitude refers to TWAF 8
3. Impact magnitude refers to TWAF 7
4. "-" indicates that project activities are not currently proposed in the terrain unit specified.

8 MANAGEMENT AND MITIGATION RECOMMENDATIONS

This section provides management recommendations for mitigation of environmental and project impacts. The proposed measures are in accordance with the Australian Pipeline Industry Association (APIA) Code of Environmental Practice for Onshore Pipelines (2009) which recommend consideration to the following hierarchy when recommending measures:

- **Avoid**: design and plan the project so that the activity has no impact.
- **Eliminate**: remove the activity or sensitive landscape element completely.
- **Accommodate**: consider designs which reduce the impact of the activity to an acceptable level (i.e., such that it has a low significance).
- **Reduce**: implement measures to reduce the impact of the activity to an acceptable level.

8.1 Management Recommendations for All Activities

The following measures apply to all project related infrastructure including the LNG plant, feed gas pipeline, mainland and island infrastructure and facilities. These issues should be considered in all phases of the project; from construction, operation and maintenance through to decommissioning. Project activity-specific mitigation measures are discussed in Section 8.2 onwards.

8.1.1 Land Degradation Management Measures

Erosion occurs throughout the study area, although (as discussed in Section: 5.2.3: Landscape Susceptibility to Erosion) some areas are more susceptible to erosion than others. The following control measures are recommended for implementation throughout the project:

Erosion Control Measures

- The erosion control measures recommended in this section should be implemented during all phases of construction, rehabilitation and maintenance phases of the project.
- Management of drainage (i.e. measures to retard and control water flow or runoff) is key and should be considered first, then erosion and sedimentation controls (APIA, 2009).
- Erosion control measures should consider: natural and constructed drainage patterns; soil erodibility; slope steepness and length; rainfall frequency and intensity; potential flow magnitudes; vegetation cover; proximity to sensitive environments and land-use impacts.
- Disturbance should be reduced to essential areas only. Areas should be cleared progressively, with construction activities and subsequent rehabilitation activities commencing as soon as is practicable following clearance.
- Gully creation should be avoided by reducing the potential for flow concentration in soils prone to gully erosion. Gullies, once initiated, are difficult to manage (see Section 4.2.1: Landform Features). Management of aggressively eroding gully networks can require major engineering structures, which often only provide temporary solutions.
- Where practicable, roads, tracks, fencing and buildings should be placed to avoid disrupting surface runoff, which tends to accumulate along topographic lows and within surface depressions (IECA, 2008). Any activity involving ground disturbance has the potential to create surface depressions, which may concentrate or disrupt flow.

- Where the location or character of a project activity is such that runoff disruption or creation of surface depressions cannot be avoided, flow velocity-reduction/flow energy dissipation and erosion control management measures should be implemented. These could include (IECA, 2008):
    - Construction of permanent or temporary channels/drains.
    - Channels/drains should be lined with appropriate erosion matting (e.g. geofabric suitable for anticipated flow volume/velocity) and revegetation encouraged, where practicable.
    - Check dams (e.g. rock, sediment socks, straw bales) should be placed within drain channels.
- Grasses and other ground-cover vegetation should be re-established on bare areas as soon as possible following construction, especially during wetter summer months (Ecosure, 2011). This can reduce overland flow velocities, act as silt traps and stabilise the soil surface (IECA, 2008).
- If necessary, erosion control measures, such as the use of erosion matting (such as Jute Mesh) or sediment socks (sand-filled UV-resistant fabric tubes), should be considered for all project activities that disturb the ground. Soils are generally erodible and it is anticipated that these measures will be required throughout the study area.
- Erosion control measures should be designed to reduce the sediment load of runoff. This may require the construction of contour banks, detention dams or sediment settlement ponds, particularly in areas of sodic soils. Sediment detention areas may require clearance following runoff events and the accumulated sediment either stockpiled on site or within designated stockpile areas (as per Section 8.1.5: Soil Management: Spoil Storage). Alternatively, the retaining structures can be enlarged to increase their capacity.
- Erosion and sediment control, and planting and seeding rehabilitation plans should be prepared during the design phase of the project and implemented without delay following construction.

Management Measures for Erodible Sodic and Dispersive Soils

- Where practicable, sodic and dispersive soils on Curtis Island and along the fringes of the Mount Larcom Range should be avoided, especially if reworking is necessary (e.g., for earthworks and backfill).
- Adverse impacts to sodic and dispersive soils can be reduced through effective implementation of land degradation management measures. In particular, water runoff and seepage should be controlled; and protective surface cover should be established and maintained.
- Application of soil amendments should be considered for areas of particularly high sodicity as these can reduce dispersivity, waterlogging and crusting (IECA, 2008). Gypsum is commonly used, as a calcium source to replace the sodium on the soil exchange complex (Raine and Loch, 2003). Where considered appropriate, gypsum and other amendment application rates should be assessed during the design phase of the project. Amendments are generally applied to the topsoil prior to stripping to allow thorough mixing prior to stockpiling. Gypsum is slow to disperse but can leach from upper soil layers over time (Raine and Loch, 2003). Periodic reapplication in conjunction with deep ripping may, therefore, be required following rehabilitation (see Section 8.4: Inspection and Maintenance Programme).
- Soil profiles should be reinstated to their pre-disturbance profiles, where practicable. Where topsoils are not sodic, they can be used to cap the sodic subsoils. This is particularly important on steeper slopes (IECA, 2008; see Section 8.1.7: Rehabilitation).

Dust Control Measures

- Land disturbance time should be reduced as far as is practicable.
- Revegetation or rehabilitation should be undertaken as soon as is practicable to reduce the exposure time of bare soil.
- Water can be sprayed onto exposed soils to reduce dust generation (APIA, 2009). Water should be of good quality (i.e., with an electrical conductivity (EC) comparable to that of typical irrigation water used in the locality) and not sprayed as concentrated flow.
- Integrity of access tracks should be maintained, with regular grading and wetting (using water trucks) during intensive operations such as construction and maintenance.
- Appropriate site vehicle weight and speed restrictions should be implemented (APIA, 2009).

8.1.2 Timing of Disturbance

During wetter periods (between December and February), appropriate erosion control measures should be implemented to manage the anticipated increase in erosive runoff (as discussed in Section 8.1.1: Land Degradation Management Measures). This will reduce the likelihood of erosion and project delays due to soft, slippery soils.

8.1.3 Management of Topographic Constraints: Steep Slopes and Undulating Ground

Steep slopes and undulating ground are anticipated to present particular management issues, in particular associated with slope instability, and surface water runoff and resultant soil erosion (particularly within the erodible soils of terrain units IIIa and IIIb on Curtis Island). In general, the project components generally avoid or eliminate steep slopes (the latter through removal of steep hills). However, there are areas where steep slopes will still be present within the Curtis Island sites. Localised steep slopes (greater than 15°) and areas dissected by gully networks are anticipated to present particular issues along the side slopes of Hamilton Point traversed by the heavy haul road and in the northeast corner of the LNG Plant site, respectively.

Within the localised areas where steep slopes cannot practically be avoided, the project design should incorporate measures to reduce land degradation. Equally, slopes should not be created steeper than is appropriate for the material encountered. Coffey Geotechnics have carried out a geotechnical assessment of the LNG plant site, and provided the following recommendations regarding maximum cut batter slopes (which are given as a guide only and are subject to revision):

- In alluvium and extremely weathered bedrock, batter slopes should not exceed 1V:2H. The exception being during construction of temporary batters of less than 4 m in height which are only anticipated to be required during periods of low rainfall. In these cases batter slopes of 1V:1H may be adopted.
- In all other materials, batter slopes should not exceed 2V:1H, with a shallower section of 1V:2H to account for loose or variable material near the crest. This geometry assumes that machinery is kept at least 4 m from the batter crest.
- Where batters exceed 10 m in height 3 m wide benches at 10 m intervals should be incorporated.
- Batter slopes should incorporate drainage measures as per the location and design recommendations given by Coffey (2011).

It is recommended that, prior to detailed design of project components, detailed geotechnical ground investigations are carried out to assess site-specific ground conditions. Geotechnical ground investigations should be designed with consideration of the geological variability in type and structure.

8.1.4 Soil Salinity

Potential management strategies are as follows:

- Prior to major earthworks, ground investigations should be carried out in soils prone to salinity (i.e., terrain unit Ib and coastal areas of terrain units IIb and IIIa), to establish the depth at which saline conditions occur.
- Excavated saline subsoil should be capped with suitable topsoil material when backfilling. This will support plant growth and provide a less-hostile medium for plant roots during establishment.
- Stockpiled saline subsoil should be bunded both up- and downstream to reduce runoff ponding and salt ingress.

8.1.5 Soil Management

The following section provides recommendations for management of soil to enable conservation of pre-disturbance characteristics, soil quality and to enhance rehabilitation potential.

Topsoil Stripping Management

Topsoil should be stripped in areas where soil disturbance is planned to provide material for rehabilitation. Prior to disturbance, the following management measures should be implemented:

- Quantify soil type, depth and resources.
- Establish handling method.
- Characterise the suitability of soil resources for rehabilitation works.
- Formulate project-specific stripping guidelines, including the nomination of appropriate depths, scheduling, location of areas to be stripped, and amendment application rates, where appropriate.

During soil stripping, the following management measures should be implemented:

- Exclude vehicular traffic from areas where soils are to be stripped, where practicable.
- Exclude traffic from soils that are sensitive to structural degradation and restricted to designated access tracks, where practicable.
- Reduce vegetation clearance.
- Use loaders and trucks, rather than scrapers, to reduce soil structure degradation.
- Stockpile soils in a manner that does not compromise the long-term viability of the soil resource, as discussed below.

Topsoil and Spoil Storage

During the project, excavation will produce spoil which requires short to long term storage for use in later rehabilitation activities. Soils should be stockpiled in a manner that does not compromise the long-term viability of the soil resource, as follows:

- Designate project component-specific stockpile locations out of work areas. These areas should be clearly marked.
- Stockpiles should be located away from watercourses and drainage lines (APIA, 2009). They should not be located in areas which may dissect ecosystem corridors or damage adjacent vegetation.
- Topsoil, subsoil and earthworks or sediment trap spoil should each be stored in separate stockpiles with consideration to soil type and salinity levels (APIA, 2009).
- Organic matter should be mulched into soil prior to stripping (APIA, 2009).
- Where necessary, an appropriate soil ameliorant should be applied to dispersive (sodic) soil stockpiles (likely on Curtis Island (LNG Plant) and along the fringes of the Mount Larcom Range (TWAF 8)).
- Stockpiles should be generally no more than 2m high, in order to reduce problems associated with anaerobic conditions and poor nutrient cycling. Where it is anticipated that long-term stockpiling is required, the height should be reduced to 1m, if space allows (Strohmayer, 1999). Stockpiles that are anticipated to be *in situ* for several years require intensive management to avoid loss of fertility (discussed further in Section 8.3: LNG Plant Recommendations).
- Stockpiles should be constructed with an appropriate patter slope and a “rough” surface to reduce erosion hazard, improve drainage and promote revegetation.
- Erosion and drainage control measures should be implemented, such as the installation of silt fences or bunds around stockpiles to control potential loss of stockpiled soil through erosion prior to vegetative stabilisation.

Indicative Topsoil Stripping Depths

Indicative depths of topsoil suitable for rehabilitation within the soils identified in the study area are outlined in Table 8.1:

Table 8.1 Indicative Soil Resources

Soil Group	Indicative Stripping Depth (m)	Notes
1. Marine Clays	0.0	Unsuitable for use in rehabilitation.
2.1 Gradational Clay Soils	0.1-0.3	Suitable for use in rehabilitation. Topsoil depth is variable across the profiles within this group.
2.2 Gradational Loam Soils	0.1-0.3	
3 Texture Contrast Soils	0.2-0.3	Suitable to use in rehabilitation. However, stripping these soils could expose dispersive subsoil. Subsoil stabilisation may be required. Avoid collecting and mixing subsoil with topsoil.
4. Alluvial Sands	0.2-0.3	Suitable for use in rehabilitation. Amelioration may be required to improve chemical properties and nutrient levels.
5. Skeletal, Rocky or Gravelly Soils	0	Skeletal soils have limited available topsoil.

8.1.6 Backfilling

Excavation backfilling should be managed as follows:

- In all locations, excavated soil should be replaced in the order in which it was excavated. Soil profiles should be recreated as far as is practicable. Subsoil should not be present at the surface.
- The land surface should be reinstated to pre-construction contours, as far as is practicable. Soil mounding to allow for settling may be required in some areas.
- Soils should be compacted to pre-construction levels, where possible.

8.1.7 Rehabilitation

Following decommissioning of the project components, rehabilitation should be carried out, where practicable, as follows:

- Surface structures should be removed from the site.
- Soils should be replaced in the order of excavation, where practicable, to increase the success of rehabilitation measures. Subsoil should not be present at the surface.
- Where possible, ground levels should be restored to their pre-existing elevation.
- Where possible, drainage lines should be re-established.
- Medium to long-term erosion control measures should be implemented (see Section 8.1.2: Land Degradation Management Measures).
- Rehabilitation should be sympathetic to pre-disturbance land-use, where practicable, particularly in GQAL areas.
- A planting and seeding plan should be developed for vegetation re-establishment, with the ultimate goal of establishing self-sustaining native vegetation.

8.1.8 Construction Materials – Borrow Pits

Should borrow pits be used as a source of construction materials during the project, management measures should be implemented as follows:

- Borrow pits should be located away from problem soil areas (e.g., steep slopes).
- If significant quantities of material are required, the excavations should be designed to direct surface water runoff to managed control points.
- Erosion control measures should be implemented, both within the pits and upslope, to avoid overland flow and sediment entering the pits.
- Pits which expose sodic or saline subsoils should be bunded.
- Rehabilitation of pits should be carried out as soon as is practicable to limit ongoing degradation. This should include:
    - Ground surface re-profiling avoiding the creation of steep, unstable slopes;
    - Topsoil respreading;
    - Revegetation;
    - Erosion control measures, including erosion bunds and contour ripping.

