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GEOLOGY, LANDFORM AND SOILS STUDY
ARROW ENERGY SURAT GAS PROJECT, SURAT BASIN, QUEENSLAND

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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 Surat Gas Project Environmental Impact Statement. Arrow Energy proposes to expand its coal seam gas operations in the Surat Basin, 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 project. Coffey Geotechnics' report provides the following:

- Study background and legislative context, where relevant to the geology, landform and soils study. Description of the Arrow Surat Gas Project and project activities relevant to the geology, landform and soils study (Section 1);
- Method of assessment (Section 2);
- Description of the existing geology, landform and soils of the study area, including sites of environmental significance (geoheritage) (Section 3);
- 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 4);
- Assessment of environmental constraints and design considerations associated with the geology, landform and soils of the study area (Section 5);
- 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 6);
- Management recommendations to mitigate against identified potential impacts, including inspection and maintenance programme recommendations (Section 7);
- Assessment of potential residual impacts following successful implementation of recommended management and mitigation measures (Section 8);
- Cumulative impact assessment (Section 9);
- Conclusion (Section 10).

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. A desk 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. As soils mapping at a scale suitable for the study was not available, the findings of the desk study were used to divide the study area into areas which have broadly similar characteristics, properties and environmental values, known as "terrain units". The terrain mapping was ground-truthed through observation of existing exposures of rock (December 2009), a targeted soils investigation (November/December 2009), and associated laboratory testing. The findings of the desk 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 3 broad physiographic regions associated with 3 major river catchments: the Condamine River, the Dawson River and the Border Rivers. These regions have the following characteristics:

- Condamine River: A broad alluvial valley flanked by the Great Dividing Range to the east (comprising resistant igneous rocks rising to over 800 mAHD) and the sandstone Kumbarilla Ridge (rising to 420 mAHD) to the west. Isolated remnant basalt mesas (rising to over 600 mAHD) and lower-relief sandstone jumpups form steep rocky hills to the south. The valley floor is characterised by extensive, intensively farmed Brigalow clay plains (GQAL), which are reactive and extensively gilgaied in places. In higher elevation areas, soils are shallow and gravelly.
- Dawson River: Characterised by broad, sandy alluvial river valleys dissecting laterised sandstone cuestas and basalt plateaux. Soils comprise rich agricultural clay soils (GQAL) on valley floors with pockets of texture contrast soils on valley floors and along the flanks and lower slopes of higher elevation areas. Shallow, gravelly soils are found at higher elevations.
- Border Rivers: Uplands associated with the sandstone Kumbarilla ridge fall in a southwesterly directly to broad Brigalow clay and sandy alluvial plains. Along the edges of the upland area, remnant resistant sandstone has formed distinct isolated ridges and swarms of jumpups (rising up to 100 m in height). Pockets of gilgai occur. Land-use is predominantly grazing, despite widespread GQAL due to lower rainfall, micro-relief and sandy soils.

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. Six broad units were defined and further sub-divided into 19 sub-units according to the intrinsic landscape properties and characteristic geomorphic processes.

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

- The Chinchilla Sands Local Fossil Fauna Site (about 3 km southeast of Chinchilla), listed on the DSEWPC Register of the National Estate. Lake Broadwater Conservation Park (at the foot of the Kumbarilla Ridge west-northwest of Tipton) is protected by an environmental park status. The Barakula State Forest Area and Scientific areas (within the northern extent of the Kumbarilla Ridge) are indicative places on the Register of the National Estate;
- Widespread occurrence of GQAL (covering about 5000 km^2 and nearly 60% of the study area) and Strategic Cropping Land (covering nearly 50% of the study area) along valley floors;
- Erodible and saline soils associated with sodic sub-soils throughout the study area;
- Soft and/or waterlogged soils prone to compression and erosion associated with 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, particularly sensitivity to water erosion (erodibility).

