11. GEOLOGY, LANDFORM AND SOILS

This chapter describes the geology, landform and soil environment within and surrounding the Arrow LNG Plant project area. The objectives of this chapter are to describe the existing environment in the Gladstone region; identify environmental values to protect within the project area; discuss the potential impacts on environmental values from the construction, operation and decommissioning of the project; and propose measures to mitigate these impacts.

This chapter is informed by the Arrow LNG Plant geology, landform and soils impact assessment prepared by Coffey Geotechnics Australia Pty Ltd (Appendix 2, Geology, Landform and Soils Impact Assessment). For impacts relating to acid sulfate soils refer to Chapter 12, Land Contamination and Acid Sulfate Soils.

Objectives have been developed based on the relevant legislative context with the aim of protecting the existing environment and identified environmental values. The objectives for geology, landform and soils are provided in Box 11.1.

Box 11.1 Objectives: Geology, landform and soils

- To avoid adverse impact on unique geological features during construction, operation and decommissioning.
- To avoid, minimise and manage impacts on the soil profile during construction, operation and decommissioning.
- To maintain soils to support the intended land use.
- To minimise alteration of drainage systems (natural and manmade) during construction, operation and decommissioning.
- To avoid adverse impact on statutorily recognised landforms during construction and operation.
- To effectively manage rehabilitation of environmental values post construction and decommissioning.

11.1 Legislative Context and Standards

In Queensland, geology, landform and soils are protected at three levels of government; Commonwealth, state and local. The legislation underpinning this protection is described below:

- *Environment Protection and Biodiversity Conservation Act 1999* (Cwth). Geological or landform features of national significance are recognised as geoheritage sites protected under this act. Geoheritage sites reflect importance within the context of Australia's natural history in terms of influence, rarity, unique characterisation or aesthetic value. Significant sites are recorded on the Australian Heritage Database administered by the Australian Heritage Council and Minister for the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPC, 2011a). Construction and operation of the Arrow LNG Plant will not impact the landform, geology and soils of any geoheritage sites protected under this act.

- *Nature Conservation Act 1992* (Qld). This act aims to conserve natural and physical resources in Queensland, recognising areas that represent biological diversity, natural features and wilderness. The act prescribes the designation and management of these locations as 'protected areas'. Construction and operation of the Arrow LNG Plant will not impact the landform, geology and soils of any protected areas under this act.

- *Vegetation Management Act 1999* (Qld). This act aims to manage and reduce land degradation as a result of vegetation clearance. In accordance with this act, measures have been taken to manage the impacts of vegetation clearance on this project.
- *Sustainable Planning Act 2009.* This act has been designed to coordinate planning at the local, regional and state levels within Queensland, and manages the processes by which development occurs. Subordinate to the act are state planning policies. The following state planning policies are relevant to management of geology, landform and soils:
  - State Planning Policy 1/92: Development and the Conservation of Agricultural Land 1992. This policy aims to protect good quality agricultural land (GQAL) as an economic resource for the region. The project terms of reference require an assessment of agricultural land under this policy. As the project area is largely contained within the industrial zone of the Gladstone State Development Area (excluding TWAF 7 and TWAF 8), the requirement for a GQAL assessment is effectively superseded in these places. In recognition of the terms of reference, this chapter considers GQAL classifications for land in the project area.
  - State Planning Policy 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide 2003. This policy requires developments to minimise potentially adverse influences on flooding, bushfire and landslide for people, property, economic activity and the environment in the surrounding area. This policy was considered when developing mitigation measures to address flood and landslide impacts of the project.
- Curtis Coast Regional Coastal Management Plan 2003 (EPA, 2003). This plan describes how the Curtis Coast regional zone should be managed in accordance with the State Coastal Management Plan 2002 (DERM, 2002a). The plan identifies key landscapes of state significance, some of which occur within the geology, landform and soils study area, and prescribes measures to preserve them. These areas have been taken into consideration when identifying the sensitivity of environmental values in the study area.

11.2 Assessment Method

The geology, landform and soils impact assessment study area extends a radius of 3 km around the project area to assist in defining the regional context. This chapter predominantly discusses the geology, landform and soils within the project area. For details of the wider regional context, refer to Appendix 2, Geology, Landform and Soils Impact Assessment.

A baseline assessment consisting of a desktop study and field study was undertaken to establish the existing geology, landform and soils environment. Impacts were assessed using a significance assessment method. This determined the significance of impacts from the construction, operation and decommissioning of the project.

11.2.1 Baseline Assessment

The desktop study involved a review of available mapping, previous impact assessments, and the development of a geospatial database (using geographic information system (GIS) software). The database was used to map areas with similar geology, landform and soil characteristics and properties, known as terrain units. Preliminary mapping was groundtruthed during a field visit targeted to observe existing rock and soil exposures and sensitive parts of the study area.

The following information was reviewed to identify the existing geology, landform and soils environment:

- Geological information was sourced from geological mapping including Queensland Department of Employment, Economic Development and Innovation 1:100,000 digital geological mapping and Queensland Department of Resource Industries 1:100,000 geological maps.
- Landforms of the study area were assessed using a combination of satellite imagery and aerial photography. Topographical contours at 10 m intervals were used to create a digital elevation model, which allowed identification of key landforms and calculation of slope steepness.
- The Australian Heritage Database (DSEWPC, 2011a) and Curtis Coast Regional Coastal Management Plan (EPA, 2003) were reviewed to identify elements of the landscape of national and local significance.
- Soils data was sourced from the Queensland Department of Environment and Resource Management land suitability and land systems mapping. The soil environment was described according to the Australian soil and land survey field handbook (CSIRO, 2009). Soils were grouped using morphological and chemical properties of the soil profile in accordance with the Australian soil classification system (Isbell, 2002).
- GQAL mapping of the mainland by the Department of Natural Resources was reviewed. However, GQAL mapping was not available for Curtis Island. Presence of GQAL was assessed in accordance with State Planning Policy 1/92 and planning guidelines for identifying good quality agricultural land (DPI & DHLGP, 1993). GQAL classes are defined under the guidelines, as follows: class A (cropland), class B (limited cropland), class C (pasture land) and class D (non-agricultural land).

This information was supplemented by relevant publicly available geology, landform, soil and geotechnical investigations.

The study area was divided into a series of terrain units representative of areas with broadly similar characteristics, attributes and behaviours. Terrain units were used to highlight the differentiation of environmental values throughout the project area and reflect the way the landscape responds to disturbance (i.e., its sensitivity). The terrain unit categorisation can be broad, and local variation may occur within each terrain unit.

11.2.2 Significance Assessment

The significance of potential impacts on the terrain units and their environmental values in the project area were assessed using the significance assessment method, combining sensitivity of the environmental value and magnitude of the impact (see Chapter 9, Impact Assessment Method). The sensitivity and magnitude of impact in a geological, landform and soils context are defined in the following sections. Launch site 4N is not considered in this assessment as land in this area has not yet been reclaimed.

Sensitivity

The sensitivity of the geological, landform and soils environmental values is governed by the susceptibility of their physical and chemical attributes to change in response to natural process and artificial disturbance, and by their significance to society (measured in accordance with statutory measures). Sensitivity is related to both the intrinsic properties of the terrain units and the geomorphic processes likely to occur in the area. Seven key attributes of terrain unit values were used to assess the overall sensitivity of each terrain unit. These attributes are defined as follows:

- Conservation status or geoheritage asset. This attribute recognises statutory significance of landforms and geoheritage assets. Areas with geoheritage status under Commonwealth legislation are considered highly sensitive. Areas unique to the region, such as areas declared as state forests or areas depicted as key sites under the Curtis Coast Regional Coastal Management Plan (EPA, 2003) are considered moderately sensitive. Areas commonly observed elsewhere in the region or nationally are classified as low sensitivity.
- Good quality agricultural land (GQAL). This attribute recognises deep fertile soils that sustain good agricultural output. Areas of GQAL (class A or B) are considered highly sensitive where disturbance is likely to reduce the productivity. Areas of class C or D land are considered to have low sensitivity, and disturbance is less likely to further reduce the productivity of the land.
- Susceptibility to water erosion. This attribute recognises the erodibility of soil (or rock) in response to water erosion processes (both surface and subsurface). Erodibility is related to the physical and chemical properties of soil and rock. Erosion is a naturally occurring process but it can be exacerbated by anthropogenic disturbance. Friable silty soils, dispersive subsoils with low organic matter and sodic texture contrast soils are highly sensitive to water erosion. Sandy, loamy soils, or non-dispersive clays are moderately sensitive; and coarse sandy soils or well-structured soils with high organic matter have low sensitivity.