8.2 Feed Gas Pipeline Management Recommendations

Management recommendations specifically related to the feed gas pipeline construction are as follows:

8.2.1 Erosion

Erosion may be reduced by adopting the management practices below:

- Grading, trenching and backfilling should be carried out as rapidly as is practicable, to reduce erosion.
- During construction, vehicle access to the feed gas pipeline right of way should be provided at regular intervals to reduce compaction and formation of wheel ruts along the right of way.
- Cleared vegetation should be placed along the edge of working areas to control runoff.

8.2.2 Trench Stability

Soft, waterlogged soils, especially within terrain unit Ib, may require battering back or shoring of trench walls to reduce the likelihood of trench collapse. A hazard analysis-based risk assessment of the trench geometry or specification of trench support should be carried out.

8.2.3 Backfill and Padding

Infilling of the feed gas pipeline trench should be managed as follows:

- Appropriately-sized trench bedding and padding material should be used to avoid damage to the pipe coating.
- If practicable, saline, acidic or sodic soils should not be used for backfill padding.
- Soils should be replaced in the order of excavation, where practicable, to increase the success of rehabilitation measures.
- Backfill should be compacted to the level of the surrounding ground (or mounded, in areas of compressible soils), to reduce trench subsidence and concentration of flow. Regular, ongoing inspection of the feed gas pipeline corridors should be carried out following construction, and subsidence depressions infilled and compacted to the level of the surrounding ground.
- Subsoil should not be exposed at the ground surface following backfilling. Any subsoil left exposed should be capped with topsoil.

8.2.4 Rehabilitation of Feed Gas Pipeline Right of Way

The feed gas pipeline should be rehabilitated as follows:

- Where possible, mulched surface vegetation should be spread over the right of way following backfilling to reduce rainsplash erosion.
- Vegetation coverage should be re-established and maintained over the feed gas pipeline easement.

8.2.5 Tunnel Spoil Disposal

A form of barrier, retaining structure and revetment should be constructed to retain the tunnel spoil. Any construction should consider hazards from seawater inundation during extreme storm events and the anticipated sediment quantity. Acid sulfate management measures should be implemented as per recommendations in Coffey Geotechnics (2011). Drainage should be incorporated within and adjacent fill that has been placed behind the barriers to manage any water within the sediment that has not been removed during processing. This water may be acidic and saline, requiring storage in evaporation dams lined with impermeable material to prevent leakage. The residue should then be removed from the site during rehabilitation.

8.3 LNG Plant Management Recommendations

The LNG plant area (including the construction camp and MOF) will have an approximate maximum disturbance area of about 218 ha. Management and mitigation measures at the LNG plant should be implemented at an appropriate scale. The following management measures specifically related to the LNG plant are recommended:

- A form of barrier should be constructed to act as a sediment trap, reducing the quantity of sediment entering the Port Curtis marine environment. These walls should be constructed prior to construction commencement at the downstream end of the land-based systems, i.e., the bay heads, above the usual intertidal zone. The barrier should consider hazards from seawater inundation during extreme storm events and the anticipated sediment quantity, and regular removal of sediment may be required. If the latter is the case, specific areas of the LNG plant should be designated to stockpile the spoil (see Section 8.1.5: Soil Management and below).
- Large scale stripping of topsoil should be undertaken prior to construction. Soil stockpiles created from this activity are likely to be stored for extended periods of time. Therefore, stockpiles should be no more than 2 m high (although this height should be reduced to 1m, if space allows), and mulched, fertilised and seeded to maintain soil structure, organic matter and microbial activity. The stockpiles should be deep ripped regularly to aerate the soil. It is likely that, even if available topsoil is successfully stockpiled, this material will be insufficient to rehabilitate the site. Importing of comparable topsoil is, therefore, likely to be required.
- Water and sediment control measures should be implemented, particularly prior to and during construction. In addition, long-term management measures should also be considered to control runoff and sediment load throughout the lifetime of the facilities, including:
    - Construction of sediment control dams to reduce the quantity of sediment entering watercourses.
    - Installation of energy dissipation structures at drainage outlets, especially those entering natural watercourses.
- Low-lying areas of the LNG plant could be subject to localised flash-flooding, which are generally high-velocity erosive flows. Contour banks may be required to slow surface water flow and reduce erosion in sensitive areas.

As the proposed LNG plant requires extensive earthworks, the following measures should also be considered:

- In cut and fill locations, consideration should be given to the thickness of colluvium, and orientation and gradient of cut batters compared with the orientation of bedrock defects to reduce the possibility of slope destabilisation. Site-specific assessments are recommended prior to final design and construction, particularly in areas with steep slopes.
- Fill selection should be developed alongside foundation assessment, considering anticipated loads and the serviceability limit state.

- Soils which have moderate swell/shrink properties (e.g., surface movements of between 10mm and 50mm), i.e., those which have clay-rich sub-soils, should have controlled moisture content when used as backfill to reduce differential erosion or settlement (Coffey Geotechnics, May 2009). Site-specific assessment will be required to locate soils of this nature.
- Site grade should be designed to readily shed water and prevent ponding around footings and other movement-sensitive areas.

8.3.1 Rehabilitation/Decommissioning of LNG Plant Area

The LNG plant area, with its large footprint, is likely to require intensive management during decommissioning to achieve successful rehabilitation. It is not anticipated that this area will be rehabilitated to pre-disturbance use. However, measures can be implemented which will increase the likelihood of successful rehabilitation, including:

- Assessment of soil contamination in accordance with regulatory requirements.
- The area should be reprofiled to limit future slope instability and erosion, and which does not require a greater level of maintenance than the pre-disturbance landscape.
- Surface drainage lines should be re-established, where practicable.
- Topsoil should be reinstated, if practicable, and measures taken to promote vegetation establishment as sections of the facility and associated components become redundant (e.g., temporary work areas, laydown areas and construction camps) and during final decommissioning.
- Sediment control dams should remain in place until suitable vegetation coverage in the disturbance area is achieved. Once an acceptable runoff quality can be achieved, sediment control dams should be filled and remoulded to pre-disturbance levels, where practicable.

The management measures outlined in Section 8.1: Management Recommendations for All Activities are suitable for the TWAF; laydown areas; and construction, operation and rehabilitation of permanent and temporary infrastructure, such as access tracks.

8.4 Inspection and Maintenance Programme

Erosion is a natural process which is likely to occur throughout the life of the project, even with the implementation of management strategies.

Disturbed and rehabilitated areas should be monitored inspected regularly for both short- and long-term adverse landform change, particularly in areas which are sensitive to erosion. Defects should be remediated as soon as is practicable. Landform change can occur rapidly, especially during intense storms or prolonged rainfall. Inappropriate land management can also contribute to rapid change. Inspection of sensitive areas should be considered after each intense rainstorm. The monitoring inspection schedule should, therefore, reflect the likely rate of change and vary accordingly. Monitoring should also be carried out in accordance with the rehabilitation (warranty) period or at 3 monthly for first year post construction and annually thereafter until rehabilitation is considered successful as per established performance criteria.

Monitoring inspection should include:

- Location and type of erosion.

- Settlement of backfill over pipelines feed gas pipeline and other buried services.
- Soil tests (exchangeable sodium percentage and electrical conductivity) in sensitive areas to assess sodicity and operations-related salinity.
- Erosion rates.
- Effectiveness and integrity of erosion control measures.
- Runoff water quality to indicate the quantity of material being eroded, transported and then deposited down-system.

Maintenance of defects observed during the monitoring should be routinely carried out, including:

- Repair of erosion-control structures.
- Removal of sediment build-up behind sediment trap erosion control measures, to maintain retention capacity.
- Reinstatement of eroded or subsided soil or landforms.
- Re-levelling within areas of differential settlement over feed gas pipelines and other buried services.
- Revegetation of areas where ground coverage is inadequate.

In addition to monitoring and maintenance, it is recommended that performance criteria are set to indicate successful rehabilitation. The main target should be to produce a safe, non-polluting landform with self-sustaining soil fertility and a low stability hazard. It is recommended that performance criteria should include:

- Creation of quasi-stable landforms which reduce erosion as far as is practicable. Erosion control measures must remain effective in the long-term.
- A landform which reduces the likelihood of accident and injury.
- A non-polluting environment which reduces suspended solids in runoff water to pre-disturbance levels, as far as is practicable.
- Self-sustaining soil fertility, such that nutrient cycling promotes consistent vegetation cover. The site should be self-sustaining for its designated land-use, as far as is practicable, with no management inputs required over and above those in adjacent undisturbed areas.
- Preservation or improvement of soil chemistry such that soil nutrient levels can support vegetation; pre-disturbance soil pH and electrical conductivity levels can be achieved; and soil sodicity can be reduced, where appropriate.

A holistic approach is recommended when defining and monitoring reporting performance criteria within the context of this study. This will assist in the creation of a balanced rehabilitated landform and environment.

Lessons learnt during initial phases of the project regarding the success of various erosion control measures should be assessed and incorporated into subsequent phases. This strategy should limit repetition of ineffective management and mitigation measures.

9 RESIDUAL IMPACTS

This section of the report assesses the significance of the residual impacts of the LNG plant on the environmental values of the study area. Residual impact as been assessed assuming successful implementation of the recommended management and mitigation measures outlined in Section 8: Management and Mitigation Recommendations. The residual impact, therefore, reflects the significance of impacts, such as land disturbance and soil disturbance (whether physical or chemical), subsequent to implementation of these measures.

The proposed construction, operation and maintenance, and decommissioning activities will disturb and, in some instances, remove landforms and soils. Properly implemented, the proposed management and mitigation measures, and inspection program, will ensure landforms (existing and resulting) and soils (in-situ and reinstated) will be stable and successfully rehabilitated.

The residual impacts, therefore, reflect the extent to which subsequent erosion of formed batters, embankments and drainage channels, or chemical imbalances in reinstated soils affect the environmental values of the adjacent landforms and soils.

The sensitivity of the environmental values within the study area will remain constant throughout the project, except where project activities require site levelling, effectively removing that environmental value. This may cause localised changes in slope steepness, which could either increase or decrease the sensitivity. However, assuming the recommended rehabilitation performance criteria are adopted, the significance of this change in sensitivity is anticipated to be negligible. The residual impacts of the Arrow LNG Plant project are, therefore, controlled by the magnitude of impact following successful implementation of the management and mitigation measures. The magnitude of residual impacts of each of the project components is assessed in Sections 9.1.1 – 9.1.6.

9.1 Magnitude of Residual Impact

9.1.1 Magnitude of Residual Impacts from Feed Gas Pipeline

Construction of the feed gas pipeline will disturb areas of terrain unit Ib and IIb on the mainland and terrain unit IIIa on Curtis Island.

Magnitude of Residual Impact of Feed Gas Pipeline on Terrain Unit Ib– Contemporary Coastal Flats

- The sensitive Port Curtis coastline will be disturbed, but the extent of disturbance is not extensive.
- Impacts will be limited to the footprint of the site and spoil areas.
- Recovery times are likely to be short-to-medium-term, and will be dependent on the physical and chemical properties of the introduced soils.

It is anticipated that the feed gas pipeline will have a **low** residual impact magnitude on the environmental values of terrain unit Ib. Measures limiting erosion, compaction and leakage of contaminated tail water will reduce land degradation and recovery times to low levels.

Magnitude of Residual Impact of Feed Gas Pipeline on Terrain Unit IIb– Coastal Rises and Plains and Terrain Unit IIIa – Wandilla Formation Undulating Rises and Plains

- Impacts will be limited to the footprint of the site.
- Recovery is anticipated to be short-term.

It is anticipated that the feed gas pipeline will have a **low** residual impact magnitude on the environmental values of terrain units IIb and IIIa, given the limited spatial extent of disturbance. Sympathetic design, construction techniques, erosion-control measures and rehabilitation plans will reduce the magnitude of impact to low levels.

9.1.2 Magnitude of Residual Impacts from LNG Plant

The LNG plant will affect terrain units Ib, IIIa and IIIb on Curtis Island.

Magnitude of Residual Impact of LNG Plant on Terrain Unit Ib – Coastal Rises and Plains, IIIa – Wandilla Formation Undulating Rises and Plains and IIIb – Wandilla Formation Steeply Undulating Hills and Rises

- Impacts will be limited to the footprint of the site.
- Although it will not be possible the landscape to be returned to its original topography and condition, rehabilitation of topographic change will aim to produce a stable, safe, non-polluting landform with self-sustaining soil fertility. Recovery times are anticipated to be medium-term, given the large scale of disturbance.

It is anticipated that the LNG plant will have a **moderate** residual impact magnitude on the environmental values of terrain unit Ib, IIIa and IIIb. Implementation of erosion- control plans and sympathetic design, construction techniques and rehabilitation plans will reduce the magnitude of impact. The topography of southwestern Curtis Island will be permanently altered, but to a sustainable new landform, with self-sustaining soils.

9.1.3 Magnitude of Residual Impacts from Heavy Haul Roads

The Heavy Haul Roads will mainly impact terrain unit Ib and the coastal margins of terrain unit IIIa.

Magnitude of Residual Impact of Heavy Haul Roads on Terrain Unit Ib – Coastal Rises and Plains, IIIa – Wandilla Formation Undulating Rises and Plains and IIIb – Wandilla Formation Steeply Undulating Hills and Rises

- Impacts will be limited to the road corridor.
- Although it will not be possible the landscape to be returned to its original topography and condition, rehabilitation of topographic change will aim to produce a stable, safe, non-polluting landform with self-sustaining soil fertility. Recovery times are anticipated to be medium-term, given the large scale of disturbance.