The overall sensitivity of terrain units impacted by the project was assessed to be moderate, other than the Chinchilla Sands Local Fossil Fauna Site, which was assessed to have a high sensitivity due to its geoheritage status. 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, highly reactive, compressible soils. These properties may cause erosion-related site damage, trafficability problems and slope instability. Localised steep slopes (associated with jumpups, mesa and plateaux edges and cuesta escarpments) may increase the level of constraint to the point where they are considered "No Go" areas.

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; introduced salinity and disturbance of fossils within the Chinchilla Sands geological formation. Other potential impacts are related to activities associated with specific project components. Levelling of large facilities sites may require semi-permanent or permanent topographic alteration. Pipeline-specific impacts include differential settlement of trench backfill, possibly resulting in creation of preferential surface and subsurface pathways. The study area contains GQAL and Strategic Cropping Land, which may be subject to particular impacts. These may include loss or fragmentation of agriculturally productive soils; adverse changes to soils; and disturbance of the topography of laser-levelled paddocks.

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 project activities would typically have a high magnitude (and significance) of impact, given the erodibility of soils within the study area and large spatial extent of anticipated disturbance. Well sites are assessed to have a moderate magnitude (and significance) of impact (other than at the Chinchilla Sands Local Fossil Fauna Site, where the magnitude of impact will be high), as well sites will have a smaller-scale disturbance than other project activities.

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.

High sensitivity areas should be avoided where possible. These areas include the heritage-listed Chinchilla Sands Local Fossil Fauna Site; GQAL and Strategic Cropping Land; and steep slopes. Specific management measures for fossil finds and GQAL should be adopted where avoidance is not possible. Given the widespread occurrence of intensive agriculture within the study area, consultation with landowners is recommended.

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 occasionally 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 activities, related to relevant project activities. In particular, measures to control activity-related land degradation, drainage and sedimentation (including construction and drilling by-products); agriculture; and reactive soils are recommended.

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 all project components. Sympathetic routing or site location; design, construction techniques, erosion-control measures and rehabilitation plans will reduce land degradation and recovery times. Rehabilitation of topographically-altered sites will be targeted to produce a stable, safe, non-polluting landform with self-sustaining soil fertility, thus resetting the baseline of the environmental values of the affected areas.

E8. CUMULATIVE IMPACT ASSESSMENT

The cumulative impact assessment considers only those future projects (either proposed or approved) that have synchronous timelines to the Surat Gas Project and that have the potential to impact the environmental values relevant to the geology, landform and soils within Arrow's defined project development area. Projects considered to be likely to impact the project development area included the Arrow Surat Pipeline, Australia Pacific LNG (pipeline component) and Queensland Curtis LNG (pipeline component). These pipeline projects appear to run along combined or adjacent corridors through the Kumbarilla Ridge, north of Miles. The proposed routes avoid heritage-listed and indicative heritage areas.

Potential residual impacts as a result of these projects include land degradation (erosion), disruption of GQAL, topographic alteration, dust creation; and impacts associated with poor rehabilitation potential of soils, trenching through rock and altered landforms. Successful implementation of management and mitigation measures should reduce the significance of these impacts to acceptable (i.e. low) levels with the exception of impacts to landforms. The number and spatial extent of infrastructure components and associated land disturbance activities associated with the Surat Gas Project is anticipated to be greater than those associated with the other pipeline projects considered. The impacts of these pipeline projects on the environmental values of the geology, landform and soils within the project development area will be limited to narrow, linear disturbance along the pipeline corridors.

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ABBREVIATIONS

AHD	Australian Height Datum
APIA	Australian Pipeline Industry Association
CBR	California Bearing Ratio
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management (QLD)
DHLGP	Department of Housing, Local Government and Planning (QLD)
DPI	Department of Primary Industries (QLD)
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities (QLD)
EC	Electrical Conductivity
EIS	Environmental Impact Statement
ESP	Exchangeable Sodium Percentage
GQAL	Good Quality Agricultural Land
IECA	International Erosion Control Association
KRA	Key Resource Area
LRA	Land Resource Area
mm/yr	Millimetres per year
MPa	Megapascals
Mya	Million years ago
NATA	National Association of Testing Authorities
RoW	Pipeline Right of Way
SPP	State Planning Policy
ToR	Terms of Reference
TU	Terrain Unit

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 "Soil Glossary" (Victoria) and Department of Environment and Resource Management (Queensland).