  In addition to soil type, the erodibility of soils is greatly influenced by rainfall characteristics, slope steepness and length, and perennial vegetation coverage. Variability of these parameters across a single terrain unit can lead to correspondingly variable degrees of erodibility.
- Susceptibility to wind erosion. This attribute recognises the erodibility of soil in the presence of wind erosion processes. Sensitivity to wind erosion is high in soils with fine, loose surface material and low vegetation cover; medium in texture contrast soils with fine sandy loam topsoils; and low in cohesive dense soils (such as shallow, gravelly soils). Dust generation is likely in areas that are susceptible to wind erosion.
- Salinity. This attribute recognises the sensitivity of soils to adverse salinity following ground disturbance. Saline soils can cause vegetation scalding and die off, and erosion when disturbed. Saline soils occur naturally but can develop as a result of anthropogenic interference or transport of naturally occurring saline soils to non-saline environments. Marine muds have high sensitivity to salinity related adverse impacts following disturbance. Low lying coastal plains and areas with texture contrast soils and sodic subsoils (i.e., soils with an exchangeable sodium percentage greater than 6%) are moderately sensitive. Inland areas and transitional zones between saline and non-saline soils are considered to have low sensitivity to adverse impacts from salinity.
- Soft soils. This attribute recognises the susceptibility of soft soils to waterlogging and compaction. Deep texture contrast soils and marine muds are considered highly sensitive. Deep, gradational to uniform soils, which may be seasonally waterlogged, are considered moderately sensitive. Shallow, dense gravelly soils are considered to have low sensitivity.
- Rehabilitation potential. This attribute reflects the potential for reinstatement of the soil profile and successful revegetation during and following rehabilitation. Rehabilitation potential is a function of soil fertility, structure, textural profile and slope steepness. Areas that may be easily reinstated following disturbance (high rehabilitation potential) are moderate to high fertility soils with deep uniform profiles and shallow slopes. Areas with moderate rehabilitation potential

include well structured soils with moderate fertility; and areas with low rehabilitation potential include texture contrast soils, compacted or shallow soils with low fertility on steep slopes.

Within a terrain unit, the variability of landform characteristics can affect the sensitivity of the above attributes. Therefore, the overall sensitivity (high, moderate or low) for each terrain unit was based on the key factors influencing landscape sensitivity within that unit.

Magnitude

The magnitude of an impact is a measure of its severity, geographic extent and duration defined as follows:

- Severity of impact. This measure considers the scale or degree of change from the existing environment that may be experienced as a direct result of a project activity. A high severity of impact on the landscape relates to major land degradation, an impact of moderate severity occurs where a change is detectible but not severe and an impact of low severity is either unlikely to be detectible or detectable but small scale.
- Geographical extent. This measure considers the footprint of the impact. Regional impacts that may be detected up to 10 km away as a result of a project activity are considered to be high extent. Local impacts that extend some way beyond the project area are considered moderate, and impacts limited to the project area are considered low.
- Duration. This measure considers the timescale of an impact. High duration impacts are those where full landscape recovery may take up to 25 or more years, moderate duration impacts are where recovery is medium term (up to 10 years) and low duration impacts are those where recovery is expected to be short term (up to 3 years).

The overall magnitude of a potential impact (high, moderate or low) was classified based on the combined severity, extent and duration of that impact.

Significance of Impacts

The significance of an impact on environmental values is a product of the sensitivity of the value itself and the magnitude of the impact it experiences. The matrix below (Table 11.1) shows how the significance of geology, landform and soils impacts has been assessed.

Table 11.1 Geology, landform and soils significance matrix

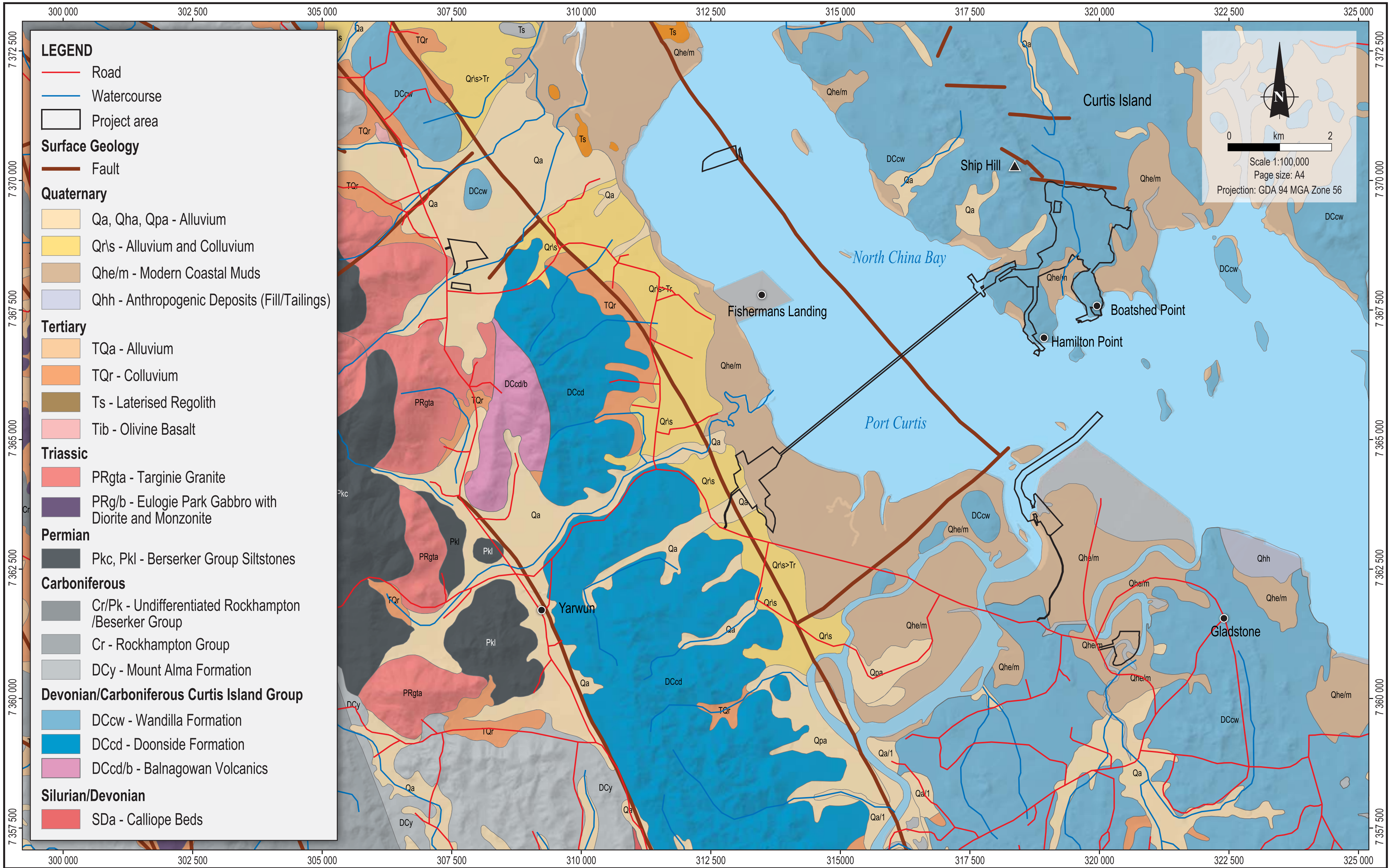
	Sensitivity of Environmental Value		
Magnitude of Impact	**High**	**Moderate**	**Low**
High	**Very High**	**High**	**Moderate**
Moderate	**High**	**Moderate**	**Low**
Low	**Moderate**	**Low**	**Negligible**

11.3 Existing Environment and Environmental Values

This section describes the existing geology, landform and soils environment in the Gladstone region, the geomorphological processes acting on this environment, and the terrain units that represent the environmental values of the landscape in the project area.

11.3.1 Geology

This section describes the geological evolution and geology of the study area and wider Gladstone region. Regional geology is shown on Figure 11.1.



Source:
Place names, roads, watercourses and faults from DME.
Project area and digital elevation model from Coffey Environments.
Surface geology and structure from DME 1:100,000 digital geological mapping.

coffey environments

Date:	15.11.2011
MXD:	7033CA_07_GIS170_v1_2
File Name:	7033_07_F11.01_GIS_GL

Arrow Energy

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Regional geology

Figure No:
11.1

Geological Evolution

The central Queensland coast represents an area of complex structural geology. The strait dividing mainland Australia and the western coast of Curtis Island (Port Curtis) follows the alignment of a major fault zone that divides the Coastal Block tectonic unit from the mainland Berserker Block.

The Coastal Block is dominated by Curtis Island Group sedimentary rocks. Within this group, the Wandilla Formation overlies the older Doonside Formation. The group comprises Devonian to Carboniferous age sediments that were deposited on a continental slope that formed the margin of the Australian land mass. The group is dominated by series of fining upwards sequences, typical of coastal shelf landslides, forming conglomerate (comprised of coarse fragments), sandstone and mudstone (comprised of fine fragments). These sequences are intensely folded and faulted as a result of movement of the earth’s crust at the tectonic boundary.

To the west of the Yarrol Fault (outside the study area), the region is dominated by sedimentary sequences of the Carboniferous Rockhampton Group and the Permian Berserker Group. These sequences have been intruded by felsic volcanic rocks in places.