It is anticipated that the heavy haul roads will have a **low** residual impact magnitude on the environmental values of terrain unit Ib, IIIa and IIIb. The spatial extent of permanent topographic change will be small, and implementation of sympathetic design, construction techniques, erosion-control measures and rehabilitation plans will reduce the magnitude of impact to low levels.

9.1.4 Magnitude of Residual Impacts from TWAF

TWAF 7 is located within terrain unit VIIa. TWAF 8 will impact small areas of terrain unit IIb, VIa and VIb.

Magnitude of Residual Impact of TWAF 7 on Terrain Unit VIIa – Reclaimed Land and Earthworks

- Site is already artificially modified; impacts are not anticipated to significantly increase this impact.
- Impacts will be limited to the footprint of the site.
- Sensitive rehabilitation following decommissioning of the TWAF could improve the environmental values of the site compared its current condition.

It is anticipated that TWAF 7 will have a **low** impact magnitude on environmental values of terrain unit VIIa. Implementation of sympathetic design, construction techniques and erosion-control measures will maintain the low magnitude of impact. Sensitive rehabilitation plans could improve the environmental values of the site.

Magnitude of Residual Impact on TWAF 8 on Terrain Unit IIb – Coastal Rises and Plains and VIa – Mount Larcom Undulating Hills and Rises

- Impacts will be limited to the footprint of the site.
- Localised land degradation is likely but is anticipated to recover within a few years.

It is anticipated that TWAF 8 will have a **low** residual impact magnitude on the environmental values of terrain units IIb and VIa. Implementation of sympathetic design, construction techniques and erosion-control measures will maintain the low magnitude of impact.

Magnitude of Residual Impact of TWAF 8 on Terrain Unit VIb – Mount Larcom Steeply Undulating Hills and Rises

- The facility will disturb 9.5 ha of GQAL within the study area. However, impacts are anticipated to be minor and the percentage of regional GQAL affected will not be extensive.
- Impacts will be limited to the footprint of the site.
- Recovery is anticipated to be short-term.

It is anticipated that TWAF 8 will have a **low** residual impact magnitude on the environmental values of terrain unit VIb. The limited spatial extent of GQAL disturbance, and implementation of sympathetic design, construction techniques, erosion-control measures and rehabilitation plans will reduce the magnitude of impact to low levels.

9.1.5 Magnitude of Impacts of Launch Site 1

Launch site 1 is partially located on a former ash pond and will also impact an area of contemporary coastal flats within terrain unit VIIa.

Magnitude of Impact of Launch Site 1 on Terrain Unit VIIa – Reclaimed Land and Earthworks

- Site is already largely artificially modified; disturbance is not anticipated to significantly increase this impact. Where the site is still unmodified, impacts on the coastal muds and mangrove swamps are not anticipated to be significant, largely due to the limited spatial extent of disturbance.
- Impacts could extend outside the footprint of the site, as the area is characterised by erodible, saline soils which are prone to waterlogging and compression. However, given the rapid industrial development of the Gladstone Urban Region, adverse impacts are not anticipated to be of local significance.
- Sensitive rehabilitation following decommissioning of the launch site could improve the environmental values of the site compared its current condition.

It is anticipated that launch site 1 will have a **low** impact magnitude on the environmental values of terrain unit VIIa. Implementation of sympathetic design, construction techniques and erosion-control measures will maintain the low magnitude of impact. Sensitive rehabilitation plans could improve the environmental values of the site.

9.1.6 Summary of Residual Impact Magnitudes

Table 9.1 provides a summary of the magnitude of residual impact on terrain units affected by the project components of the Arrow LNG Plant.

Table 9.1 Summary of Significance of Residual Impacts on Environmental Values

Significance of Impact	Feed Gas Pipeline	LNG Plant	Heavy Haul Roads[1]	TWAF	Launch Site 1
Terrain Unit					
Ib – Contemporary Coastal Flats	$M_sxL_m=L$	$M_sxM_m=M$	$M_sxL_m=L$	-	-
IIb – Coastal Rises and Plains	$M_sxL_m=L$	-	-	$M_sxL_m=L$[2]	-
IIIa – Wandilla Formation Undulating Rises and Plains	$M_sxL_m=L$	$M_sxM_m=M$	$M_sxL_m=L$	-	-
IIIb – Wandilla Formation Steeply Undulating Hills and Rises	-	$M_sxM_m=M$	-	-	-
VIa – Mt. Larcom Undulating Hills and Rises	-	-	-	$M_sxL_m=L$[2]	-
VIb – Mt. Larcom Steeply Undulating Hills and Rises	-	-	-	$M_sxL_m=L$[2]	-
VIIa – Reclaimed Land and Earthworks	-	-	-	$M_sxL_m=L$[3]	$M_sxL_m=L$[3]

Notes:

1. The magnitude of impact of other road infrastructure is assessed as part of the larger project component.
2. Residual Impact Magnitude refers to TWAF 8

3. Residual Impact Magnitude refers to TWAF 7
4. "-" indicates that project activities are not currently proposed in the terrain unit specified.

9.2 Significance of Potential Residual Impacts

The study findings indicate that, despite the variability of ground conditions and impacts, providing the recommended management and mitigation measures are successfully implemented, the residual impact can be limited to tolerable levels.

The overall sensitivity for the environmental values of all terrain units remains moderate, as this is a constant. The overall magnitude of potential residual impact of project components except the LNG plant was assessed to be low. The magnitude of potential residual impact of the LNG plant was assessed to be moderate due to the large scale earthworks, which will cause major topographic and landscape system change, including major localised disruption or removal of landforms and soils. However, successful rehabilitation will produce a stable, safe, non-polluting landform with self-sustaining soil fertility and, thus, long-term adverse impacts will be mitigated.

Therefore, the significance of potential impacts is low for the majority of the study area. At the LNG plant the significance of potential impacts is moderate.

10 CUMULATIVE IMPACT

This section discusses the anticipated cumulative significance of impacts to the geology, landform and soils of the study area and region. The Arrow LNG Plant project is only one of many similar projects which could impact the study area. In particular, proposals to construct other LNG plant and associated facilities adjacent to the LNG plant site discussed in this study.

10.1 Cumulative Assessment Baseline

The Gladstone LNG (GLNG) and Queensland Curtis LNG (QCLNG) projects have been included in the baseline, as they have already been approved by the Queensland Coordinator-General. A financial investment decision to proceed on these projects has been made, and work has commenced on their sites. Both projects involve construction of a gas pipeline from the Surat Basin to Gladstone, and development of LNG facilities along the southwestern coastline of Curtis Island. These activities will involve major topographic alteration of this area of Curtis Island and regional impacts along the pipeline routes. Although these projects have commenced and are, therefore, included in the baseline for assessment of cumulative impact, they are anticipated to affect the landscape of the region to a greater extent than the LNG plant project. These projects are, therefore, anticipated to affect the significance of cumulative impacts to the landscape at a regional level, as discussed in Sections 10.1.1 and 10.1.2. However, the impacts are spatially separate from the Arrow LNG plant site and, therefore, impacts will not be cumulative at the site level.

10.1.1 Regional and Site-Level Impacts of Projects Considered for the Cumulative Impact Baseline

The potential residual impacts of the GLNG and QCLNG projects are not specifically considered in their relevant specialist reports. However, sufficient information is provided to infer the significance of residual impacts. None of the reports discuss the impact of major site levelling on the geology, landforms and soils of Curtis Island to any great length.

Assessed Residual Impacts of GLNG Project

The GLNG buried gas pipeline runs from the Surat Basin crossing into the Arrow LNG Plant study area adjacent to Fishermans Landing, then crossing the Narrows onto Curtis Island. The pipeline then runs adjacent to the Spine to the LNG facility adjacent to the Arrow LNG Plant. URS (2009) has assessed the GLNG project using a constraints approach to infer impact (i.e., low constraints are inferred to produce low impacts) and provided management and mitigation measures to limit these impacts. An assessment of residual impact is not provided, but the significance of residual impacts can be inferred based on the level of recommended management measures (i.e., further detailed studies recommended) and severity of impact. These residual impacts are assessed as follows:

- Land erosion, particularly on sloping land on Curtis Island.
- Dust creation and wheel rutting (causing erosion) due to trafficking of access tracks.
- Gully and piping erosion of dispersive, sodic soils.
- Adverse impacts to plant growth and soil chemistry as a result of increasing groundwater levels in saline areas of Curtis Island.
- Embankment construction or filling over soft, saturated soils (i.e. marine muds).

The significance of these residual impacts is inferred to be low, as no mention is made of anticipated issues following implementation of management and mitigation measures.

Assessed Residual Impacts of QCLNG Project

The QCLNG buried gas pipeline runs from the Surat Basin along a similar corridor to the GLNG pipeline: across the mainland and the Narrows, then adjacent to the Spine on Curtis Island to an LNG facility. The LNG facility is sandwiched between the GLNG LNG facility to the north, and the Australia Pacific LNG facility to the south (see Table 10.1). The impact assessment of the pipeline (Houghton Environmental Management, 2009) is constraint-based, with no qualitative assessment of impact. The assessment of the LNG facility (ERM, 2009) concentrates on a description of the existing environment and provides little analysis of impact. Residual impacts have, therefore, been inferred from information contained in these reports, as follows:

- Gully and sheetwash erosion, particularly in steep areas and associated with large-scale cut and fill. The significance of this residual impacts is inferred to be moderate, as site levelling is anticipated to generate over 6 million m^3 of material.
- Dust generation due to trafficking of access tracks, particularly during construction, and inferred to be of low significance.

10.2 Projects Considered for Cumulative Residual Impact Assessment

There are many other projects currently proposed in the Gladstone area, but these are not anticipated to impact the Study Area from a geology, landform and soils perspective. Those projects considered for the cumulative impact assessment and the significance of their potential impacts summarised In Table 10.1.

Table 10.1 Projects Considered for the Cumulative Impact Assessment

Project and Relevant Study	Activities Anticipated to Interact with Arrow LNG Plant project	Assessed Residual Impact
Australia Pacific LNG Project (APLNG) WorleyParsons (2010)	Feed gas pipeline supplying LNG from the Surat Basin, crossing to an LNG plant at Laird Point (north of the Arrow LNG facility) on Curtis Island. LNG Plant requires large-scale levelling (cut and fill).	The report takes a constraints and risk-based approach. With management and mitigation measures recommended to address potential impacts. Only residual risks assessed as being “medium” or above are included below. Potential residual impacts, and the risk rating, include: • Moderate risk of slope Instability, soil destabilisation, changes to drainage and sedimentation (inferred from comment regarding reduction in water quality) resulting from landform modification; • Moderate risk of impacts to soil resources resulting from poor site management (e.g. poor or improper management implementation), resulting in soil erosion, poor rehabilitation potential and dust generation.
Arrow Surat Pipeline Project (formerly Surat Gladstone Pipeline Project) AECOM (2009)	Pipeline running from Surat Basin to Gladstone will have laterally restricted but regional impacts. May have some shared laydown or stockpile areas with Arrow LNG Plant.	Potential impacts include erosion associated with sodic and dispersive soils, particularly associated with steep slopes and high-banked watercourses, necessitating effective erosion control measures. Residual impacts are not specifically addressed, but it is inferred that the significance of potential residual impacts will be low.

Project and Relevant Study	Activities Anticipated to Interact with Arrow LNG Plant project	Assessed Residual Impact
Central Queensland Pipeline Project	Pipeline running from Bowen Basin to Gladstone will have laterally restricted but regional impacts.	Residual impacts related to geology, landform and soils are not anticipated to interact with the residual impacts of the Arrow LNG Plant at the site or regional level, largely due to lack of spatial overlap and/or stringent adoption of suitable management and mitigation measures.
Wiggins Island Coal Terminal Project	Project is within the artificially disturbed Gladstone area or offshore.	
Gladstone Steel Plant Project	Project is not anticipated to significantly impact the study area in the vicinity of Arrow LNG Plant project activities.	
Moura Link-Aldoga Rail Project	Construction of maintenance yard at Aldoga and new rail line between Aldoga and Yarwun will cause localised and laterally restricted but regional impacts.	
Gladstone-Fitzroy Pipeline Project	Pipeline running from Laurel Bank to Yarwun will have laterally restricted but regional impacts.	
Gladstone LNG Project (Fishermans Landing)	Project is within the artificially disturbed Fisherman's Landing area or offshore.	

10.3 Cumulative Impact Triggers

Specific project activities associated with the different phases of the assessed projects will contribute to the cumulative impact within the study area. These activities are not specifically discussed in the relevant EIS reports, but are indirectly referred to within constraints and impact assessments. The activities that are likely to contribute to the cumulative impact within the study area are as follows:

- Pipeline-related activities:
    - Route preparation (vegetation clearance, soil stripping, earthworks, etc.).
    - Trenching on land and tunnelling beneath Port Curtis and the Narrows.
    - Use of temporary laydown areas and access tracks.
    - Maintenance during use.
    - Reinstatement (backfilling, rehabilitation).

- Activities associated with the LNG plants and associated facilities:
  - Site preparation (vegetation clearance, soil stripping etc.).
  - Large-scale earthworks.
  - Use of temporary laydown areas, tracks and construction camps.
  - Long-term stockpiling of soil.
  - Maintenance during use.
  - Decommissioning (removal of structures, rehabilitation of landform, soils and vegetation).

10.4 Significance of Cumulative Residual Impacts

The cumulative assessment carried out for this study has mainly considered the Australia Pacific LNG Project (APLNG), using information from the relevant published EIS reports. However, these reports give an impact rating apparently based on environmental constraint rather than environmental impact. This study has, therefore, interpreted the potential cumulative impact based on our understanding of the proposed relevant project activities and the findings of the EIS reports. The published EIS reports (WorleyParsons, 2010) present similar broad conclusions to this study, i.e., residual constraints are as follows:

- The main residual impact is generally considered to be earthworks causing major, long-term topographic change and disruption of landscape systems.
- Widespread land degradation resulting from landform modification, in particular water erosion and localised creation of dust, is considered to be the greatest potential impact.
- Exhaustion of finite soil resources is possible.