A Horizon	*n.*	Surface soil horizons which contain organic material.
Alluvial Fan	*n.*	Outspread mass of alluvium deposited by a flow when it debouches from a steeper, narrow canyon to a plain or valley floor.
Alluvium	*n.*	Sedimentary deposit made by rivers or streams.
Aeolian	*adj.*	Pertaining to wind action.
Anticline	*n.*	Upwardly convex fold with stratigraphically older rocks at the centre of the curvature.
B Horizon	*n.*	Subsoil horizons differing from the overlying A horizon by either colour, mineralogy, organic content or structure.
Bed Scour	*n.*	The removal of granular channel bed material by hydrodynamic forces.
Breccia	*n.*	A course grained, clastic rock comprised of angular lithic fragments either within a fine-grained matrix or bound by a mineral cement.
California Bearing Ratio (CBR)	*n.*	A standard penetration test for the evaluation of mechanical soil strength.
Cation	*n.*	A positively charged ion that migrates towards the cathode during electrolysis.
Cathode	*n.*	Negative electrode.
Chromosol	*n.*	ASC soil profile with a strong texture contrast, where the upper B-horizon is neither strongly acidic nor sodic.
Clear or abrupt soil horizon change	*n.*	Horizon boundary less than 50 mm in thickness.
Colluvium	*n.*	Unconsolidated material at the base of a slope or cliff that has been deposited by gravity.
Conglomerate	*n.*	A course grained, clastic rock comprised of approximately rounded fragments at least 2mm in diameter, and set within a fine grained matrix.
Convex	*adj.*	Having a surface that is curved outwards.
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.
Dermosol	*n.*	ASC soil profile lacking strong texture contrast, with a well structured B2 horizon, and low in free iron.
Dip	*n.*	The angle between a horizontal plane and an inclined surface or subsurface feature.
Dissection	*n.*	Erosion resulting in the cutting of ravines, gullies or valleys.
Downcutting	*n.*	Erosion of material from a steam bed or valley floor that results in the deepening of that particular feature.

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Downwarp	*n.*	Part of the crust that has been bent downwards or subsided.
Emerson Aggregate Test	*n.*	The classification of soil aggregates based on their coherence in water.
Escarpment	*n.*	A steep slope or cliff separating two relatively level areas of ground, resulting from erosion or faulting.
Fault	*n.*	A fracture in the Earth’s crust whereby opposite sides have been relatively displaced parallel to the plane of movement (fault plane).
Ferruginous	*adj.*	Red or rust-coloured due to the presence of ferric oxide.
Fining Upwards Sequence	*n.*	A sedimentary sequence consisting of a coarser grade base member overlain by a series of increasingly fine grained sediments. Such a sequence is associated with a reduction in hydraulic energy.
Fold	*n.*	A bend or buck in a structure as a result of deformation.
Gilgai	*n.*	Patterned or hummocky microrelief formed by the shrink/swell of Vertosols.
Gullying (Gully Erosion)	*n.*	Soil erosion by running water causing clearly defined, narrow, and usually ephemeral channels.
Incised Channel	*n.*	A stream or river channel which cuts through the bed of the valley floor.
Jumpup	*n.*	Steep-sided, rounded, isolated hills formed by remnant resistant sandstone.
Kandosol	*n.*	A non-calcareous ASC soil profile lacking strong texture contrast, with a massive or weakly structured B2 horizon.
Kaolinite	*n.*	Phyllosilicate clay mineral.
Kaolinisation	*n.*	The formation kaolinite by weathering/alteration of alkali feldspars.
Kurosol	*n.*	ASC soil profile with a strong texture contrast and strongly acidic B horizon.
Labile	*adj.*	Unstable, easily decomposed.
Laterisation	*n.*	Weathering of a substance into laterite.
Laterite	*n.*	Soil residue comprised of secondary oxides of iron and/or aluminium with clay minerals and silica.
Linear Shrinkage	*n.*	The decrease in length of a dispersive soil sample with an initial moisture content at the liquid limit when oven-dried.
Liquid Limit	*n.*	The moisture content of a soil at the boundary of liquid and plastic consistency
Low Order Stream	*n.*	A small recurring or perennial stream with few or no other stream systems feeding into it.
Marine Transgression	*n.*	The encroachment of the sea over land, usually induced by sea level rise.
Meander Bend	*n.*	A loop or curve within a stream channel.