Tectonic instability during the Cretaceous and Tertiary periods resulted in igneous intrusions of granite and trachyte, which form the high peaks of the Mount Larcom Range. Later in the Tertiary period, tectonic stability resulted in deep weathering producing the lateritic soils seen in the region today.

Geological Structure, Faulting and Seismic Activity

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

Faulting within the Coastal Block resulted in development of the downthrust block that forms Port Curtis, now partially infilled by thick (possibly up to 1,000 m) sedimentary sequences, overlying the Wandilla Formation. Faulting has also produced a high degree of rock type variability and depth to rock. The location of major faults may not be well defined by the geological mapping, as their surface expressions are masked by the drape of more recent sediments. Curtis Island Group sediments are typically folded and faulted. Minor faulting occurs throughout the study area.

The study area is one of the most tectonically active in Australia, and the most active area in Queensland. The region has been subject to earthquakes strong enough to cause damage to buildings and infrastructure, on average, every five years over the last century. The study area is generally considered to be at low risk of fault movement, liquefaction or earthquake induced slope instability. Liquefaction may be a risk within the coastal and marine muds and reclaimed land.

Surface Geology

The study area is characterised by folded, steeply dipping, well-jointed, variable strength, variably weathered sedimentary sequences of mudstone and siltstone outcrops. Exceptions to these more fine-grained sequences include:

- The sandstones, conglomerates and breccias of the Wandilla and Doonside formations, particularly on Curtis Island.
- Occasional limestone layers and conglomerate clasts that may outcrop within the Wandilla Formation on Curtis Island.
- Igneous intrusions and flows including:

  - Mafic basalt plug to the northeast of Mount Larcom Range.
  - Intermediate Balnagowan Volcanics within the Doonside Formation to the east of Mount Larcom and andesitic Targinie Granite on the eastern flanks of the Mount Larcom Range.
  - Felsic granite forming the eastern foothills of the Mount Larcom Range, trachyte forming the Mount Larcom peaks and rhyolitic intrusions along the northwest flanks of the Mount Larcom Range. Felsic dykes are also found intruded into the Wandilla Formation at Boatshed Point.
- Contact metamorphic rocks and weakly metamorphosed quartzose mudstone and sandstone associated with the above igneous intrusions.

At the LNG plant site, the geology 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 hogback ridgelines and hilltops, with weaker, thinly interbedded finer-grained rocks, including mudstones, forming valleys.

Lower lying areas throughout the study area are blanketed by Tertiary and Quaternary alluviums associated with fluvial and hillslope processes. Tertiary and Quaternary colluvium has accumulated along lower slopes of hills throughout. Marine muds are found along coastal fringes, bays and estuaries.

Mineral Resources

Mineral resources in the study area include the Stuart Oil Shale deposit located west of Targinnie; this resource does not outcrop in the project area.

11.3.2 Landform

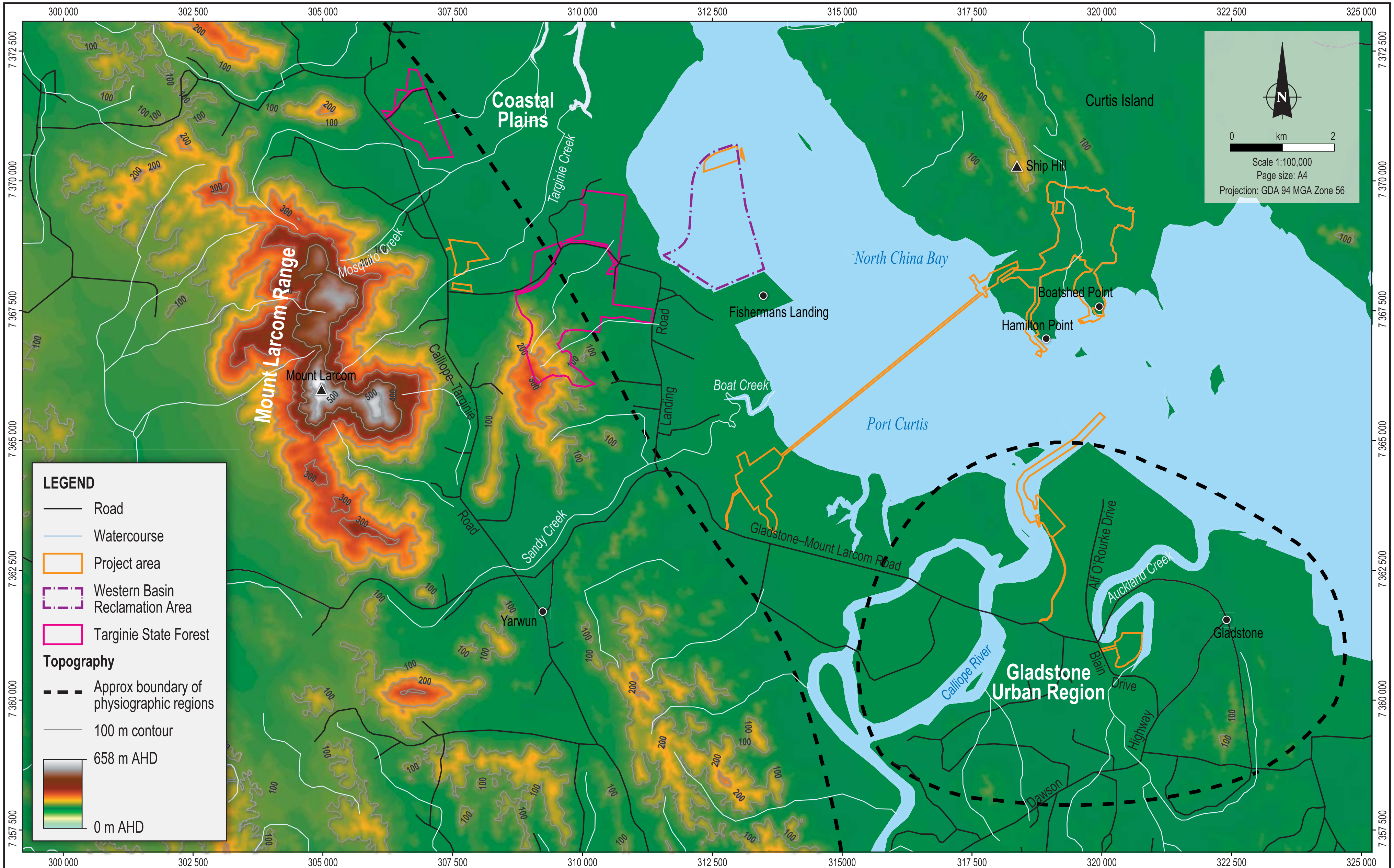
Landscape features (landforms) of the study area are strongly influenced by the underlying geology and geomorphological evolution. Landforms range from low lying coastal plains to high elevation and relief hills and mountain ranges. Figure 11.2 shows the topography and key landform features within the study area.

The Gladstone urban region is characterised by large scale artificial alteration associated with rapid recent industrial development. 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, as well as large areas of reclaimed land.

The study area does not contain landform sites listed on the Australian Heritage Register. The Curtis Coast Regional Coastal Management Plan recognises certain sites within or adjacent to the project area as key elements of the coastal landscape, including:

- Hogback ridges on Curtis Island.
- Mount Larcom and the Mount Larcom Range.
- Coastal plains of Port Curtis.
- Targinie State Forest.

Southern Curtis Island is characterised by a series of north northwest trending, steep sided hogback ridges and remnant hills rising above broad, deeply gullied valleys, and separated by broad intertidal mudlfats. Hogbacks are formed by the erosion of tilted sedimentary rocks, when the bedrock dips at greater than about 40°. The dip slope (i.e., the slope parallel to the dip of the rock) is roughly symmetrical to the scarp slope (the eroded face). These features are common in



Source:
Place names, roads and watercourses from DME.
Targinie State Forest from DERM.
Project area and digital elevation model from Coffey Environments.
Topography constructed from DERM 5m contours.

coffey environments

Date: 17.11.2011
MXD: 7033CA_07_GIS171_v1_3
File Name: 7033_07_F11.02_GIS_GL

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Regional topography

Figure No: 11.2

the Wandilla and Doonside formations. The dominating landform of southern Curtis Island is the hogback ridge known as The Spine, which rises to 173 m AHD at Ship Hill. Associated remnant hills can rise up to 100 m above the surrounding valleys. The ridges and hills form a significant part of the coastal landscape and the Curtis Coast Regional Coastal Management Plan recommends that development in these areas is restricted to below ridgelines and that any scarring of the landscape be screened or rehabilitated.

Mount Larcom is the highest point in the region with an elevation of 658 m AHD. The striking peaks and crags loom above the forested surrounding area. The mountain forms part of the Mount Larcom Range, located west of Yarwun and Targinnie. The Mount Larcom Range is referenced as a key site in the Curtis Coast Regional Management Plan. 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.