These issues are discussed in Sections 10.4.1 – 10.4.3

10.4.1 Impact of Major Earthworks

The LNG projects will result in major, long-term ground disturbance. Along the south-western margins of Curtis Island, several LNG facilities are proposed (APLNG) or already under construction (GLNG and QCLNG). Construction of the Arrow LNG Plant and APLNG facilities is anticipated to extend the spatial extent of impact further; once constructed, virtually the entire coastline between Boatshed Point and Laird Point is expected to be permanently altered.

The extent of long-term impacts is dependent on the success of rehabilitation. It will be impractical to attempt reinstatement of the pre-disturbance landforms. However, these long-term impacts will be reduced assuming the rehabilitation target of other proponents matches that recommended by this study, i.e., to produce, as far as is practicable, a safe, non-polluting landform with self-sustaining soil fertility and a low instability hazard.

10.4.2 Widespread Land Degradation

Erodible soils are likely to be exposed, particularly on Curtis Island. Therefore, an increase in erosion rates and quantities is likely, with associated deposition further down-system. This is particularly likely during the intense summer rain events characteristic of the Gladstone area. Impacts associated with the cumulative effects of large facility construction are likely to be more widespread, requiring successful implementation of erosion management controls and monitoring to reduce this cumulative impact.

10.4.3 Exhaustion of Finite Resources

Soils within the study area are generally shallow, with low fertility. This study considers this to be a management issue (see Section 8.1.5: Soil Management), rather than an environmental impact. The large extent of topsoil required for rehabilitation during all major projects may result in exhaustion of these finite resources. **The presence of shallow soils throughout the region may be the single most limiting factor to rehabilitation of areas affected by construction projects in the region.** It is likely that suitable topsoil will require importing into the region to enable successful rehabilitation of all the major projects that are proposed.

Assuming the recommended management and mitigation measures are implemented by all proponents, all aspects of the anticipated impacts are likely to be affected, i.e., the magnitude of impact (severity, spatial extent and duration) is likely to remain at low to moderate levels. On Curtis Island, the regional impact of the combined projects will result in wholesale disturbance or removal of geology, landform and soils over a large area of the southwestern section of the island. However, as each site is spatially separate, at the site level, these impacts will not be cumulative. Compared with the extensive linear disturbance associated with pipeline construction and maintenance, the impact of the mainland areas of the Arrow LNG Plant project are anticipated to be minor, due to their small scale and low anticipated residual impact.

11 CONCLUSION

The geology, landform and soils environmental values of the study area should be a constant consideration for the lifetime of the project. Modified landforms (batters, embankments, benches and drainage channels) resulting from bulk earthworks are susceptible to erosion if not properly rehabilitated. The steepness of slopes, extent of soil profile inversion, and exposure of sodic and saline soils are factors in the resilience of modified landforms to change.

In contrast, the impact of each project element will differ according to the footprint size, activities involved and the landscape characteristics: The large-scale LNG plant will have a longer-term impact over a larger area than, for example, the smaller TWAF sites. Invasive activities, such as major topographic change, will have a permanent impact on the landscape and land use. The magnitude of impact can be successfully reduced by appropriate implementation of management and mitigation measures.

When compared with other proposed development projects in the study area, the LNG plant project is likely to have a similar impact due to the degree of topographic alteration proposed by other proponents along pipeline routes and at LNG plant sites. The topography of southwest Curtis Island will be particularly affected. However, assuming the rehabilitation target for these projects matches that recommended by this study (i.e., to produce a safe, non-polluting landform with self-sustaining soil fertility and a low stability hazard), cumulative impacts should be reduced to tolerable levels. Projects considered likely to impact the study area included APLNG Project, GLNG and QCLNG. Cumulatively, these projects are not anticipated to increase the significance of potential impacts on the geology, landform and soils of the study area at the regional or site level, assuming successful implementation of management and rehabilitation measures.

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12.6 GIS Metadata

Information	Source	Date	Scale
Topographic contours (5m)	DERM	Purchased Jan 2010	1:25,000
Aerial photography	SPOT	2004-2007	2.5 m imagery
Cadastre/LGA Boundaries	DERM	30/10/2009	ranges from 1:2500 to 1:250000
Infrastructure	Shell Australia	Supplied 2010	Unknown
Watercourses	Alluvium	2010	1:100.000
Queensland geological mapping	Department of Mines and Energy	2007	1:100,000
Atlas of Australian Soils*	CSIRO	1960-1968	1:2million
Terrain Mapping	GLS Team Interpretation	2011	1:100,000
GQAL Mapping	Ross (1999)	2011	1:100,000

* Full Reference: Northcote, K. H. with Beckmann, G. G., Bettenay, E., Churchward, H. M., Van Dijk, D. C., Dimmock, G. M., Hubble, G. D., Isbell, R. F., McArthur, W. M., Murtha, G. G., Nicolls, K. D., Paton, T. R., Thompson, C. H., Webb, A. A. and Wright, M. J. (1960-1968). Atlas of Australian Soils, Sheets 1 to 10. With explanatory data (CSIRO Aust. and Melbourne University Press: Melbourne).

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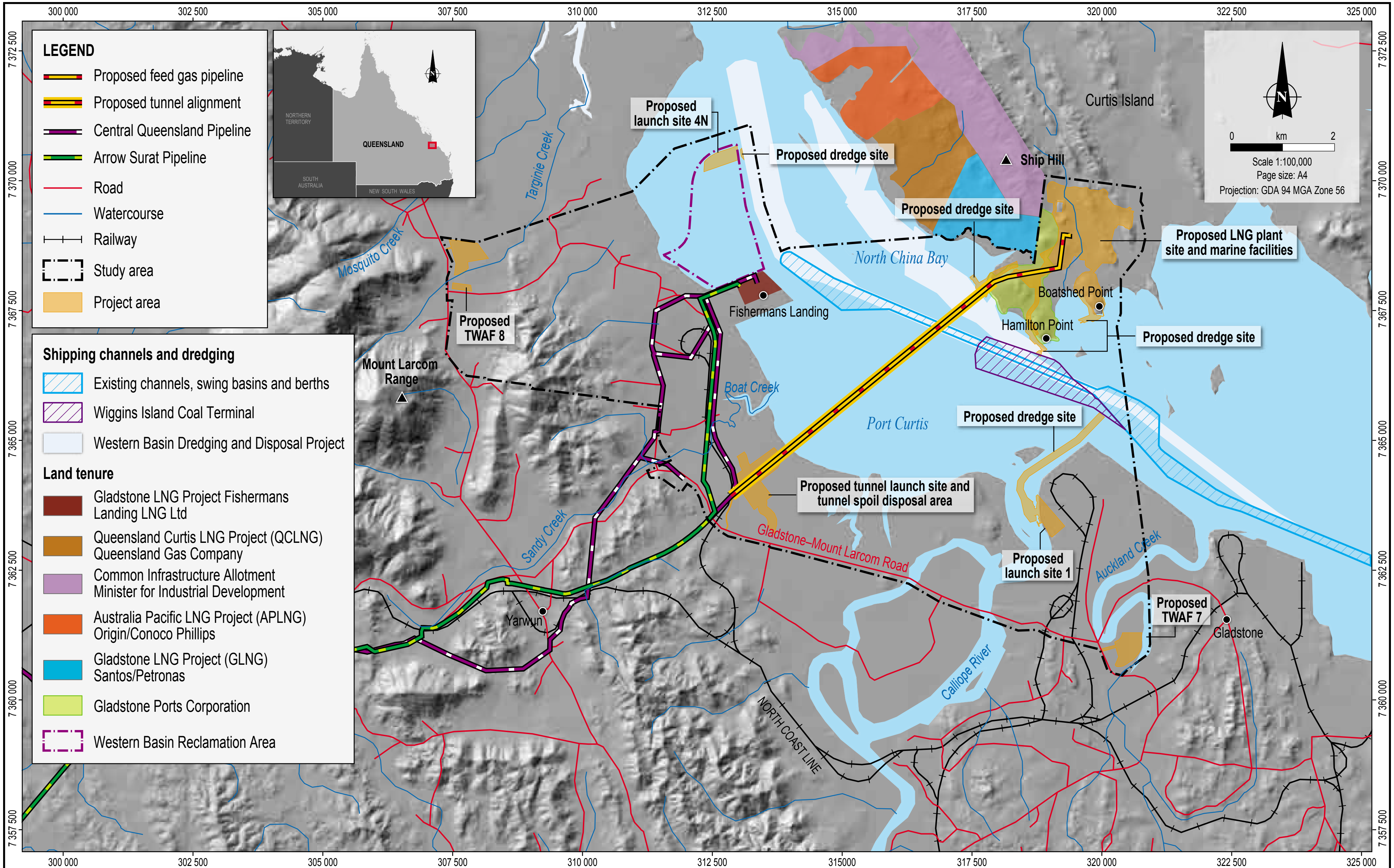
Figures



Source:
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline, proponents and DEM from Coffey Environments.
Western Basin Dredging Master Plan from Gladstone Ports Corporation.

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Date: 10.08.2011
MXD: 7033CA_07_GIS034_v1_3
File Name: 7033CA_GLS_F01.01_GIS_GL

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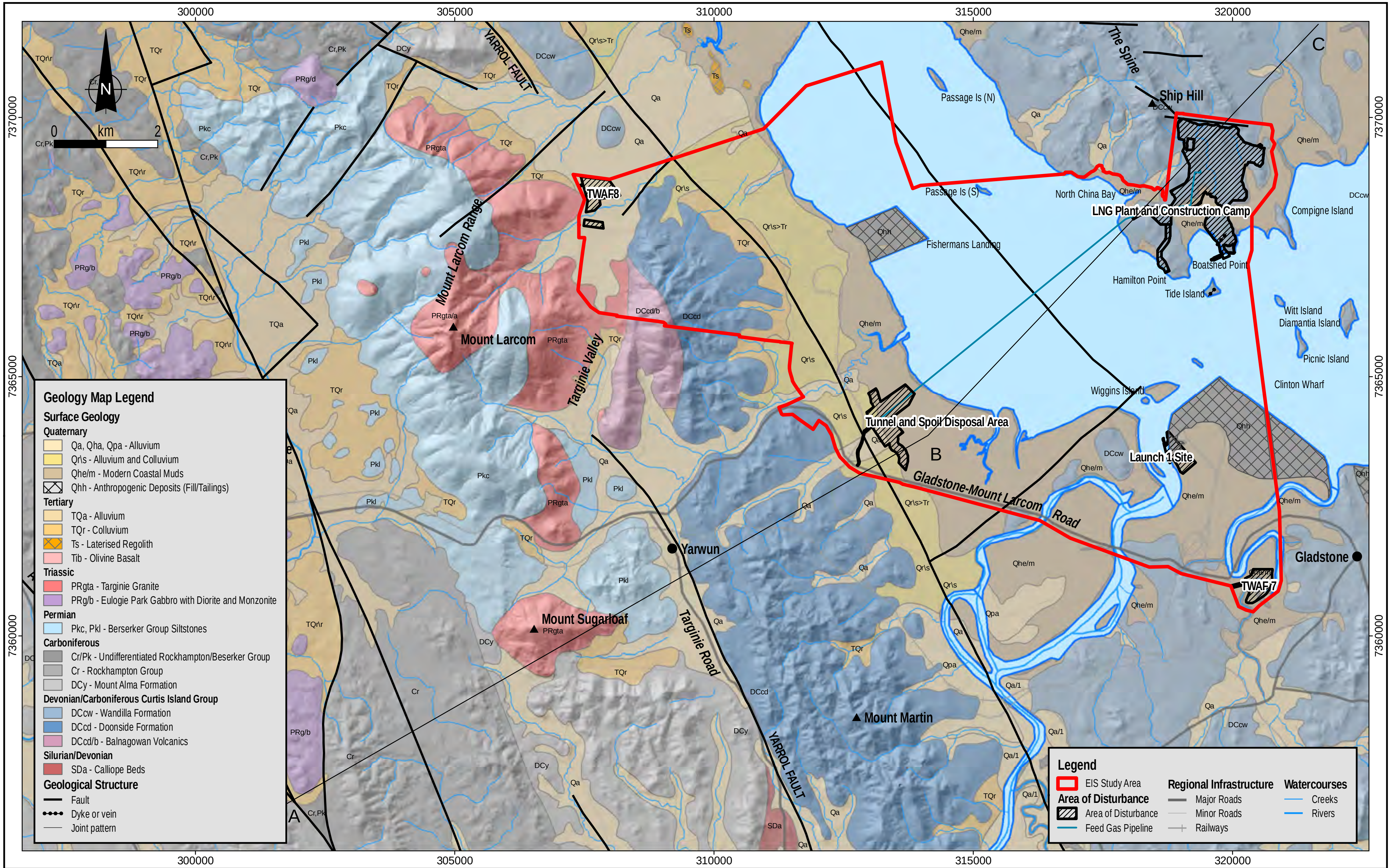
Overview map of the study area

Figure No: 1.1



Source and Notes:
1. Geology and structure from DME 1:100,000 digital geological mapping; Cross-section A-B-C shown in Figure 4.2
2. No differentiation has been made between concealed, inferred or approximate fault locations
3. Place names, roads and railways from DME
4. Watercourses from Alluvium (2010)
5. Coastline digitised by Coffey GLSTeam