GLOSSARY

Mesa	*n.*	An elevated area of relatively level land, surrounded by steeper slopes or cliffs. Mesas are smaller in extent than plateaux.
Microrelief	*n.*	Earth surface features that generally have a relief of less than 15m.
Monocline	*n.*	Local steepening of the dip of layered rock strata in an area where the bedding is otherwise relatively flat.
Onlap	*n.*	Successive increase in the area covered by beds in a sedimentary sequence, commonly related to transgression.
Optimum Moisture Content	*n.*	The water content at which a soil mass can be compacted to its maximum dry unit weight.
Outcrop	*n.*	An area where rocks occur at the surface.
Palaeochannels	*n.*	Inactive stream channel that is generally in filled with alluvium.
Ped	*n.*	A natural unit of soil structure formed by cracking along planes of weakness.
Plastic Limit	*n.*	The moisture content of a soil at the boundary of plastic and semi-solid consistency.
Plateau	*n.*	An elevated area of relatively level land, surrounded by steeper slopes or cliffs. Plateaux are larger in extent than mesas.
Point Load Strength Test	*n.*	Index test for rock strength classification.
Point Load Index	*n.*	The force needed to fracture a sample of rock between conical points.
Regolith	*n.*	Unconsolidated material overlying bedrock that has been formed by weathering, erosion, transport and/or deposition of older materials.
Rudosol	*n.*	ASC soil profile with negligible pedological development.
Sidelong	*adj.*	Directed to or from the side.
Silicification	*n.*	Introduction or replacement by silica.
Sodosol	*n.*	ASC soil profile with a strong texture contrast and strongly sodic, but not strongly acidic, B horizon.
Sub-Parallel	*n.*	Approximately parallel, but displaying minor convergence or divergence.
Subsidence	*n.*	The downwards settlement of material with little horizontal movement.
Syncline	*n.*	Upwardly concave fold with stratigraphically younger rocks at the centre of the curvature.
Tenosol	*n.*	ASC soil profile with weak pedological development that is typically sandy with naturally acidic surface soils.
Texture Contrast Soil	*n.*	Soils with a clear or abrupt change in texture between the A and B Horizons. A horizons are typically bleached.

GLOSSARY

Traprock	*n.*	Defined locally as metamorphosed sediments and volcanics
Stream Channel Erosion	*n.*	Erosion of the stream channel by hydrodynamic forces.
Tunnelling	*n.*	Sub-surface erosion caused by the movement of water through dispersive subsoils.
Unconformable	*adj.*	A layer that does not parallel underlying strata, or does not overlie rocks in an immediate age sequence.
Uniaxial Compressive Strength	*n.*	The value of uniaxial compressive stress that is reached when a material fails.
Uplift	*vb.*	Process by which one section of the earth is elevated above adjacent areas.
Vertosol	*n.*	Clay rich (>35%) ASC soil profile with a uniform texture and tendency to crack and slickenslide.

1. INTRODUCTION

This section of the report provides an overview of the Surat Gas Project (the project). An overview of the Geology Landform and Soils Study is also provided.