A low relief coastal plain is located to the east of the Mount Larcom Range. This land is generally below 20 m AHD, with slopes of below 5°. The coastal 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 presence of oil shale and mineral deposits (outside the study area), combined with flat, relatively undeveloped land of the coastal plains, has led to considerable industrial development and landform modification along this strip. 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 and around such landforms should maintain vegetation buffers to reduce impacts from acid sulfate soils and disturbance of sedimentation, natural drainage and tidal patterns.

The Targinie State Forest and surrounding remnant vegetation is characterised by coastal landforms that support remnant vegetation and wildlife corridors. Under the Curtis Coast Regional Management Plan, development in this area is considered a management issue and alterations to sedimentation and erosion rates in adjacent areas must be managed to prevent impacts on the values of this site.

11.3.3 Soils

Soils in the study area are varied and have been categorised into six broad groups based on their physical and chemical properties. These are:

- Marine clays. These soils are typically grey, uniform sandy clay soils formed from marine sediments under wet, saline conditions at elevations below 5 m AHD. Organic matter content can be high where the soils have been colonised by mangroves (Plate 11.1). They can be acid sulfate soils or potential acid sulfate soils, with a typical pH of less than 4 due to oxidisation of sulfides. Marine clays are classified as intertidal hydrosols or supratidal hydrosols under the Australian soil classification system. Within the study area, marine clays are found in intertidal flats or areas with shallow, saline groundwater along the west and south coast of Curtis Island, and the east coast of the mainland.
- Gradational soils. Two types of gradational soils were identified within the study area. Both types typically have a gradual increase in clay content with depth:
  - Gradational clays. These soils typically grade from a silty clay loam to a clay with depth, and are generally red or brown in colour (Plate 11.2). Subsoils can be sodic. These soils are classified as dermosols or ferrosols. Within the study area, gradational clays are found

in isolated areas of the low lying coastal plains (Curtis Island and the mainland) and along the base of the Mount Larcom Range.

– Gradational loams. These soils typically grade from a loamy sand to a sand clay loam. They can be shallow, acidic and generally with a high gravel content. These soils are classified as kandosols or tenosols and are found on the mid slopes of Curtis Island.

- Texture contrast soils. These soils have a clear, abrupt or sharp change in particle size (texture) between the surface horizon and subsoil (Plate 11.3). Subsoils can be strongly acidic and are commonly sodic. These soils are classified as sodosols, chromosols or kurosols. Within the study area, texture contrast soils are found on lower slopes of Curtis Island on the mainland, and on undulating land of the flanks of Mount Larcom.
- Alluvial sands. These sandy soils are typically very shallow and may contain water worn rounded gravels and cobbles. These soils are classified as rudosols or tenosols and, within the study area, occur in isolated areas along creek lines and creek terraces.
- Rocky skeletal soils. These are shallow soils which occur adjacent to rock outcrops (Plate 11.4). These soils are classified as rudosols and occur on steep slopes or tops of ridges, hills and mountains.
- Imported fill. Soils of unknown origin used to fill artificially modified areas are classified as anthroposols. Within the study area, imported fill is observed in areas modified by the residential and industrial sprawl of Gladstone City.

Soils that contain enough sodium to affect the structural stability of the soil are termed sodic. When these soils become wet, the clay particles lose their bond and disperse. Erosion of dispersive soils tends to occur along existing cracks within the soil mass, with material carried by flowing water. Sodic soils are prone to sheetwash, rilling and gully erosion, particularly during the intense rainfall events that are characteristic of the local area.

Within the project area, soils are generally of class C or class D agricultural land, predominantly used for grazing beef cattle (where industrial or residential development has not occurred) (see Figure 30.2). Ferrous gradational clay soils along the foothills of the Mount Larcom Range are suitable for agricultural production and include 9.5 ha of GQAL (class A or B agricultural land) located within the TWAF 8 site. This land is not farmed at present.

11.3.4 Geomorphological Processes

Erosion is the most commonly observed geomorphological process in the study area. 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. Rills are small channels (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. Within the study area, runoff, rill and gully erosion are characteristic of erodible soils (particularly on Curtis Island), especially where flows have become concentrated. Along the coastal margins, wind erosion of susceptible soils can occur, especially where surface cover has been removed.

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).

Source: Coffey

Plate 11.1
Example of marine clay soils on the mainland

Source: Coffey

Plate 11.2
Example of gradational clay soils on Curtis Island

Source: Coffey

Plate 11.3
Example of texture contrast soils on Curtis Island

Plate 11.4

Example of rocky skeletal soils on the mainland

Landslides are typically triggered by prolonged or intense rainfall (the latter being a characteristic of the region). Earthquakes may also trigger failures on susceptible slopes. No evidence of large scale slope instability was found within the study area.

11.3.5 Terrain Units and Environmental Values

The study area was divided into 7 terrain units and 17 subunits (Figure 11.3) based on geology, landform and soil characteristics, properties and behaviour in the study area. Of these, seven subunits are located within the project area (renumbered from those used in Appendix 2, Geology, Landform and Soils Impact Assessment, for clarity):

- Terrain unit 1: contemporary coastal flats.
- Terrain unit 2: coastal rises and plains.
- Terrain unit 3a: undulating rises and plains of the Wandilla Formation.
- Terrain unit 3b: steeply undulating hills and rises of the Wandilla Formation.
- Terrain unit 4a: undulating rises and hills of felsic igneous uplands.
- Terrain unit 4b: steeply undulating rises and hills of felsic igneous uplands.
- Terrain unit 5: artificially altered areas.

The environmental values and sensitivity of terrain units within the project area are discussed in Table 11.2. Further detail on the complete range of terrain units in the wider Gladstone region is contained in Appendix 2, Geology, Landform and Soils Impact Assessment.

11.4 Issues and Potential Impacts

Earthworks and ground disturbance have the greatest potential to impact on landform, geology and soils within the project area. It is anticipated that the majority of impacts will be experienced during the construction phase when the area of land disturbed is the greatest. Impacts during operation will be reduced following partial rehabilitation. Impacts during decommissioning will relate to the degree of landscape re-profiling and rehabilitation required.

A series of common impacts will be experienced across most project locations due to similar construction activities taking place; these are defined as general impacts. The significance of these impacts is a function of the sensitivity of the land being disturbed and the magnitude of disturbance caused by the project activity. The significance of impacts is discussed by project activity.

11.4.1 General Impacts

All project activities resulting in ground disturbance or vegetation removal may lead to land degradation as a consequence of erosion, compaction, concentration of water runoff and disruption of the soil profile. Ground disturbance can also lead to secondary and offsite impacts including erosion, transport and deposition of sediments and generation of dust. These land degradation processes often occur in combination, increasing the significance of impacts experienced.

Erosion

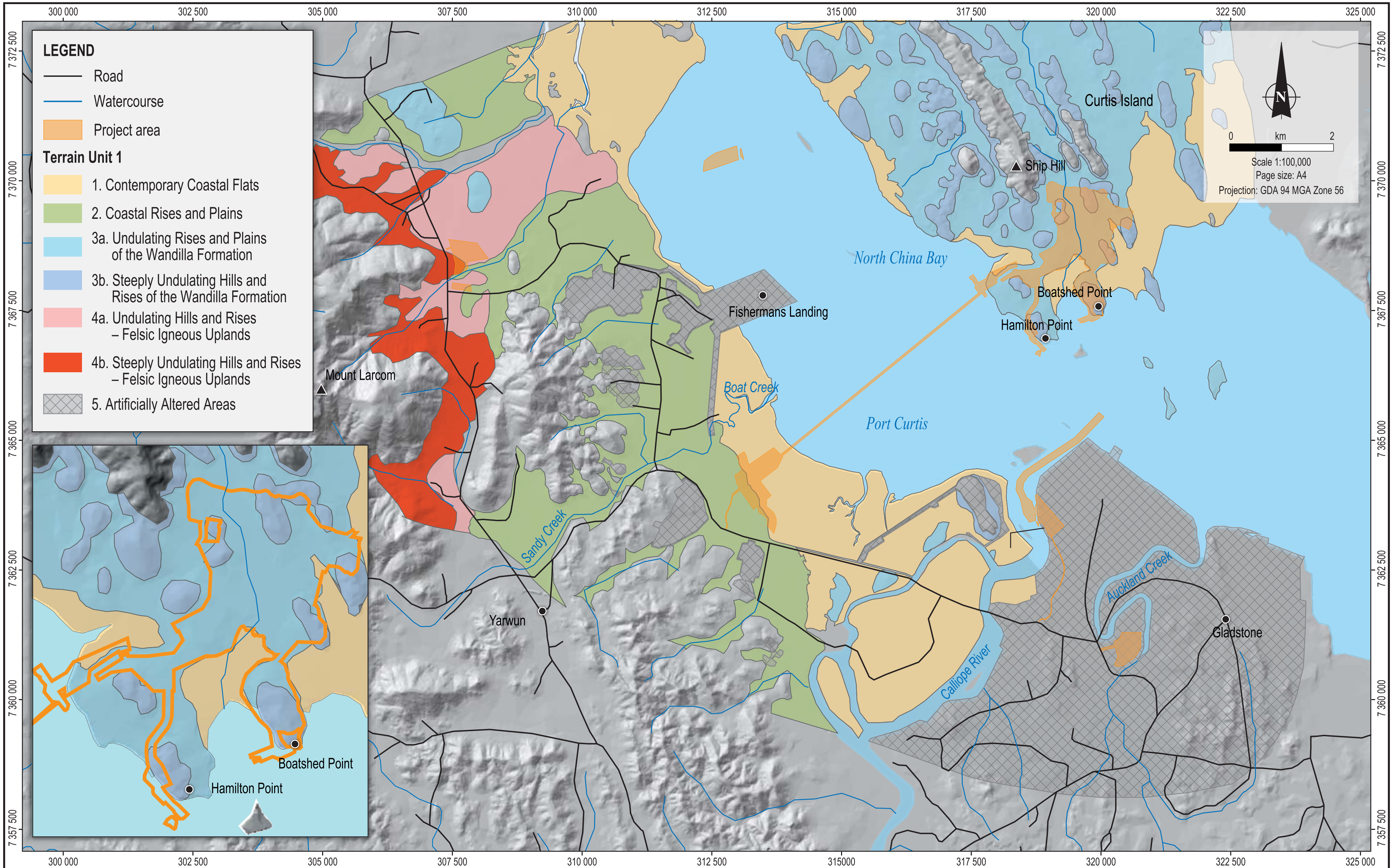
Erosion can be exacerbated as a result of ground disturbance, vegetation clearance, alteration of natural drainage and flow concentration due to construction activities (i.e., excavation, trenching, drilling, earthmoving). Erosion is more likely in erodible soils (particularly sodic soils) and in areas without ground cover (i.e., vegetation). Project components, such as access tracks and laydown areas, which have been cleared of vegetation and are subject to trafficking (which can result in