Page size: A4

Scale: 1:100,000

Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011

MXD: Geology_Final

File Name: 7033CA_GLS_F4.1_GEOT

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Regional Surface Geology

Figure No: 4.1

Geology Legend

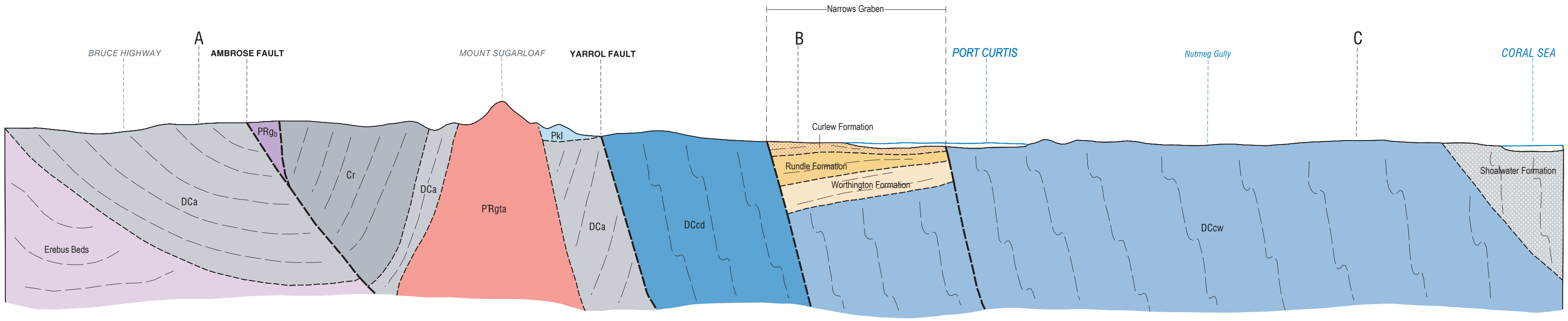
Triassic
- PRgta - Targinie Granite
- PRgb - Eulogie Park Gabbro with Diorite and Monzonite

Permian
- Pkl - Berserker Group Siltstones

Carboniferous
- Cr - Rockhampton Group
- DCa - Mount Alma Formation

Devonian/Carboniferous Curtis Island Group
- DCcw - Wandilla Formation
- DCcd - Doonside Formation

Geological Structure
- Fault
- Joint pattern



NOTES
1. Cross-Section Taken from 1:100,000 Gladstone Geological Map, Sheet 9150, Department of Natural Resources, Mines and Water, 2006.
2. Section is schematic with vertical topographic exaggeration, illustrative folding and omission of Quaternary units.
3. Rock units are named where not explained in Figure 3.1 Geological Map of the Study Area and Environs.

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Date: 06.10.2011
AI: Geological Section.AI
File Name: ENAUBRIS07033CA_B02_F4.2_GSL

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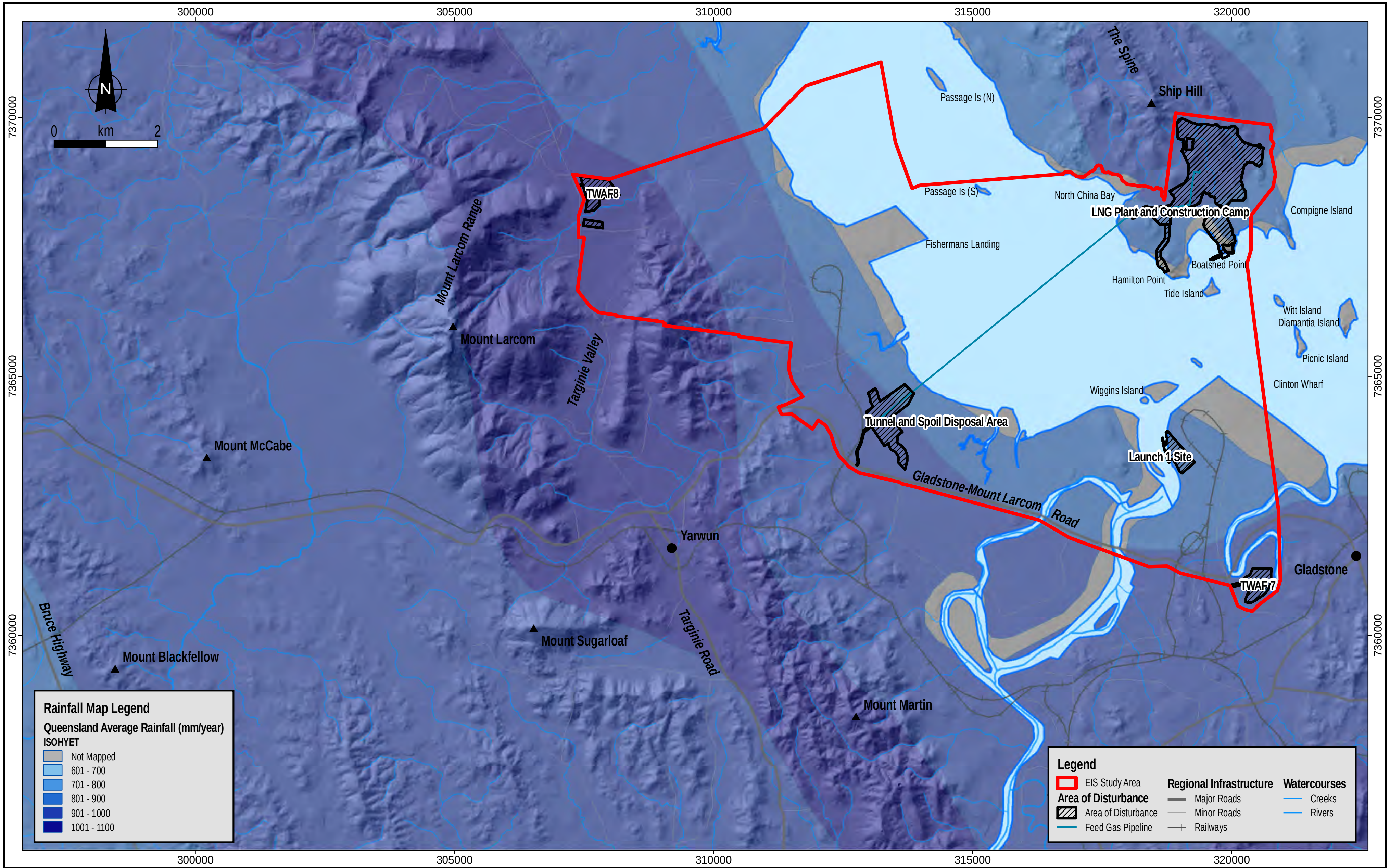
Geological Cross-Section through the Study Area

Figure No: 4.2



Source:
1. Rainfall from Australian Bureau of Meteorology
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GSL Team

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: Rainfall_Final
File Name: 7033CA_GLS_F4.3_GEOT

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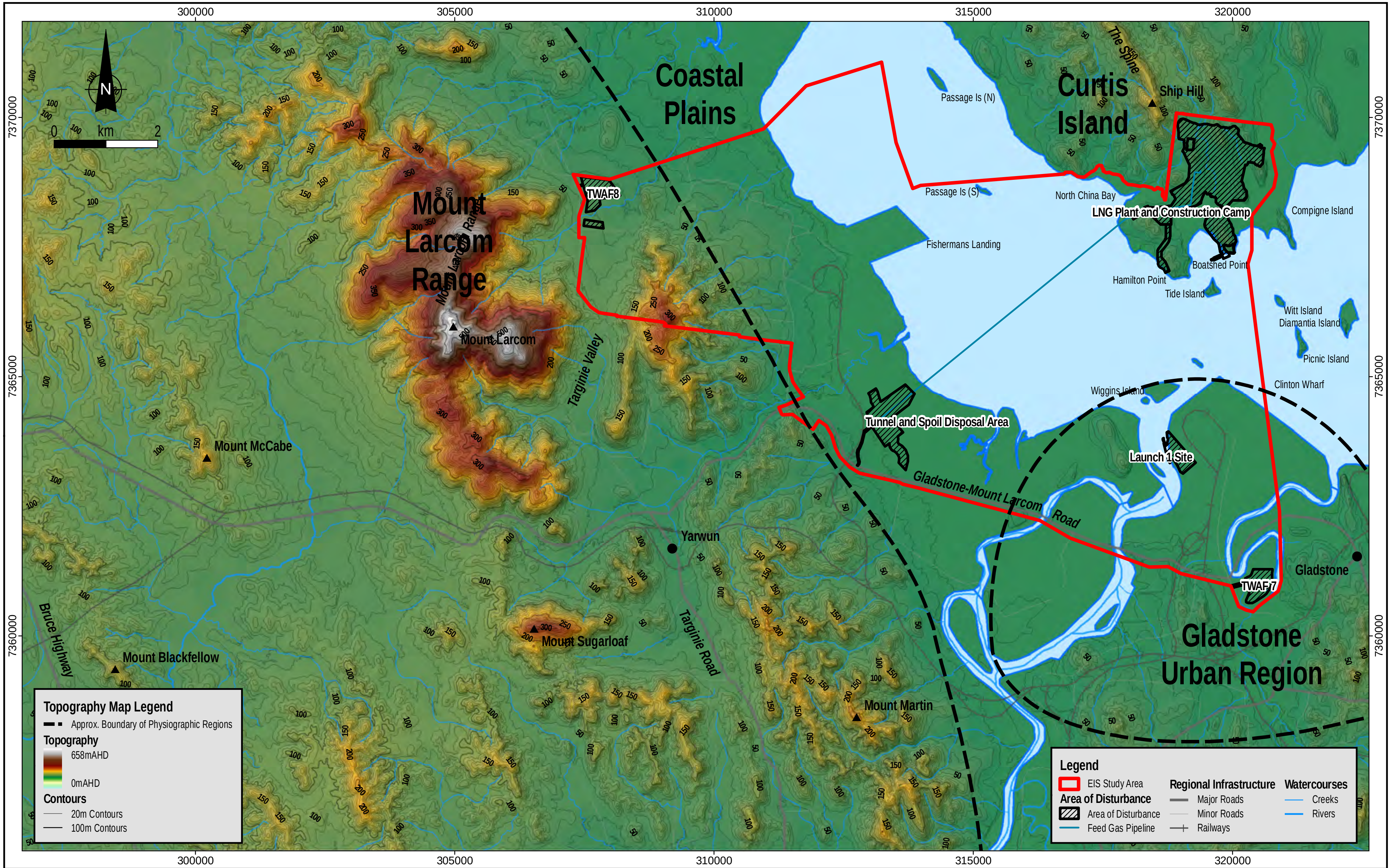
Regional Average Rainfall

Figure No: 4.3



Source:
1. DEM constructed from DERM 10m contours
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GSL Team

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: Topography_Final
File Name: 7033CA_GLS_F4.4_GEOT

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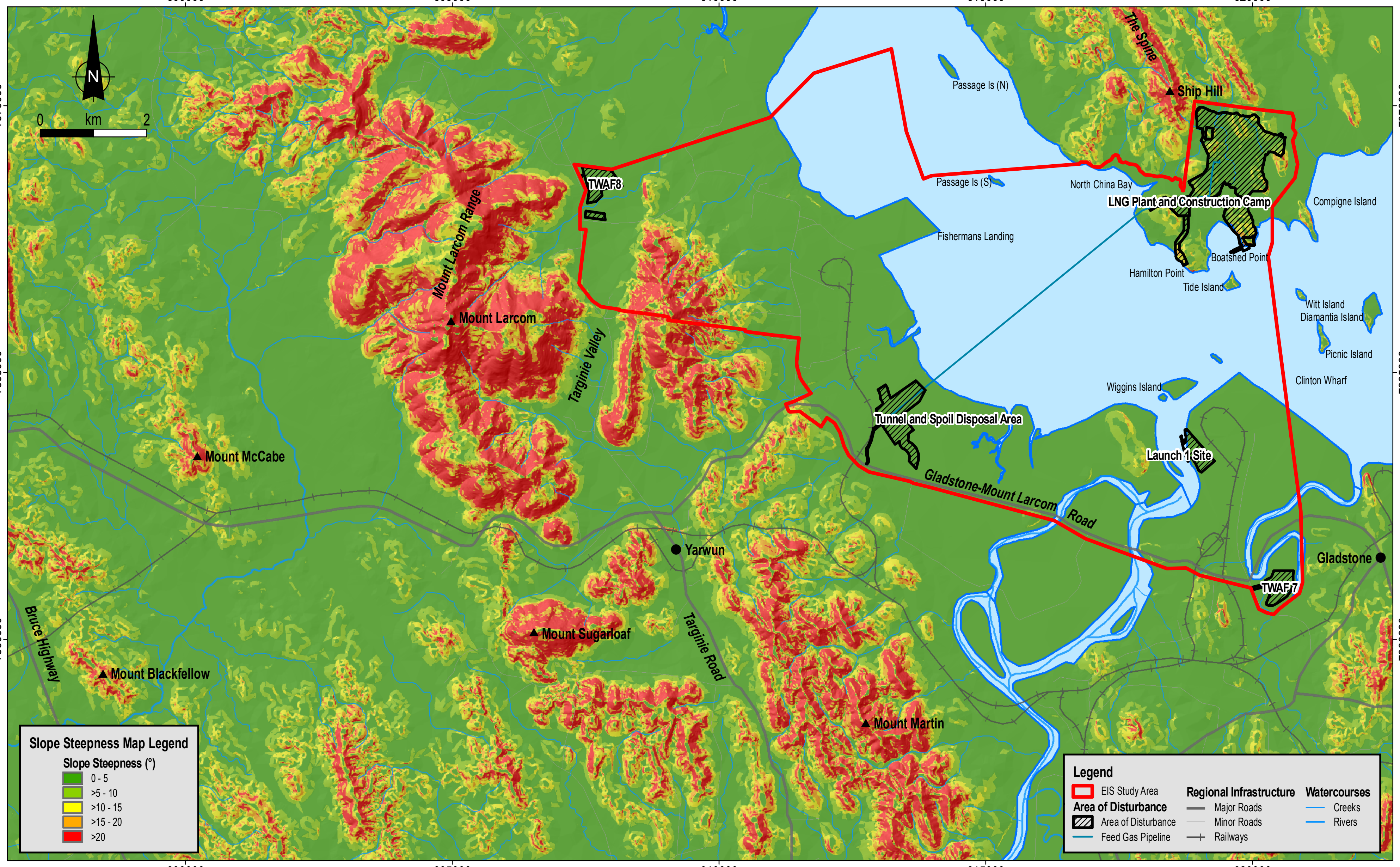
Regional Topography and Physiography