1.1 Project Proponent

Arrow Energy Pty Ltd (Arrow) is an integrated energy company with interests in coal seam gas field developments, pipeline infrastructure, electricity generation and proposed liquefied natural gas (LNG) projects.

Arrow has interests in more than 65,000 km^2 of petroleum tenures, mostly within Queensland's Surat and Bowen basins. Elsewhere in Queensland, the company has interests in the Clarence-Moreton, Coastal Tertiary, Ipswich, Styx and Nagoorin Graben basins.

Arrow's petroleum tenures are located close to Queensland's three key energy markets; Townsville, Gladstone and Brisbane. The Moranbah Gas Project in the Bowen Basin and the Tipton West, Daandine, Kogan North and Stratheden projects in the Surat Basin near Dalby comprise Arrow's existing coal seam gas production operations. These existing operations currently account for approximately 20% of Queensland's overall domestic gas production.

Arrow supplies gas to the Daandine, Braemar 1 and 2, Townsville and Swanbank E power stations which participate in the National Electricity Market. With equity in Braemar 2, Daandine and Townsville power stations Arrow has access to up to 600 MW of power generation capacity.

Arrow and its equity partner AGL Energy have access rights to the North Queensland Pipeline which supplies gas to Townsville from the Moranbah Gas Project. They also hold the pipeline licence for the proposed Central Queensland Gas Pipeline between Moranbah and Gladstone.

Arrow is currently proposing to develop the Arrow LNG Project, which is made up of the following aspects:

- Arrow LNG Plant – The proposed development of an LNG Plant on Curtis Island near Gladstone, and associated infrastructure, including the gas pipeline crossing of Port Curtis.
- Surat Gas Project – The upstream gas field development in the Surat Basin, subject of this assessment.
- Arrow Surat Pipeline Project – (Formerly the Surat Gladstone Pipeline), the 450 km transmission pipeline connects Arrow's Surat Basin coal seam gas developments to Gladstone.
- Bowen Gas Project – The upstream gas field development in the Bowen Basin.
- Arrow Bowen Pipeline – The transmission pipeline which connects Arrow's Bowen Basin coal seam gas developments to Gladstone.

1.2 Project Overview

Arrow proposes expansion of its coal seam gas operations in the Surat Basin through the Surat Gas Project. The need for the project arises from the growing demand for gas in the domestic market and global demand and the associated expansion of LNG export markets.

The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc adjacent Dalby. The towns of Brigalow, Cecil Plains, Chinchilla, Columboola, Dalby, Macalister, Millmerran and Warra are located within the project development area. Project infrastructure including coal seam gas wells and production facilities (including both water treatment and power generation facilities where applicable) will be located throughout the project development area but not in towns. Facilities supporting the petroleum development activities such as depots, stores and offices may be located in or adjacent to towns.

The conceptual Surat Gas Project design presented in the environmental impact statement (EIS) is premised upon peak gas production from Arrow's Surat Basin gas fields of approximately 1,050 TJ/d. The peak gas production comprises 970 TJ/d for LNG production (including a 10% fuel gas requirement for facility operation) and a further 80 TJ/d for supply to the domestic gas market.

A project life of 35 years has been adopted for EIS purposes. Ramp-up to peak production is estimated to take between 4 and 5 years, and is planned to commence in 2014. Following ramp-up, gas production will be sustained at approximately 1,050 TJ/d for at least 20 years, after which production is expected to decline.

Infrastructure for the project is expected to comprise:

- Approximately 7,500 production wells drilled over the life of the project at a rate of approximately 400 wells drilled per year.
- Low pressure gas gathering lines to transport gas from the wells to production facilities.
- Medium pressure gas pipelines to transport gas between field compression facilities and central gas processing and integrated processing facilities.
- High pressure gas pipelines to transport gas from central gas processing and integrated processing facilities to the sales gas pipeline.
- Water gathering lines (located in a common trench with the gas gathering lines) to transport coal seam water from production wells to transfer, treatment and storage facilities.
- Approximately 18 production facilities across the project development area expected to comprise of 6 of each of the following:
  - Field compression facilities.
  - Central gas processing facilities.
  - Integrated processing facilities.
- A combination of gas powered electricity generation equipment that will be co-located with project infrastructure and electricity transmission infrastructure that may draw electricity from the grid (via third party substations).