Table 11.2 Geology, landform and soil terrain units

Location within Project Area	Environmental Values		Sensitivity
	Geology, Landform and Soils	Intrinsic Landscape Properties	
Terrain Unit 1: Contemporary Coastal Flats			**Moderate**
Curtis Island: • Along sections of the Boatshed Point haul road option. • Adjacent to proposed maintenance workshops. Mainland: • Majority of the tunnel entrance and tunnel spoil disposal area footprint.	• Tidal flats along Curtis Island and mainland coastlines. • Geologically recent marine muds.	• Acid sulfate soils. • Salinity. • Soft soils. • Regular tidal inundation.	• Port Curtis marine plains key regional coastal site. • Soft, saline, soils prone to compression and moderately susceptible to erosion. • Risk of liquefaction (if seismic activity occurs). • Rehabilitation constrained by salinity and waterlogging. • Acid sulfate soils requiring rehabilitation are likely to occur.
Terrain Unit 2: Coastal Rises and Plains			**Moderate**
• Feed gas pipeline tunnel entrance and access track. • Southwest corner of TWAF 8.	• Gently undulating coastal rises and plains. • Colluvial and alluvial gradational loam and clay loam soils, with areas of texture contrast soils.	• Areas of sodic, erodible, hard crusting, saline soils. • Waterlogging. • Variable soil type/depth.	• Targinie remnant vegetation and Targinie State Forest key regional coastal sites (outside project area). • Texture contrast soils are moderately sensitive to salinity, waterlogging and erosion, which may constrain rehabilitation. • Soils with fine loamy topsoils are moderately sensitive to wind erosion particularly in low-lying areas.
Terrain Unit 3a: Undulating Rises and Plains of the Wandilla Formation			**Moderate**
• Majority of LNG plant site. • Hamilton Point feed gas pipeline reception shaft.	• Gently undulating relief dissected by deep gullies. • Variable colluvial or alluvial soils; shallow soils on slopes, texture contrast soils on valley floors.	• Variable soil depth. • Erodible, sodic soils. • Salinity near coastline. • Undulating terrain. • Rill and gully erosion. • Flash flooding in narrow valleys.	• Southwest Curtis Island hogback ridges key regional coastal site. • Soft, compressible texture contrast soils with thin topsoils and sodic subsoils that are prone to waterlogging. • Soils highly sensitive to water erosion, moderately sensitive to wind erosion, and prone to rapid gullying. • Rehabilitation potential constrained by soil profile and poor fertility.

Table 11.2 Geology, landform and soil terrain units (cont'd)

Terrain Unit 3b: Steeply Undulating Hills and Rises of the Wandilla Formation			**Moderate**
• Steep slopes on the LNG plant site. • Boatshed Point construction camp. • Hamilton Point MOF option.	• Steeply undulating relief. • Wandilla Formation. • Gradational and shallow, rocky soils.	• Soil depth dependent on slope position overlying variable strength rock. • Erodible, sodic subsoils. • Steeply undulating terrain. • Rill and gully erosion.	• Element of southwest Curtis Island hogback ridges key regional coastal site. • Sodic subsoils highly sensitive to water erosion (exacerbated by steep slopes). • Rehabilitation potential constrained by low fertility soils and steep slopes.
Terrain Unit 4a: Undulating Rises and Hills of Felsic Igneous Uplands			**Moderate**
• Northern section of TWAF 8.	• Undulating rises and hills. • Colluvial texture contrast soils from felsic igneous hills.	• Acidic, sodic, erodible soils. • Waterlogging. • Rill and gully erosion.	• Mount Larcom Range key regional coastal site. • Texture contrast soils highly sensitive to water erosion (particularly on steeper slopes) and waterlogging, and moderately sensitive to wind erosion. • Rehabilitation potential constrained by soil profile and poor fertility.
Terrain Unit 4b: Steeply Undulating Rises and Hills of Felsic Igneous Uplands			**Moderate**
• Southern section of TWAF 8.	• Steeply undulating rises and hills. • Felsic igneous intrusions (trachyte and rhyolite). • Sandy gradational soils becoming more clay rich with depth.	• Can be acidic. • Areas of GQAL along flanks of igneous uplands, where deep, gradational soil is present. • Generally shallow soils; variable depth to variable strength rock.	• Mount Larcom Range key regional coastal site. • Soils moderately sensitive to water erosion (particularly on steeper slopes) and waterlogging. • Rehabilitation potential constrained in areas of shallow soils or steeper slopes.
Terrain Unit 5: Artificially Altered Areas			**Moderate**
• TWAF 7. • Launch site 1.	• Predominantly characterised by former fly ash settling ponds.	• Sheetwash, rill and wind erosion. • Compaction and waterlogging. • Salinity.	• Highly sensitive to water and wind erosion. • Prone to compaction, salinity and waterlogging. • Risk of liquefaction (if seismic activity occurs). • Low rehabilitation potential due to poor soil fertility.



Source:
Place names, roads and watercourses from DME.
Project area and digital elevation model from Coffey Environments.
Terrain units digitised by Coffey Geotechnics.

coffey environments

Date: 28.11.2011
MXD: 7033CA_07_GIS172_v1_1
File Name: 7033_07_F11.03_GIS_GL

Arrow Energy

Arrow LNG Plant

arrow energy go further

Geology, landform and soil terrain units

Figure No: 11.3

compaction and concentration of runoff along wheel ruts) are particularly susceptible to rill and gully erosion. Disturbed soils, which have been left uncompacted, may also be prone to erosion, e.g., stockpiles that have not yet settled to an equilibrium consolidation state.

Erosion processes may occur throughout the project area. The erodible soils of terrain unit 3a on Curtis Island and sodic texture contrast soils within terrain unit 4a are highly susceptible to erosion. Project activities that may cause concentration of runoff include wheel rutting along access tracks, poorly compacted trenches and foundation pads, fencing and the building of structures.

Slope Instability

Slopes susceptible to instability in the project area include the erodible soils of terrain units 3a and 3b on Curtis Island.

The project design has avoided most steep slopes or will remove them through earthworks. Some areas on Curtis Island may still exhibit slope instability during construction, including localised slopes greater than 15° along the side slopes of the Hamilton Point and Boatshed Point heavy haul road options and areas dissected by gully networks at the northeast corner of the LNG plant site.

Where borrow pits are excavated in the local area, steep slopes are often created around the pit margins. These have the potential to become unstable, particularly if associated with adverse geological and drainage conditions.

The rainfall that is characteristic of the Gladstone region may exacerbate the intensity and frequency of landslides by artificial over steepening and destabilisation. Earthquakes may also trigger failures on susceptible slopes. A detailed seismic hazard assessment undertaken for the project indentifies that the four faults crossing the Gladstone region do not pose any fatal flaws associated with active faulting (Arup, 2010).

Soil Compaction

Soil compaction can occur when the ground is subject to loading. Soft, compressible soils are common in low lying and low relief areas. These areas include the LNG plant site and haul roads on Curtis Island; the mainland entry shaft for, and access road to, the feed gas pipeline; and fly ash settlement ponds on TWAF 7 and launch site 1.