Figure No: 4.4



Source:
1. Slope calculated from DEM constructed from DERM 10m contours
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GSL Team

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: Slope_Final
File Name: 7033CA_GLS_F4.5_GEOT

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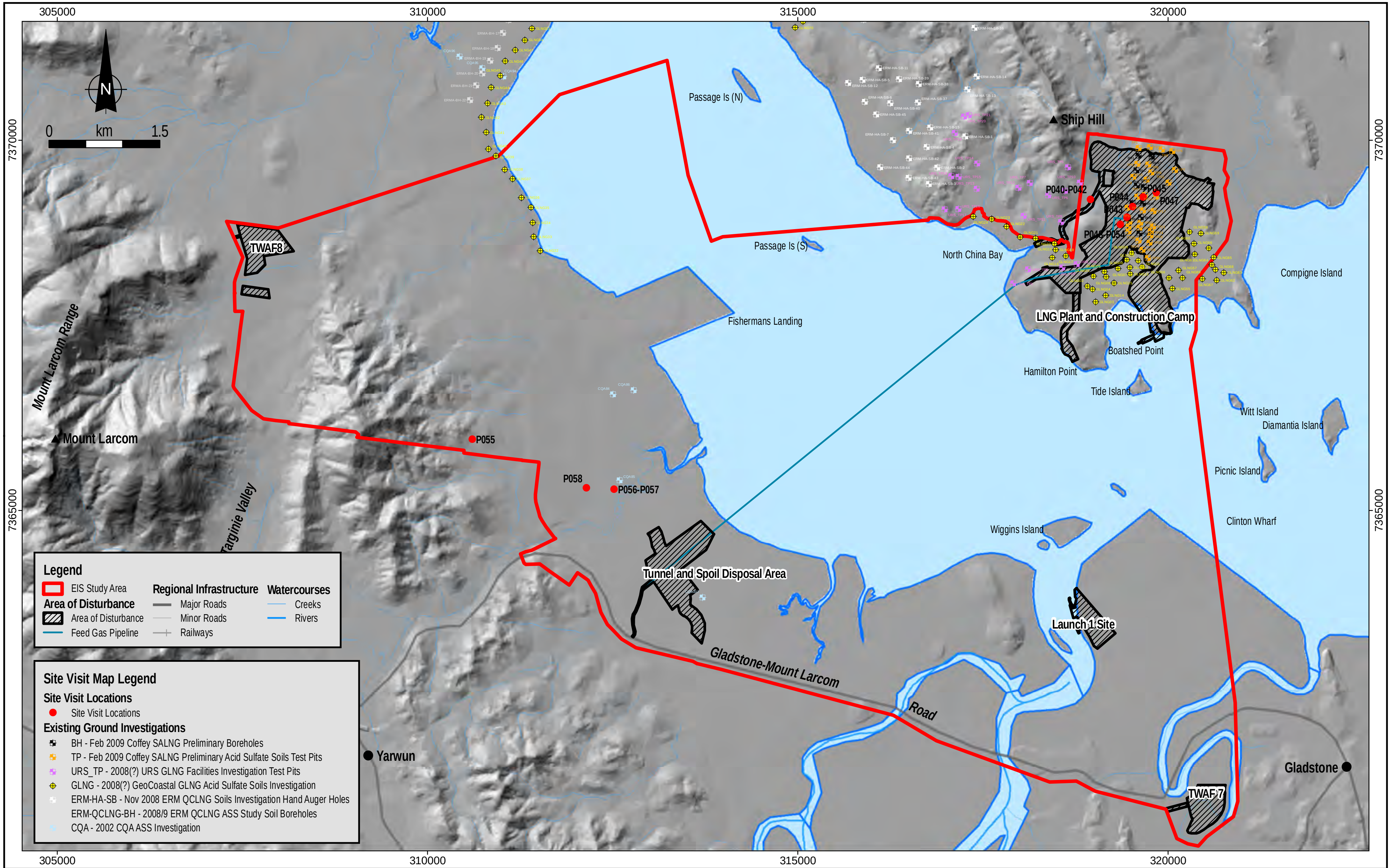
Regional Slope Steepness

Figure No: 4.5



Source:
1. Site visited by GLS team on 16 and 17 June 2010
2. Ground investigation locations digitised from named sources.
3. Place names, roads and railways from DME
4. Watercourses from Alluvium (2010)
5. Coastline digitised by Coffey GSL Team

Page size: A4

Scale: 1:70,000

Projection: GDA 94 MGA Zone 56

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Date: 01.07.2011

MXD: PrevInv_Rev2

File Name: 7033CA_GLS_F4.6_GEOT

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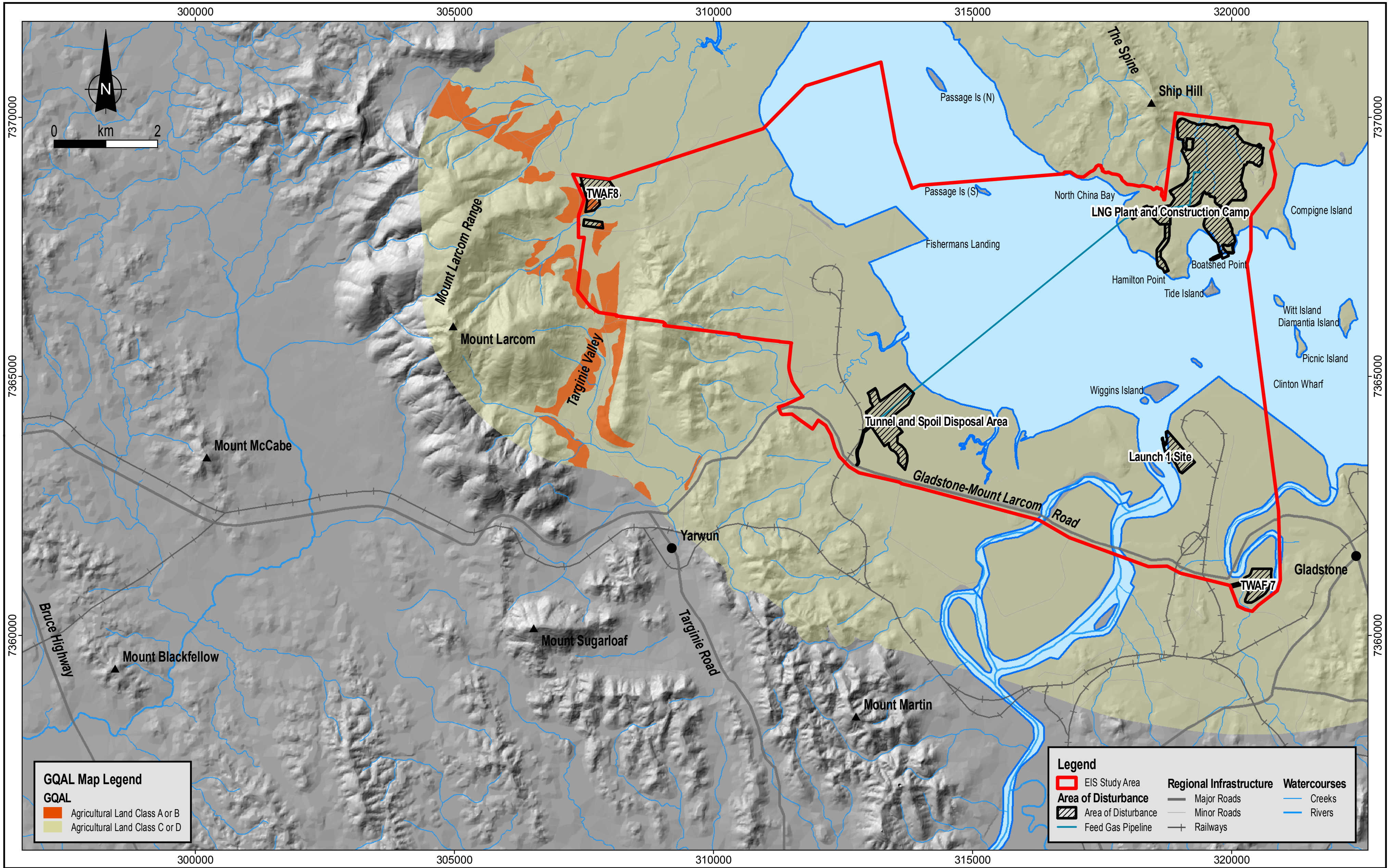
Site Visit and Investigation Locations of the Study Area and Environs

Figure No: 4.6



Source:
1. Agricultural Land Classification from Ross (1999) and interpretation of GLS Team terrain unit mapping
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GSL Team

Page size: A4

Scale: 1:100,000

Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011

MXD: GQAL_Final

File Name: 7033CA_GLS_F4.7_GEOT

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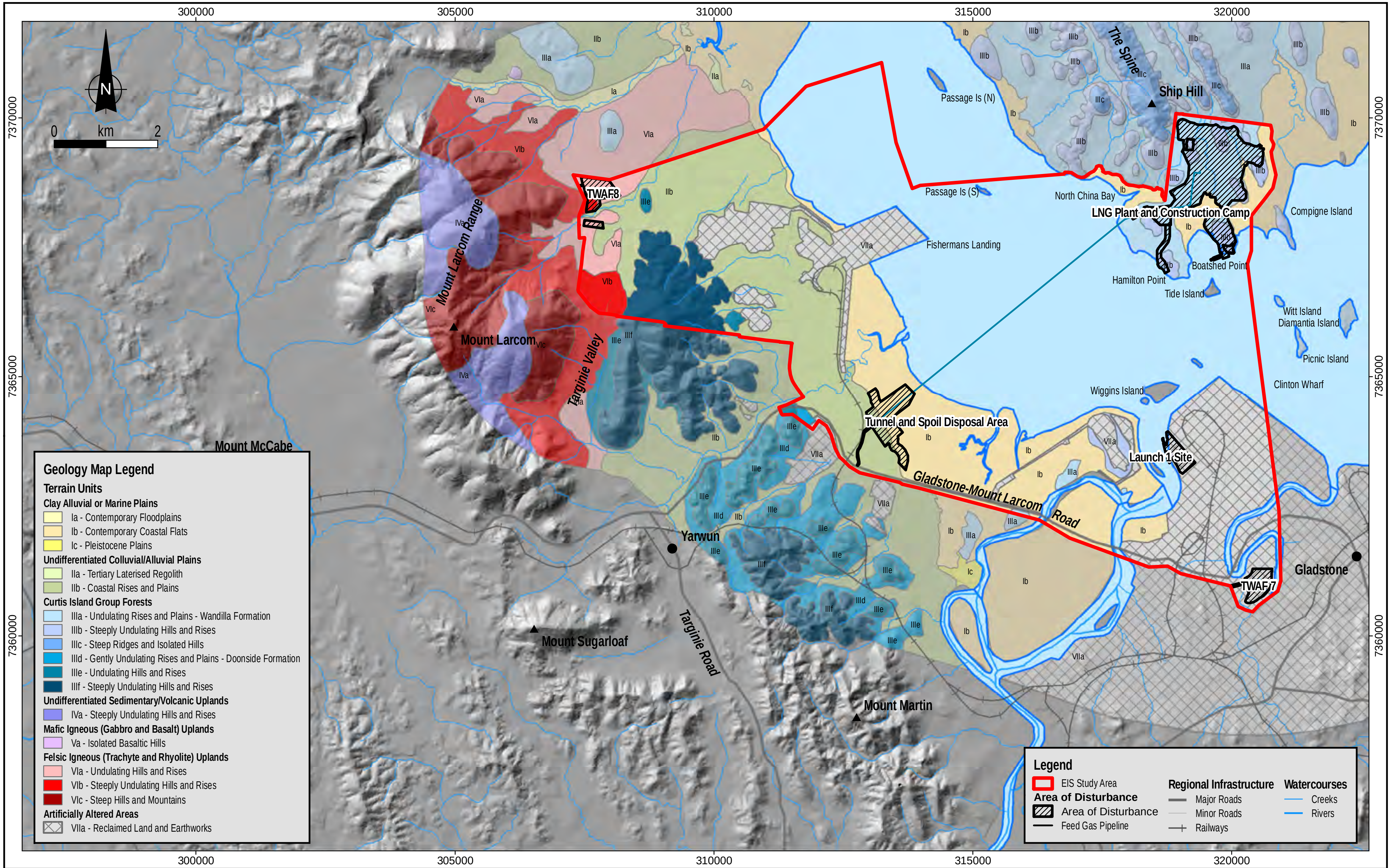
Agricultural Land Class (GQAL) of the Study Area and Environs

Figure No: 4.7



Source and Notes:
1. Terrain Units digitised by Coffey GLS Team
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GLSTeam

Page size: A4
Scale: 1:100,105
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: TUs_Final
File Name: 7033CA_GLS_F5.1_GEOT