Further detail regarding the function of each type of production facility is detailed below.

Field compression facilities will receive gas from production wells and are expected to provide 30 to 60 TJ/d of first stage gas compression. Compressed gas will be transported from field compression facilities in medium pressure gas pipelines to multi-stage compressors at central gas processing facilities and integrated processing facilities where the gas will be further compressed to transmission gas pipeline operating pressure and dehydrated to transmission gas pipeline quality. Coal seam water will bypass field compression facilities.

Central gas processing facilities will receive gas both directly from production wells and field compression facilities. Central gas processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Coal seam water will bypass central gas processing facilities and be pumped to an integrated processing facility for treatment.

Integrated processing facilities will receive gas from production wells and field compression facilities. Integrated processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Coal seam water received at integrated processing facilities is treated and then balanced to ensure that it is suitable for the intended beneficial use. Coal seam water received from the field, treated water and brine concentrate will be stored in dams adjacent to integrated processing facilities.

It is envisaged that development of the Surat Gas Project will occur in five development regions: Wandoan, Chinchilla, Dalby, Kogan/Millmerran and Goondiwindi. Development of these regions will be staged to optimise production over the life of the project.

Arrow has established a framework to guide the selection of sites for production wells and production facilities and routes for gathering lines and pipelines. The framework will also be used to select sites for associated infrastructure such as access roads and construction camps. Environmental and social constraints to development that have been identified through the EIS process coupled with the application of appropriate environmental management controls will ensure that protection of environmental values (resources) is considered in project planning. This approach will maximise the opportunity to select appropriate site locations that minimise potential environmental and social impacts.

Arrow has identified 18 areas that are nominated for potential facility development to facilitate environmental impact assessment (and modelling). These are based on circles of approximately 12 km radius that signify areas where development of production facilities could potentially occur.

Arrow intends to pursue opportunities in the selection of equipment (including reserve osmosis units, gas powered engines, electrical generators and compressors) and the design of facilities that facilitates the cost effective and efficient scaling of facilities to meet field conditions. This flexibility will enable Arrow to better match infrastructure to coal seam gas production. It will also enable Arrow to investigate the merits of using template design principles for facility development, which may in turn generate further efficiencies as the gas reserves are better understood, design is finalised, or as field development progresses.

1.3 Geology, Landform and Soils Study Aims and Objectives

The aims and objectives of the geology, landform and soils study and impact assessment (the study) are as follows:

- Fulfil the requirements of the Terms of Reference (ToR) for the Surat Gas Project Environmental Impact Statement (EIS) (see Appendix D: ToR Cross-Reference Table)).
- Address those reasonable questions or issues that may be asked by stakeholders and relevant government departments, including the Department of Environment and Resource Management (DERM) and the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC).
- Undertake background research and desktop analyses as required to assess the existing environment (as relevant to the study) and identify the key environmental values.
- Identify project activities that have the potential to impact upon environmental values.

- Assess the impact of the project on key environmental values and prepare management recommendations to address any issues.
- Discuss any cumulative impacts on relevant environmental values as a result of other future projects planned for development in the vicinity of the Surat Gas Project.

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

- Assess the potential impact of the proposed project on geology, landforms, soils and the existing environment.
- Identify measures to limit adverse impacts upon landforms, soil and rock features for the design, construction, operation, maintenance, production and rehabilitation phases of the project.
- Assess and map the presence, location and significance of landforms, soils and shallow subsurface rock features that may have the potential to influence the design, construction and operation of the proposed project (i.e. the surface geological and geomorphological constraints).