Activities that may compact soils include construction of buildings, the movement of vehicles moving along access tracks, storage of components in laydown areas, placement of spoil and temporary soil stockpiling. The soft, waterlogged marine mud of terrain unit 1 is particularly prone to compaction. This soil will be affected by construction and operation of the heavy haul road along Boatshed Point and during deposition of tunnel spoil and construction of the tunnel entrance site.

Compaction of clay soils can impact long term crop productivity. Topsoil disturbance of soils in the GQAL area of TWAF 8 is likely to result in a long term reduction in fertility levels within the project area.

Sedimentation

Within the project area, sedimentation is likely to occur downslope, downstream or downwind of any site where erosion has been exacerbated by project activities. The large scale earthworks at the LNG plant site are likely to generate significant quantities of erodible material that may be transported downstream and downslope unless appropriately managed.

Disturbance of Unfavourable Soils

Project activities involving excavation may expose unfavourable soils, i.e., those which are sodic, saline, compressible, acid sulfate soils or prone to waterlogging. Within the project area, sodic soils are typical on Curtis Island and along the flanks of the Mount Larcom Range. Construction activities likely to disturb sodic soils include cut and fill activities associated with earthworks.

Saline soils within the project area are associated with coastal and marine muds subject to tidal inundation. Saline subsoils are likely to be exposed in terrain unit 1 and coastal areas of terrain units 2 and 3a. Project activities that are likely to disturb saline soils include earthworks (e.g., trenching and tunnelling) at the feed gas pipeline mainland entry shaft and tunnel, and earthworks along the low lying coastal margins of Port Curtis. Stockpiling of these subsoils may lead to salt ingress into non-saline soils.

Reduced Soil Quality

The quality of soils can be reduced by inversion of the soil profile, long term stockpiling and introduction of imported soils. Soil quality may be compromised during earthworks including excavation, stockpiling and backfilling. Most soils within the project area have a low fertility, which can be further reduced by stockpiling. The removal of construction material from borrow pits often exposes shallow, remnant or residual soils in the borrow areas, making revegetation difficult.

Dust Generation

Soils with fine, loose surface material (gradational loams and texture contrast soils) are moderately susceptible to dust generation when disturbed. These soils occur in terrain unit 2 at the tunnel launch site access track, terrain units 3a and 3b on Curtis Island, and terrain unit 4a at TWAF 8. Silty ash pond material at TWAF 7 and launch site 1 is also prone to dust generation when disturbed.

Project activities likely to generate dust include vegetation clearing, topsoil stripping, vehicle movements (haul roads and access tracks), pipeline trenching, earthworks and blasting.

Rock, Soil and Mineral Resources

Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site, as part of the bulk earthworks. Alternatively, aggregate will be sourced from mainland quarries and transported to the plant site by barge as required. The requirement and location of quarries or borrow pits will be further investigated through the FEED process prior to construction. A concrete batching plant will be established on the plant site, and bulk cement will also be delivered to the site by barge.

Construction materials required include (approximately):

- Moderately weathered rock for cut and fill requirements (1,600,000 m^3).
- Fresh rock sourced to meet cut and fill requirements (700,000 m^3).
- Aggregate or rock for shore protection (100,000 m^3).
- Sand (140,000 m^3).
- Cement (100,000 m^3).

Geological resources of extractive value are not expected to be impacted or sterilised by project activities.

11.4.2 Significance of Impacts

The significance of impacts experienced across the project area will vary due to the differing sensitivity of terrain units, and differing magnitude of impact from project activities. This section assesses the magnitude of impact prior to successful implementation of management and mitigation measures, and resultant significance of impacts for terrain units within the project area.

LNG Plant

This section considers the LNG plant site, Boatshed Point construction camp, and Hamilton Point and Boatshed Point haul road options on Curtis Island. Construction and operation of this infrastructure will disturb areas of terrain units 1, 3a and 3b.

Construction of the LNG plant will involve extensive earthworks to transform a naturally undulating landscape to a series of platforms of elevations between approximately 10 m AHD and approximately 18 m AHD. Ridges will be cut into, while saddles and gullies will be filled to achieve these level platforms. Most structures will have shallow, engineered rock fill foundations while those subject to heavy loads or tall buildings (e.g., the flare) are likely to have piled foundations. General impacts associated with the LNG plant construction and operation include erosion, reduction in soil quality and down system sedimentation. The most significant impact will be the large scale topographic alteration of the project area.

The project design avoids most steep slopes or will remove them through earthworks. The large scale earthworks on Curtis Island could cause slope instability, particularly where steep hills are partially removed, and along the side slopes of the Hamilton Point and Boatshed Point haul road options. Failures in bedrock are more likely to occur where a relatively permeable layer overlies a relatively impermeable layer, or where rock defects dip towards the artificial cut. Areas with deep colluvium, especially on steep slopes (greater than 20°) are also more likely to be destabilised.

Large scale filling of two bay heads above the intertidal zone east and west of Boatshed Point will modify the local topography, and could affect the local sediment dynamics. An increase in down system sediment outputs from this area may occur. In many areas, the topographic alterations will require removal of the entire soil profile. Stockpiling of considerable quantities of material for extended periods of time will be necessary, resulting in medium term topographic alteration.

Eastern sections of the LNG plant site (near administrative buildings) are located partly within terrain unit 1. Construction of the LNG plant will result in localised permanent topographic change to reach the required bench heights. Specifically, two bay heads will be filled during construction. These landforms represent the down system limits of land based processes. Their alteration will have a major impact on the sediment dynamics of the affected area and natural soils will be buried. The magnitude of impact at the LNG plant locations is high, the sensitivity of the terrain unit is moderate and the resulting significance of impact is **high**.

The Boatshed Point haul road will also affect a small area of terrain unit 1. Impacts may include minor topographic change, and disturbance, compaction and burial of the soft, saline marine muds. The magnitude of impact in this limited area is low, the sensitivity of the terrain unit is moderate and the significance of impact is **low**.

The majority of the LNG plant site, Boatshed Point construction camp and Hamilton Point and Boatshed Point haul road options are located within terrain unit 3. Construction will involve permanent large scale topographic change. Gullying and slope instability may be triggered, particularly along artificially steepened slopes, or the naturally steep slopes of terrain unit 3b. Large amounts of eroded and disturbed sediment may enter watercourses and be transported down system into Port Curtis. The magnitude of impact at the LNG plant and construction camp is high, the sensitivity of the terrain unit is moderate and the resulting significance of impact is **high**. The haul road is anticipated to have a lower impact due to the small spatial extent of disturbance. The magnitude of impact is moderate, and the resulting significance of impact is **moderate**.

Parts of the LNG plant site, laydown areas and Boatshed Point construction camp and Boatshed Point haul road options are located within the steep slopes of terrain unit 3b. Soils in this terrain unit are erodible and impacts of gullying and slope instability are likely. Large amounts of eroded and disturbed sediment may enter watercourses and be transported down system into Port Curtis. The magnitude of impact at the LNG plant and construction camp is high, the sensitivity of the terrain unit is moderate and the resulting significance of impact is **high**. The Boatshed Point haul road traverses a small section of terrain unit 3b. The route traverses erodible soils and steep slopes, and impacts relating to gullying and slope instability are likely. The magnitude of impact at this location is moderate, the sensitivity of the terrain unit is moderate and the resulting significance of impact is **moderate**.

Feed Gas Pipeline

Construction of the feed gas pipeline will disturb areas of terrain units 1 and 2 on the mainland and terrain unit 3a on Curtis Island. The feed gas pipeline will require tunnelling under Port Curtis (with a mainland tunnel entry shaft south of Boat Creek and a reception shaft at south Hamilton Point on Curtis Island), and a length of trenching or underboring on either side of the tunnel. The tunnelling of the feed gas pipeline will produce a significant amount of spoil which will be deposited in a contained stockpile adjacent to the mainland entry shaft. The largest impacts are anticipated to be associated with trenching and tunnel spoil stockpiling:

- Trenching: Differential settlement of backfill and fill may cause depressions or mounds to form, which could lead to drainage concentration and gullying or waterlogging. Burial of the feed gas pipeline in subsoil (particularly sodic subsoils) may create preferential pathways for subsurface flow, resulting in piping erosion. Collapse of the subsurface void created by this erosion may lead to pipeline exposure.
- Tunnel spoil disposal: Storage of tunnel spoil on marine muds is likely to compress the saline waterlogged soils of this area. Tunnel spoil itself is likely to be waterlogged and have different physical/chemical properties to that of the surface soils. Differential settlement of tunnel and trench spoil may create preferential surface and subsurface drainage pathways. Leakage of tail water could cause alteration of soil chemistry and destabilisation of spoil stockpiles.