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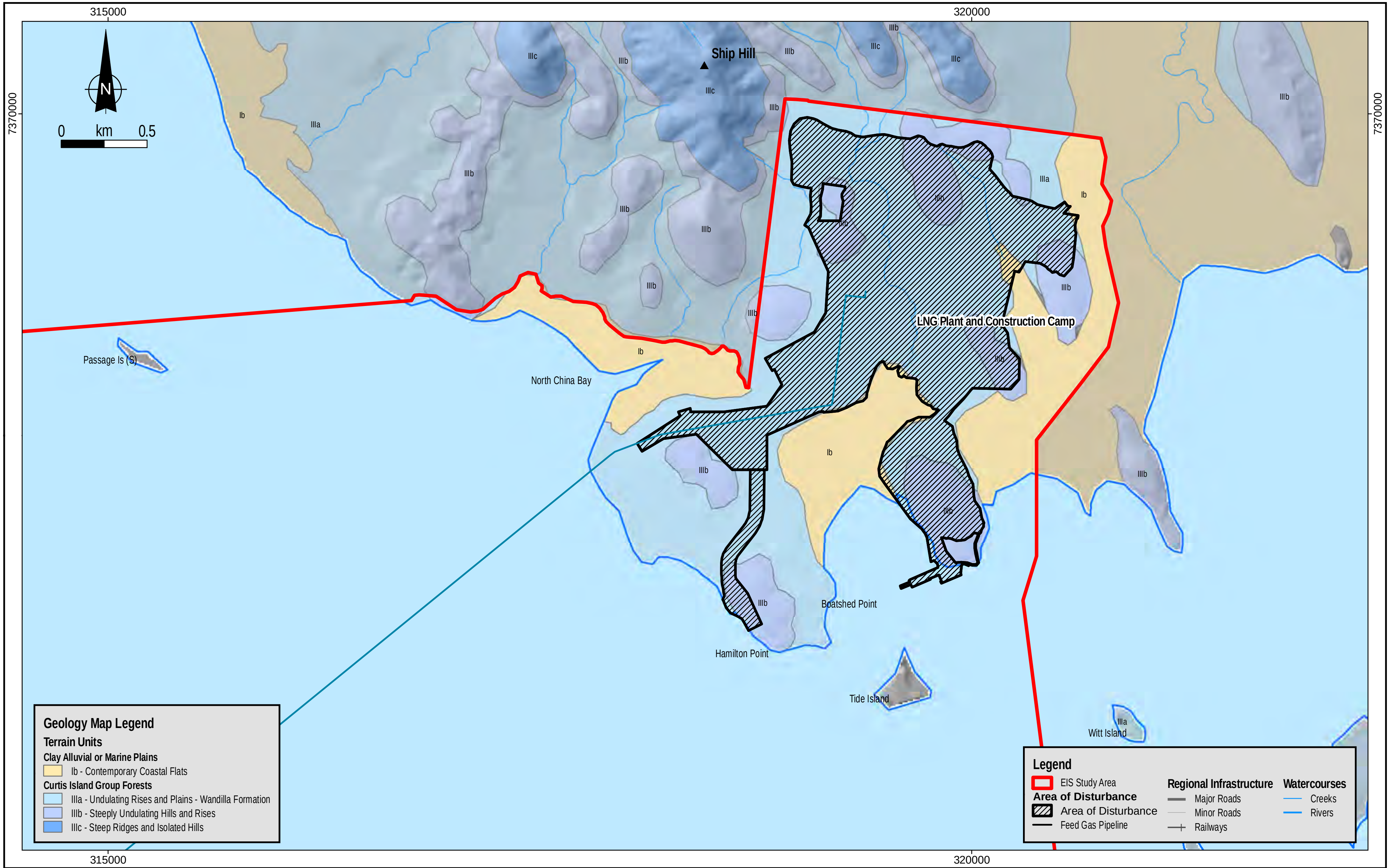
Terrain Units of the Study Area and Environs

Figure No: 5.1



Source and Notes:
1. Terrain Units digitised by Coffey GLS Team
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GLSTeam

Page size: A4
Scale: 1:30,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: CITUs_Final
File Name: 7033CA_GLS_F5.1a_GEOT

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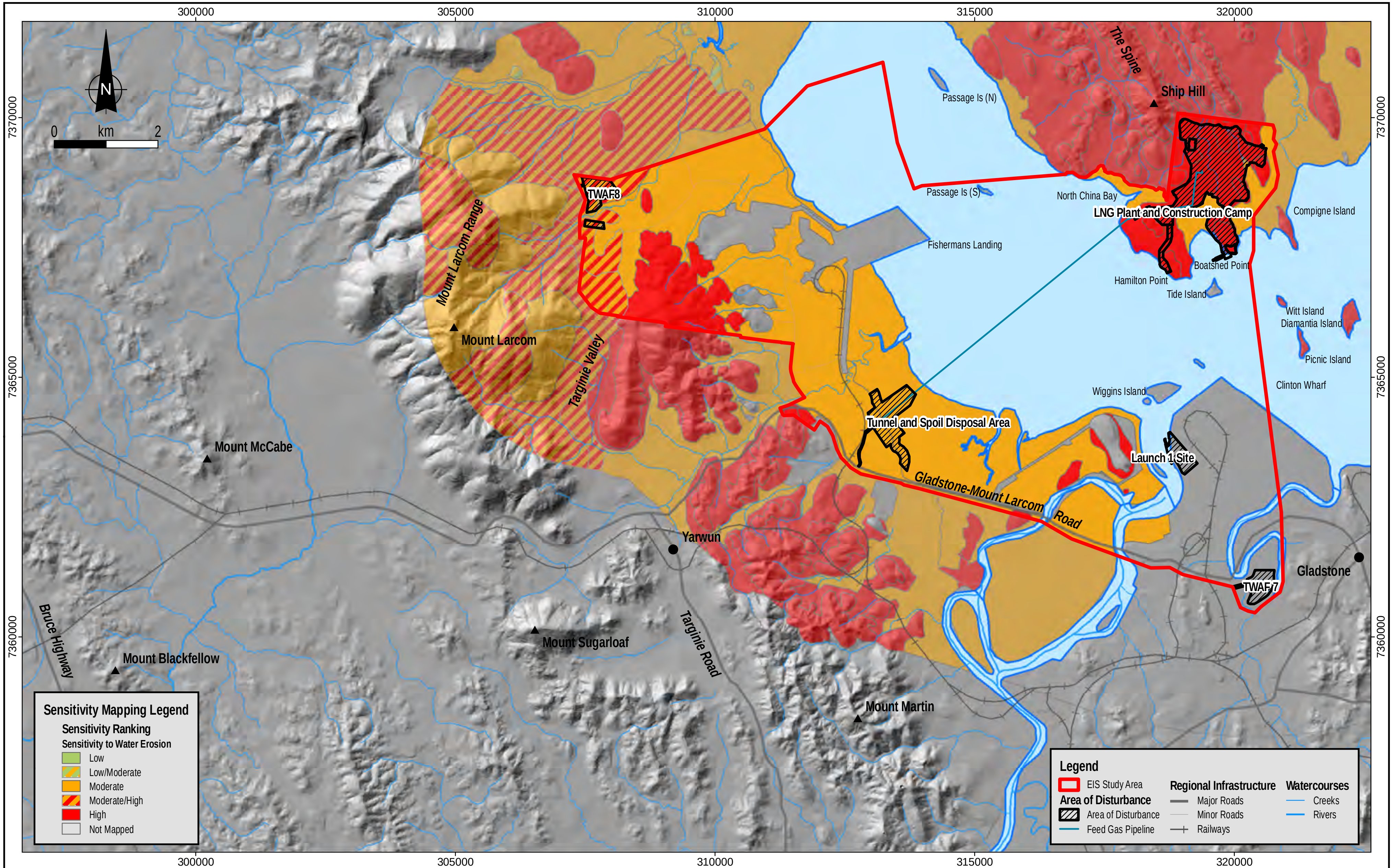
Terrain Units of the Curtis Island Section of the Study Area

Figure No: 5.1a



Source and Notes:
1. Terrain Units digitised by Coffey GLS Team
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GLSTeam

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: WaterSens_Final
File Name: 7033CA_GLS_F5.2_GEOT

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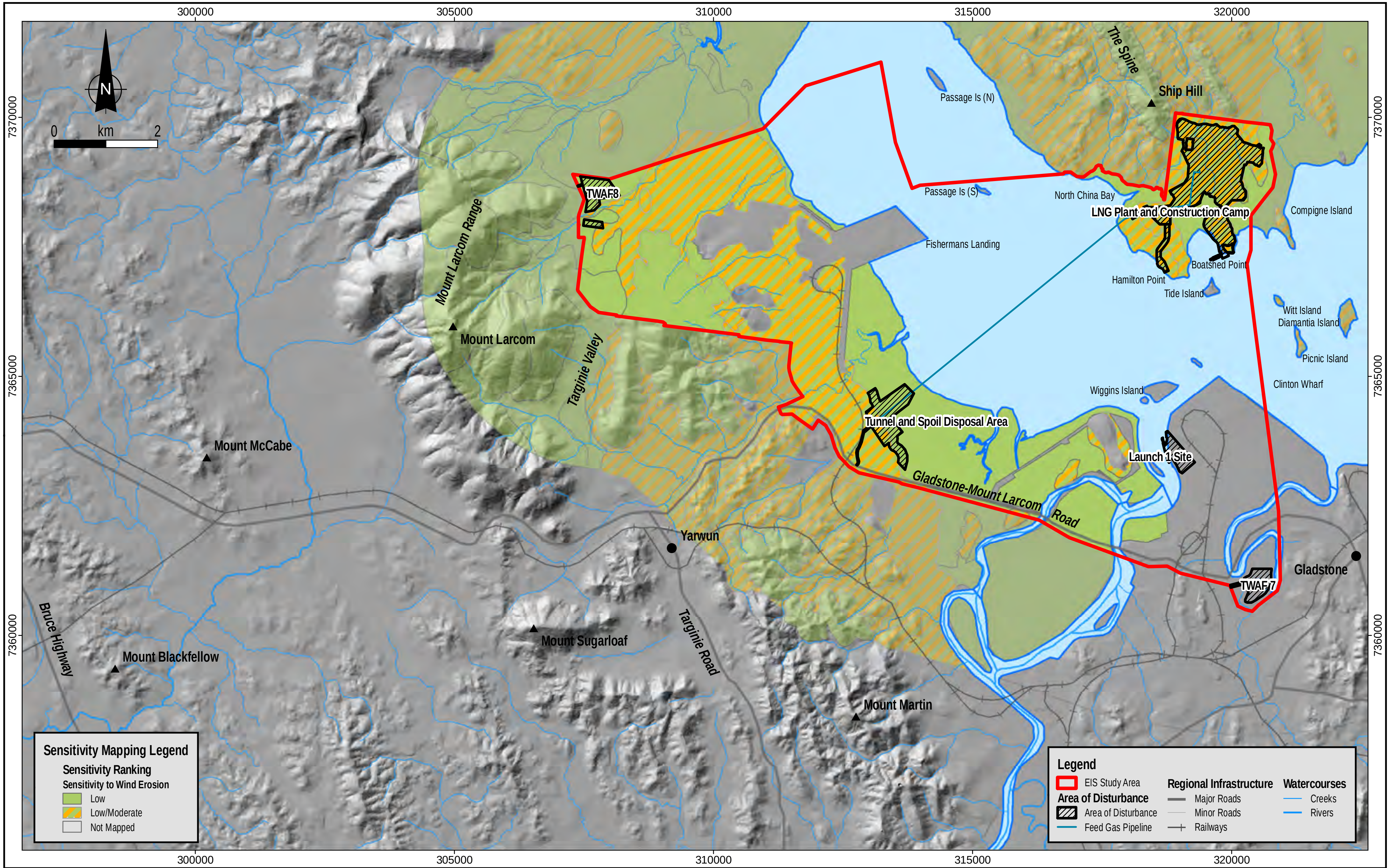
Soil Sensitivity to Water Erosion in the Study Area and Environs

Figure No: 5.2



Source and Notes:
1. Terrain Units digitised by Coffey GLS Team
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GLSTeam

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: WindSens_Final
File Name: 7033CA_GLS_F5.3_GEOT

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Arrow LNG Plant

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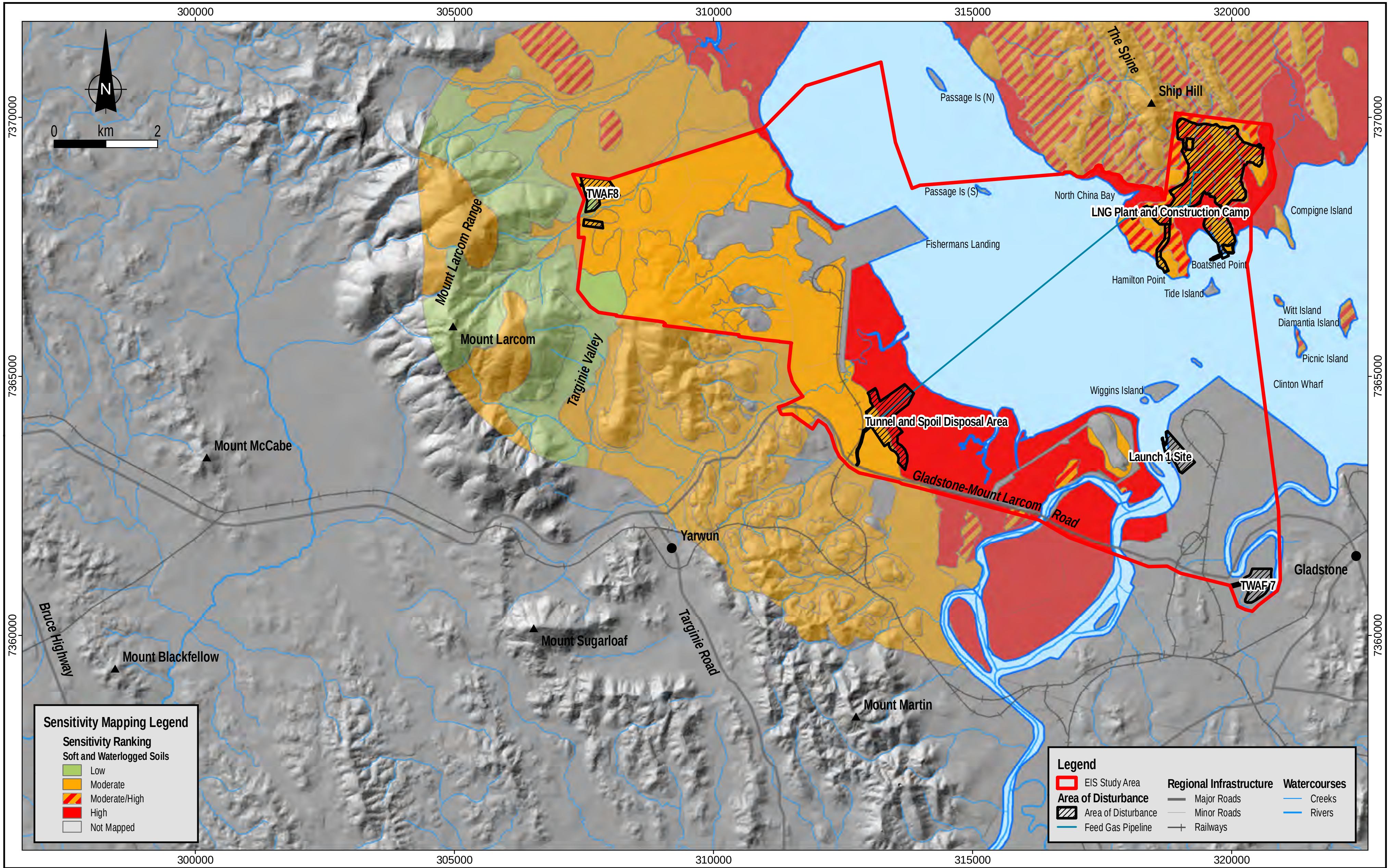
Soil Sensitivity to Wind Erosion in the Study Area and Environs