The impact assessment concentrated on the surface and near-surface geology, as this has the most impact on the contemporary soils and landform of the area.

This assessment provides reference to other Surat Gas Project EIS studies but does not provide specialist comments outside of 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 Study, including information regarding the deeper stratigraphy associated with the Surat Gas Project. (Coffey Environments; 2011);
- Surface Water Study, including an assessment of fluvial forms and processes (Alluvium Consulting, 2011);
- Terrestrial Flora and Fauna Study, including potential flora and fauna impacts (3D Environmental, 2011);
- Agriculture Study, assessing the agricultural values of the study area within the Surat Basin and identifying potential impacts of the project to the region’s agricultural industries (Gilbert and Sutherland, 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 Explanation of the Terms “Project Development Area” and “Study Area”

This study assesses the geology, landform and soils within the Surat Gas project development area, as defined in Figure 1.1. To gain a broad understanding of constraints, impacts and issues associated with the geology, landform and soils over the approximate 8600 square kilometre (km^2) project development area, a high level desktop assessment and targeted field investigation were undertaken within the project development area. Therefore the “study area” for this assessment and the “project development area” coincide, and the terms are used interchangeably throughout the report.

1.6 Legislative Context and Standards

The study considered key statutory regulations governing land management relevant to the Surat Gas Project, as stipulated in the Terms of Reference. These are listed below.

- Queensland *Soil Conservation Act 1986*. This Act provides a framework for the management of soil erosion on agricultural land through the approval of voluntary soil conservation property plans. Such plans are generally aimed at either private agricultural land owners intending to implement soil conservation works, or where soil conservation works are proposed in a catchment area under the responsibility of a statutory authority. The framework of this Act is not commonly applied. Therefore, it has not been considered within the scope of this study.
- Queensland *Nature Conservation Act 1992.* The objective 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 Surat Gas 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. Lake Broadwater Environmental Park is an example of a listed protected area within the project development area that is considered to have landforms and soil types of conservation significance.
- Queensland *Environmental Protection Act 1994.* The object of this Act is to protect Queensland’s environment while allowing for development that improves total quality of life, both now and in the future. This Act is relevant to the Surat Gas Project as it provides the framework for the EIS under which the project is being assessed.
- Queensland *Vegetation Management Act 1999.* Objects of this Act considered relevant to the Surat Gas Project geology, landform and soils assessment 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 object 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. Several state planning policies which advance the purpose of this Act are relevant to the Surat Gas Project and are discussed in detail below.
- *Queensland Government Environmental Offsets Policy 2008*. The purpose of which is to guide the appropriate use of environmental offsets across terrestrial and aquatic ecosystems. This policy is of relevance to this assessment as it applies to all developments assessed under the *Environmental Protection Act 1994*. Amendments to 210, 305 and s310O of the

Environmental Protection Act 1994 and to s346A of the *Sustainable Planning Act 2009* made in March 2011 place it beyond doubt that offset conditions can be imposed on development approvals.

- State Planning Policies (SPP) and their associated Guidelines including:
  - SPP1/92 Development and Conservation of Good Quality Agricultural Land (GQAL, see Section 1.4.1: SPP1/92). Discussed further in Section 1.7.1;

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 or 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. No KRAs have been identified within the project development area.

1.6.1 State Planning Policy SPP1/92 Development and Conservation of Good Quality Agricultural Land

Agricultural land is considered by the Queensland Government to be a finite resource that must be observed and managed for the longer term (SPP1/92). Agriculture is a fundamental land use in the project development area and, therefore, requires specific consideration in the EIS.