The mainland tunnel entry shaft and supporting infrastructure is predominantly situated within terrain unit 1. Soils within this terrain unit are susceptible to waterlogging and compression and impacts of this nature are anticipated during construction of the tunnel entrance pad and laydown areas. Trenching and excavation activities are likely to disturb and displace saline soils and may result in oxidisation of potential acid sulfate soils. Deposition of tunnel spoil material onto the mudflat could cause sedimentation of surrounding areas and chemical contamination of the existing topsoil. The spatial extent of disturbance is limited but impacts may extend out the project footprint and could result in a long term effect on the landscape. The magnitude of impact at this location is high, the sensitivity of the terrain unit is moderate and the significance of impact is **high**.

The access track for the mainland tunnel entry shaft and some laydown areas are located on terrain unit 2. Soils in this terrain unit are susceptible to surface and subsurface erosion, compaction and dust generation, particularly as a result of heavy vehicle trafficking. The magnitude of impact at this location is moderate, the sensitivity of the terrain unit is moderate and the significance of impact is **moderate**.

The tunnel reception shaft on Hamilton Point and the feed gas pipeline trench to the LNG plant are located within terrain unit 3a. Soils in this terrain unit are susceptible to surface and subsurface erosion, compaction and dust generation. The impact footprint is of limited spatial extent, and recovery is anticipated to be medium. The magnitude of impact in this location is low, the sensitivity of the terrain unit is moderate and the significance of impact is **low**.

TWAF 7

Construction of TWAF 7 will disturb areas of terrain unit 5. The landform, geology and soils of this site are already significantly modified due to the effects of previous uses as a temporary ash pond and laydown area. The magnitude of impact at this location is low. The sensitivity of this terrain unit is moderate, resulting in a **low** significance of impact.

TWAF 8

Construction of TWAF 8 will disturb areas of terrain units 2, 4a and 4b.

The TWAF 8 site will impact a small area of terrain unit 2. Construction will involve surface works with a small area of disturbance. Project impacts are anticipated to be minor and landscape recovery is expected to be short term. The magnitude of impact at this location is low and the sensitivity of the terrain unit is moderate, resulting in a **low** significance of impact.

The majority of the TWAF 8 site is located on terrain unit 4a. The sodic texture contrast soils in this terrain unit are susceptible to erosion, compaction and waterlogging. Impacts are anticipated to be minor due to shallow slopes and limited requirement for cut and fill. The greatest impacts are likely to be associated with traffic movements along access tracks. The magnitude of impact at this location is low and the sensitivity of this terrain unit is moderate, resulting in a **low** significance of impact.

Construction of the temporary workers accommodation will temporarily remove approximately 9.5 ha of GQAL from potential agricultural production in terrain unit 4b. Soils in this terrain unit are moderately erodible, and recovery is anticipated to be medium term. The magnitude of impact at this location is moderate and the sensitivity of the terrain unit is moderate, resulting in a **moderate** significance of impact.

Launch site 1

Construction of launch site 1 will disturb areas within terrain unit 5. The landform, geology and soil at this site have already been significantly modified through human activity. The site contains erodible saline soils and fly ash prone to waterlogging and compression. The magnitude of impact at this location is low and the sensitivity of the terrain unit is moderate, resulting in a **low** significance of impact.

Summary of Impacts

A summary of the geology, landform and soil impacts across the project area is shown in Table 11.3.

Table 11.3 Summary of significance of impacts on terrain units

	Curtis Island (LNG Plant)	Curtis Island (Haul Roads)	Feed Gas Pipeline	TWAF 7	TWAF 8	Launch Site 1
Terrain unit 1: contemporary coastal flats	High	Low	High			
Terrain unit 2: coastal rises and plains			Moderate		Low	
Terrain unit 3a: undulating rises and plains of the Wandilla Formation	High	Moderate	Low			
Terrain unit 3b: steeply undulating hills and rises of the Wandilla Formation	High	Moderate				
Terrain unit 4a: undulating hills and rises of the felsic igneous uplands					Low	
Terrain unit 4b: steeply undulating hills and rises of the felsic igneous uplands					Moderate	
Terrain unit 5: artificially altered areas				Low		Low

11.5 Avoidance, Mitigation and Management Measures

This section describes measures to avoid, mitigate and manage the potential impacts on geology, landform and soils from the construction, operation and decommissioning of the project. Where possible, impacts have been avoided through project design. The remaining impacts will be reduced through mitigation and management measures. A set of general mitigation measures will be adopted across the wider project area, with site specific management measures applied to areas with a high significance of impact.

11.5.1 General Mitigation

General mitigation measures have been developed in accordance with the following industry standard management guidelines:

- International Erosion Control Association’s best practice erosion and sediment control manual (IECA, 2008).
- Australian Pipeline Industry Association’s code of environmental practice for onshore pipelines (APIA, 2009).

The following mitigation measures are sorted by impact and are applicable to all areas during construction, operation and decommissioning.

Erosion

- Limit clearing of vegetated areas to the project area. Areas will be stabilised and progressively rehabilitated to reduce prolonged exposure of soils. [C11.05]
- Consider use of erosion matting (jute mesh) or sediment socks (sand filled, UV-resistant fabric tubes) in areas of ground disturbance outside of purpose built drainage channels. [C11.06]
- Manage surface runoff to reduce concentration of surface flow, particularly in erodible soils. Provide drainage channels with suitable design features to minimise erosion where surface runoff is disrupted by roads, tracks, fencing and buildings. Place structures within drainage channels to reduce flow velocity where appropriate. [C11.07]

- Rehabilitate batters, embankments and borrow pits and revegetate as soon as practical after construction. Reinstate areas no longer required for construction or support services and revegetate as per planting and seeding rehabilitation plans to be developed for the project. [C11.28]

Slope Instability

- Do not create slopes that are steeper than is appropriate for the material encountered. Consider the orientation of cut batters compared with the orientation of bedrock defects. Where batters exceed 10 m in height and 3 m wide, construct benches at 10 m intervals,unless local conditions dictate otherwise. [C11.08]
- Avoid works near stream banks during periods of heavy rainfall where practical. If works cannot be timed to avoid heavy rainfall, adopt additional measures, such as the use of berms and silt fences. [C11.09]
- Prior to construction, carry out geotechnical investigations to assess site specific ground conditions and provide recommendations on slope placement, geometry and drainage. [C11.01]

Soil Compaction

- Exclude vehicles from operating in areas not in use for construction or operation and, in general, restrict vehicles to designated access tracks. [C11.10]

Sedimentation

- Implement sediment and erosion control measures upslope of watercourses, wetlands and coastal areas or in areas with sodic soils to minimise increases in natural sediment discharge. Measures may include sediment traps, silt fencing, riprap, contour banks, detention dams, sediment ponds and vegetation and diversion berms. [C11.11]
- Use control measures such as drains, swales, silt fencing and sediment traps around the lower slopes of erodible stockpiles. [C11.12]

Disturbance of Unfavourable Soils

- Where sodic soils are encountered, implement control measures (such as soil ameliorants) to soils and soil stockpiles to reduce dispersion, waterlogging and crusting. [C11.13]
- For pipeline trenching activities reinstate soil profiles to pre disturbance orientation, where practical, using excavated topsoil. [C11.14]
- Design saline and sodic subsoil stockpiles to reduce ponding and salt migration to non-saline soils. [C11.15]
- Cap excavated sodic or saline subsoils with non-sodic or non-saline topsoil material, during reinstatement. [C11.27]

Maintaining Soil Quality

- Prior to construction, prepare topsoil stripping guidelines, which include a schedule and location of areas to be stripped. Quantify the soil type, depth and resources and establish a handling method. Nominate appropriate, site-specific stripping depths and characterise for suitability for use in rehabilitation works. [C11.03]
- Prior to construction commencing, develop a site drainage plan to define how the civil construction will address site drainage, stormwater management, erosion control and stockpile

placement. Risks relating to flood events will also be addressed with appropriate mitigation measures to minimise erosion and surface water quality issues. [C11.16]

- Store topsoil, subsoil and sediment trap soil in separate stockpiles to avoid mixing soil types and introducing salinity to non-saline soils. [C11.17]
- Design topsoil stockpiles to allow for nutrient cycling. [C11.18]
- Where insufficient topsoil is available at the site, use comparable topsoil imported for rehabilitation. Marine clays, skeletal soils, rock or gravelly soils will not be used in the rehabilitation of topsoil layers. [C11.19]

Dust Generation

- Control speed limits on site via posted speed limit signs and confine vehicles generally to marked trafficable areas. [C11.20]
- Keep trafficked surfaces damp during construction with sprayed water when conditions are dry to suppress dust generation. Use water of a similar quality to that which is available in the locality and do not spray as concentrated flow. [C11.21]

11.5.2 Site Specific Mitigation

It is anticipated that impacts on the geology, landform and soils of the study area from the LNG plant site and mainland tunnel entrance and tunnel spoil disposal area for the feed gas pipeline will be of high significance. This section outlines site-specific mitigation measures for managing these high significance impacts.