Figure No: 5.3



Source and Notes:
1. Terrain Units digitised by Coffey GLS Team
2. Place names, roads and railways from DME
3. Watercourses from Alluvium (2010)
4. Coastline digitised by Coffey GLSTeam

Page size: A4
Scale: 1:100,000
Projection: GDA 94 MGA Zone 56

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Date: 06.10.2011
MXD: SoftSoil_Final
File Name: 7033CA_GLS_F5.4_GEOT

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Sensitivity from Soft Soils and Waterlogging in the Study Area and Environs

Figure No: 5.4

Appendix A

Site Photographs

P1: Bleached clay surface soils in low relief area prone to waterlogging. Looking toward Ship Hill, the highest point of the Spine hogsback ridge.

P2: Hard-crusted, bleached sodic surface soils overlying ferruginised subsoils exposed by track erosion.

P3: Bleached, extremely weathered mudstone exposed on track with some gravel on surface.

drawn	**RJH**	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client: **Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd**
approved	**LAE**		project: **Geology, Landform and Soils Impact Assessment Arrow LNG Plant**
date	**24.08.11**		
scale	**N/A**		title: **Photographs 1-3 – Curtis Island**
original size	**A4**		project no.: ENAUBRIS10733 figure no.: A1

P4: Brown clay dermosol point bar deposit exposed within a gully crossing track.

P5: Sodic, bleached soil with remnants of hard-crusted A-horizon in places.

drawn	**RJH**	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client: **Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd**
approved	**LAE**		project: **Geology, Landform and Soils Impact Assessment Arrow LNG Plant**
date	**24.08.11**		
scale	**N/A**		title: **Photographs 4-5 – Curtis Island**
original size	**A4**		project no.: ENAUBRIS10733 figure no.: A2

Left and Above – P6 and P7: Headcutting gullies approximately 1m deep eroding track. Gullies expose a hard-crusting bleached A-horizon on lower slopes (not present at higher elevations), with a gravelly, ferrous B-horizon.

Below – P8: Close-up of exposed soils. Bleached horizon very apparent above ferrous, sodic subsurface soils.

drawn	**RJH**	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client:	**Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd**
approved	**LAE**		project:	**Geology, Landform and Soils Impact Assessment Arrow LNG Plant**
date	**24.08.11**			
scale	**N/A**		title:	**Photographs 6-8 – Curtis Island**
original size	**A4**		project no.: ENAUBRIS10733	figure no.: A3

P9: Mangrove swamp and path adjacent to track along borders of North China Bay. Photo shows hydrosols within swamp and red, gravelly soils exposed in track.

P10: Coarse beach deposits comprising sandstone and mudstone cobbles and boulders.

drawn	**RJH**	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client: **Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd**
approved	**LAE**		project: **Geology, Landform and Soils Impact Assessment Arrow LNG Plant**
date	**24.08.11**		
scale	**N/A**		title: **Photographs 9-10 – Curtis Island**
original size	**A4**		project no.: ENAUBRIS10733 figure no.: A4

P11: Ferrous mainland soils exposed in recent cutting. Soil developed on colluvium.
Bleached A2 Horizon, clayey B horizon, becoming gravelly with depth.

drawn	RJH	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client:	Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd
approved	LAE		project:	Geology, Landform and Soils Impact Assessment Arrow LNG Plant
date	24.08.11			
scale	N/A		title:	Photograph 11 – Foot of Doonside Formation Hills
original size	A4		project no.: ENAUBRIS10733	figure no.: A5

Above – P12: Marine muds and ferrous mainland soils.

Right – P13: Rill erosion of the track exposing grey, silty, hard-crusting clay underlain by gravel.

Below – P14: Ferrous surface soils and bauxite conveyor.

drawn	**RJH**	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client: **Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd**
approved	**LAE**		project: **Geology, Landform and Soils Impact Assessment Arrow LNG Plant**
date	**24.08.11**		
scale	**N/A**		title: **Photographs 12-14 – South of Fishermans Landing**
original size	**A4**		project no.: ENAUBRIS10733 figure no.: A6

Appendix B

Terms of Reference Cross-Reference Table

Section No.	Terms of Reference Requirement	Technical Specialist	Technical Report Section Reference
2 Description of the project			
3 Environmental values and management of impacts			
3.2	Describe the existing environmental values of the land area that may be affected by the project. It should also define and describe: • The objectives and practical measures for protecting or enhancing land-based environmental values • How nominated quantitative standards and indicators may be achieved. • How the achievement of the objectives would be monitored, audited and managed. Schedules of disturbance should be described and discussed for all aspects of the project in accordance with the DERM guideline Financial assurance for petroleum activities. Information should be provided demonstrating that the financial assurance estimates will be adequate for worst-case scenarios (including maximum possible areas of disturbance, maximum proportion of problem soil areas and maximum proportion of environmentally sensitive areas).	Geology, Landform and Soils Study	Section 5.1: Terrain Unit Mapping and Environmental Values Section 8: Management and Mitigation Measures Section 8.4: Inspection and Maintenance Programme
3.2.1.1	Topographical maps should be provided locating the project in both regional and local contexts using the Geocentric Datum of Australia (GDA94). The topography of the project sites should be detailed with contours at suitable increments, shown with respect to Australian Height Datum. Commentary on the maps should be provided highlighting the significant topographical features.	Geology, Landform and Soils Study	Figure 4.4: Regional Topography and Physiography
	The EIS should provide a description, map and a series of cross-sections of the geology of the project area, with particular reference to the physical and chemical properties of surface and sub-surface materials and geological structures within the proposed areas of disturbance.	Geology, Landform and Soils Study	Section 4.1: Geology Figure 4.1: Regional Surface Geology and Figure 4.2: Geological Cross-Section through the Study Area
	Geological properties of all project sites which may influence stability, occupational health and safety, rehabilitation programs, or the quality of waste water leaving any area disturbed by the project should be described. This section should also consider any mineral resources that may be impacted or sterilised by the	Geology, Landform and Soils Study	Section 4.1.4: Geotechnical Properties Section 6: Environmental Constraints and Design Considerations (particularly Sections 6.8: Rock Excavatibility Constraints and 6.9: Construction Material Constraints)

Section No.	Terms of Reference Requirement	Technical Specialist	Technical Report Section Reference
	project.		
3.2.1.2	Provide information on potential impacts to the land resources, and proposed mitigation and management methods. In particular information should be provided on: • Need for rock, sand and gravel for construction materials, including any new or expanded quarry and screening operations required to service the project. • Environmental consequences of the excavation and removal of materials and soils from any borrow pits. Details should be provided of measures to be undertaken to mitigate or avoid the identified impacts.	Geology, Landform and Soils Study	Section 7.6.1: GQAL Impacts Section 6.9: Construction Material Constraints, Section 7.2: Use of Rock Resources in Construction Activities Section 8.1.3: Topographic Constraints: Steep Slopes and Undulating Ground Section 8.1.8: Construction Materials: Borrow Pits
3.2.2.1	A soil survey of the areas to be disturbed by the project should be conducted at a suitable scale, with particular reference to the physical and chemical properties of the materials that influence erosion potential, storm water run-off quality, rehabilitation and agricultural productivity of the land. Information should also be provided on: • Soil stability • Suitability for construction of proposed facilities • Any approved soil conservation plans.	Geology, Landform and Soils Study	Section 4.3: Soils Section 5.1: Terrain Unit Mapping and Environmental Values (Note: A soil investigation was not conducted. Information based on visual assessment of soil exposures and review of existing studies.)
	An appraisal of the depth and quality of useable soil should be undertaken.	Geology, Landform and Soils Study	Section 8.1.5: Soil Management
	Soil profiles should be mapped at a suitable scale and described according to the Australian Soil and Land Survey Field Handbook (McDonald et al, 2009) and Australian Soil Classification (Isbell, 2002). Information should be presented according to the standards required in the Planning Guidelines: The Identification of Good Quality Agricultural Land (DPI & DHLGP, 1993), and the State Planning Policy 1/92: Development and the Conservation of Agricultural Land (DME, 1995).	Geology, Landform and Soils Study	Section 4.3: Soils Figures 4.7 and 5.1
	The requirement for soils mapping in terms of area and mapping scale should follow the Queensland Department of Mines and Energy: Technical Guidelines for Environmental Management of Exploration and	Geology, Landform and Soils Study	See section 3.4: Soils Assessment Method for rationale for using desktop study and observations of existing soils exposures for soils mapping. (Note: A soil

Section No.	Terms of Reference Requirement	Technical Specialist	Technical Report Section Reference
	Mining in Queensland (1995). These guidelines recommend that disturbed areas be mapped more intensively than non-disturbed areas and provide guidance on acceptable mapping scale and site intensity.		investigation was not conducted. Information based on visual assessment of soil exposures and review of existing studies.)
3.2.2.2	Possible erosion rates and management techniques should be described for all permanent and temporary landforms. The erosion potential (wind and water) and erosion management techniques should be outlined for each soil type identified. An erosion-monitoring program, including rehabilitation measures for erosion problems identified during monitoring, should also be outlined. Mitigation strategies should be developed to achieve acceptable soil loss rates, levels of sediment in rainfall runoff and wind-generated dust concentrations. The EIS should include an assessment of likely erosion effects for all disturbed areas such as: • Areas cleared of vegetation. • Dams, banks and creek crossings. • Gas pipeline corridor. • LNG plant area and surrounding buildings. • Access roads or other transport corridors. • Areas under rehabilitation. Methods proposed to prevent or control erosion should be specified and should be developed with regard to preventing soil loss in order to maintain land capability / suitability and preventing significant degradation of local waterways by suspended solids.	Geology, Landform and Soils Study	Section 4.2.1: Study-Specific Landform Features and Geomorphological Processes Section 5.2.3: Landscape Susceptibility to Erosion (Erodibility) and Erosion Hazard Section 5.3: Sensitivity Ranking and Overall Terrain Unit Sensitivity Section 7.1: Generic Environmental Impacts – Land Degradation Section 7.3: Feed Gas Pipeline Impacts Section 7.4: LNG Plant Impacts Section 7.5: Temporary and Permanent Infrastructure Impacts Section 8.1.1: Land Degradation Management Measures Section 8.1.2: Timing of Disturbance Section 8.1.3: Management of Topographic Constraints Section 8.2: Feed Gas Pipeline Management Measures Section 8.3: LNG Plant Management Recommendations
3.2.3.1	In particular, the EIS should indicate if the land affected by the proposal is, or is likely, to become part of the protected area estate, or is subject to any treaty. The following should be identified and mapped: • National parks. • Marine parks (State and Commonwealth). • Conservation parks.	Geology, Landform and Soils Study	Section 4.6: Specific Sites of Environmental Significance – Geoheritage Section 5.1: Terrain Unit Mapping and Environmental Values Figure 5.1 Figure 5.1a

Section No.	Terms of Reference Requirement	Technical Specialist	Technical Report Section Reference
	• Nature refuges (conservation agreements). • Declared fish habitat areas. • Wilderness areas. • Areas of state significance (scenic coastal landscapes). • Areas of state significance (natural resources). • Coastal wetlands. • Aquatic reserves. • Heritage/historic areas or items. • National estates. • World heritage listings and sites covered by international treaties or agreements (e.g. Ramsar, JAMBA, CAMBA). • Areas of cultural significance. • Scientific reserves. MNES under the Commonwealth's EPBC Act should be described in section 8 and mapped where possible.		
3.2.6.1	The EIS should contain strategies aimed at minimising the amount of land disturbed at any one time. The strategic approach to progressive rehabilitation should be described. The consistency of the approach with relevant guidelines should be provided. The methods to be used for the project, including backfilling, covering, re-contouring, topsoil handling and revegetation, should be described.	Geology, Landform and Soils Study	Section 8.1.1: Land Degradation Management Measures Section 8.1.6: Backfill and 8.2.3: Backfill and Padding Section 8.1.5: Soil Management Section 8.1.7: Rehabilitation
12.2	A cross reference table should be provided which links the requirements of each section/subsection of the TOR with the corresponding section/subsection of the EIS where those requirements have been addressed.	Geology, Landform and Soils Study	Appendix B