LNG Plant

The project has been designed to limit the amount of excavation required on Curtis Island as far as is practical to reduce the topographic impact. The following measures will be adopted to further reduce the level of impact at the LNG plant site:

- Design and construct a barrier and sediment control pond to trap sediment leaving the LNG plant site before it enters the Port Curtis marine environment or other surface waters. [C11.22]
- Protect stream channels in soils prone to gully erosion with rock armouring or other appropriate structures and material to reduce erosion potential. [C11.23]
- Consider the thickness of colluvium, orientation and gradient of cut batters and orientation of bedrock defects when designing cut and fill locations to reduce the potential for slope destabilisation. [C11.24]
- Re-profile and reinstate topsoil, vegetation and re-establish a stable surface, where practical, during decommissioning and rehabilitation of the LNG plant site. [C11.29]

Feed Gas Pipeline

The following measures will be adopted to reduce the level of impact from construction of the feed gas pipeline:

- Design the tunnel spoil placement area to minimise adverse impacts associated with ground compaction, erosion and surface water runoff such that a self sustaining landform is achieved. Incorporate appropriate drainage measures into the design. [C11.04]
- Prior to construction, carry out geo-environmental investigations to identify the depths at which saline soils occur in terrain unit 1, and coastal areas of terrain units 2 and 3a. The cut and fill

program will be designed to segregate saline soils from non-saline soils, where these soils are intended for stockpiling for future rehabilitation of the site. [C11.02]

- Batter or shore trench walls in soft, waterlogged soils (particularly in terrain unit 1) to increase stability. [C11.25]
- Do not use saline, acidic or sodic soils for backfill padding of trenched pipelines where alternatives are available. [C11.26]

11.6 Significance of Residual Impacts

The magnitude of residual impacts and resulting significance of impact is low for all activities across all terrain units, excluding terrain units 1, 3a and 3b on Curtis Island.

The magnitude of residual impacts from the LNG plant on terrain units 1, 3a and 3b on Curtis Island is moderate. This reduces the significance of potential impacts to moderate. The large scale earthworks will result in major topographic and landscape system changes, including major localised disruption or removal of landform and soils. Successful implementation of erosion control plans and rehabilitation plans will reduce the magnitude of impact. Successful rehabilitation of the LNG plant site will produce a stable, safe, non-polluting landform with self sustaining soil fertility; and it will reduce the long term significance of impacts.

Sensitive rehabilitation of terrain unit 5 could improve the environmental values and condition of the TWAF 7 site and launch site 1. The capping of fly ash and establishment of vegetation is anticipated to have a positive residual impact.

11.7 Inspection and Monitoring

Conduct inspections at regular intervals during construction to check that mitigation measures are effective in reducing the magnitude of impact and:

- Record location and types and rates of visible erosion.
- Record location of settlement or subsidence of backfill.
- Check for the build-up of sediment in sediment traps.
- Test soils in areas sensitive to salinity.
- Identify areas where ground cover is inadequate.
- Observe and record effectiveness and integirity of erosion control measures.
- Test runoff water and quantify material being eroded and deposited downstream.

Inspect sensitive areas after intense rainstorm events, where appropriate, and maintain erosion control structures where required.

Monitor rehabilitation works quarterly for the first year post construction and annually thereafter until rehabilitation is considered successful in accordance with established performance criteria.

11.8 Commitments

The measures (commitments) that Arrow Energy will implement to manage impacts on geology, landform and soils are set out in Table 11.4.

Table 11.4 Commitments: Geology, landform and soils

No.	Commitment
C11.01	Prior to construction, carry out detailed geotechnical ground investigations to assess site specific ground conditions and provide recommendations on slope placement, geometry and drainage.
C11.02	Prior to construction, carry out geo-environmental investigations to identify the depths at which saline soils occur in terrain unit 1, and coastal areas of terrain units 2 and 3a. The cut and fill program will be designed to segregate saline soils from non-saline soils, where these soils are intended for stockpiling for future rehabilitation of the site.
C11.03	Prior to construction, prepare topsoil stripping guidelines, which include a schedule and location of areas to be stripped. Quantify the soil type, depth and resources and establish a handling method. Nominate appropriate, site specific stripping depths and characterise for suitability for use in rehabilitation works.
C11.04	Design the tunnel spoil placement area to minimise adverse impacts associated with ground compaction, erosion and surface water runoff such that a self sustaining landform is achieved. Incorporate appropriate drainage measures into the design.
C11.05	Limit clearing of vegetated areas to the project area. Areas will be stabilised and progressively rehabilitated to reduce prolonged exposure of soils.
C11.06	Consider use of erosion matting (jute mesh) or sediment socks (sand filled, UV-resistant fabric tubes) in areas of ground disturbance outside of purpose built drainage channels.
C11.07	Manage surface runoff to reduce concentration of surface flow, particularly in erodible soils. Provide drainage channels with suitable design features to minimise erosion where surface runoff is disrupted by roads, tracks, fencing and buildings. Place structures within drainage channels to reduce flow velocity where appropriate. Common with Chapter 13, Surface Water Hydrology and Water Quality.
C11.08	Do not create slopes that are steeper than is appropriate for the material encountered. Consider the orientation of cut batters compared with the orientation of bedrock defects. Where batters exceed 10 m in height and 3 m wide, construct benches at 10 m intervals, unless local conditions dictate otherwise.
C11.09	Avoid works near stream banks during periods of heavy rainfall where practical. If works cannot be timed to avoid heavy rainfall, adopt additional measures, such as the use of berms and silt fences. Common with Chapter 13, Surface Water Hydrology and Water Quality, and Chapter 18, Freshwater Ecology.
C11.10	Exclude vehicles from operating in areas not in use for construction or operation and, in general, restrict vehicles to designated access tracks.
C11.11	Implement sediment and erosion control measures upslope of watercourses, wetlands and coastal areas or in areas with sodic soils to minimise increases in natural sediment discharge. Measures may include sediment traps, silt fencing, riprap, contour banks, detention dams, sediment ponds and vegetation and diversion berms. Common with Chapter 13, Surface Water Hydrology and Water Quality.
C11.12	Use control measures such as drains, swales, silt fencing and sediment traps around the lower slopes of erodible stockpiles. Common with Chapter 13, Surface Water Hydrology and Water Quality.
C11.13	Where sodic soils are encountered, implement control measures (such as soil ameliorants) to soils and soil stockpiles to reduce dispersion, waterlogging and crusting.
C11.14	For pipeline trenching activities, reinstate soil profiles to predisturbance orientation, where practical, using excavated topsoil.
C11.15	Design saline and sodic subsoil stockpiles to reduce ponding and salt migration to non-saline soils.

Table 11.4 Commitments: Geology, landform and soils (cont'd)

No.	Commitment
C11.16	Prior to construction commencing, develop a site drainage plan to define how the civil construction will address site drainage, stormwater management, erosion control and stockpile placement. Risks relating to flood events will also be addressed with appropriate mitigation measures to minimise erosion and surface water quality issues. Common with Chapter 13, Surface Water Hydrology and Water Quality.
C11.17	Store topsoil, subsoil and sediment trap soil in separate stockpiles to avoid mixing soil types and introducing salinity to non-saline soils.
C11.18	Design topsoil stockpiles to allow for nutrient cycling.
C11.19	Where insufficient topsoil is available at the site, use comparable topsoil imported for rehabilitation. Marine clays, skeletal soils, rock or gravelly soils will not be used in the rehabilitation of topsoil layers.
C11.20	Control speed limits on site via posted speed limit signs and confine vehicles generally to marked trafficable areas. Common with Chapter 21, Air Quality.
C11.21	Keep trafficked surfaces damp during construction with sprayed water when conditions are dry to suppress dust generation. Use water of a similar quality to that which is available in the locality and do not spray as concentrated flow. Common with Chapter 21, Air Quality.
C11.22	Design and construct a barrier and sediment control pond to trap sediment leaving the LNG plant site before it enters the Port Curtis marine environment or other surface waters.
C11.23	Protect stream channels in soils prone to gully erosion with rock armouring or other appropriate structures and material to reduce erosion potential. Common with Chapter 13, Surface Water Hydrology and Water Quality.
C11.24	Consider the thickness of colluvium, orientation and gradient of cut batters and orientation of bedrock defects when designing cut and fill locations to reduce the potential for slope destabilisation.
C11.25	Batter or shore trench walls in soft, waterlogged soils (particularly in terrain unit 1) to increase stability.
C11.26	Do not use saline, acidic or sodic soils for backfill padding of trenched pipelines where alternatives are available.
C11.27	Cap excavated sodic or saline subsoils with non-sodic or non-saline topsoil material, during reinstatement.
C11.28	Rehabilitate batters, embankments and borrow pits and revegetate as soon as practical after construction. Reinstate areas no longer required for construction or support services and revegetate as per planting and seeding rehabilitation plans to be developed for the project.
C11.29	Re-profile and reinstate topsoil, vegetation and re-establish a stable surface, where practical, during decommissioning and rehabilitation of the LNG plant site. Common with Chapter 13, Surface Water Hydrology and Water Quality.