State Planning Policy 1/92 – Development and the Conservation of Good Quality Agricultural Land (SPP 1/92) was put in place to protect GQAL against competing land uses, and maintain the productivity of agricultural land uses into the future. SPP 1/92 has been jointly prepared by the Department of Housing, Local Government and Planning (DHLGP) and the Queensland Department of Primary Industries (DPI). It requires local governments to identify and protect GQAL through local planning schemes. The policy has two key principles directly related to the Surat Gas Project:

1. GQAL has a special importance and should not be built on unless there is an overriding need for the development, in terms of a public benefit, and no other site is suitable for the particular purpose;
2. The alienation of some productive agricultural land will inevitably occur as a consequence of development, but the government will not support such alienation when equally viable alternatives exist, particularly where developments do not have specific locational requirements.

Four classes of agricultural land have been defined in Queensland, as defined in Table 1.1.

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.

1.6.2 Strategic Cropping Land Framework

Under the Sustainable Planning Act 2009, a new statutory planning instrument will be implemented to guide planning for strategic cropping. The policy aims to address land-use competition issues, particularly between mining and agricultural industries, to ensure that cropping land resources are given the same consideration as other types of development (DERM, 2010). 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). This framework includes the development of:

- A new Act specifically for protection of strategic cropping land resources;
- A new SPP under the SPA 2009;
- Amendments to existing resources legislation (including the Environmental Protection Act, 1994) to recognise the requirements of the new Act.

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. Several of these principles are considered relevant, and should be accounted for in the Surat Gas Project, as listed below.

1. Relevant development should avoid locating or impacting upon strategic cropping land.
2. Except in 'demonstrated exceptional circumstance', relevant development will not be allowed on strategic cropping land, unless the site can be fully restored to strategic cropping land condition.
3. To be considered a 'demonstrated exceptional circumstance' it must be demonstrated that:
    a. for resources development, the resource is not found at an alternative site in Queensland which is not on strategic cropping land; or for development assessed under the SPA 2009, it cannot occur anywhere else other than on strategic cropping land, and
    b. there is a significant community benefit from the development.

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. The mapping will be ground truthed and is subject to further change following provision of final assessment criteria when the legislation is released in 2011. The new legislation for strategic cropping land will allow landholders to apply to amend the maps.

On 25 October 2011, the Queensland Government introduced the Strategic Cropping Land Bill 2011 into Parliament and intends to enact the legislation in early 2012. Currently in draft form, this policy operates under the Sustainable Planning Act with DERM as the administering agency. It aims to manage and protect strategic cropping land and ensure relevant developments, planning schemes and regional plans appropriately consider strategic cropping land. While the laws have not yet been enacted, the principles are to be taken into account. It will operate in tandem with State Planning Policy 1/92.

1.6.3 Relevant Industry Guidelines and Codes of Practice

This study considered standard industry guidelines and codes of practice that were directly relevant to the geology, landform and soils study, as follows:

- *Best Practice Erosion and Sediment Control Manual* (International Erosion Control Association (IECA), 2008). This document is the standard Queensland guideline for erosion and sediment control, and provides an overview of how to manage erosion and sedimentation throughout the various planning and construction stages of the development. Several items within Book 5 (which provides guidelines on the management of erosion and sediment control on typical construction sites) are considered to be of relevance to this assessment. These include guidelines relating to:
  - Management of soils (including dispersive soils);
  - Implementation of erosion and sediment control measures;
  - Site management and monitoring;
  - Site rehabilitation.
- *Code of Environmental Practice for Onshore Pipelines* (Australian Pipeline Industry Association (APIA), 2009). This document provides information on appropriate techniques and methods to best manage the environmental impacts of on-shore pipeline construction.
- *Healthy HeadWaters Coal Seam Gas Water Feasibility Study: Assessment of the Salinity Impacts of Coal Seam Water on Landscapes and Surface Streams* (DERM, in prep.; Final Report, December 2010, but not yet released to the general public). This document provides information relating to when and where Coal Seam Gas (CSG) water can be used for irrigation without adversely impacting upon landscape and stream salinity. It will eventually be used to develop formal guidelines to assist the preparation and assessment of proposals to irrigate with CSG water. This document is considered to be of relevance to this assessment as the suitability of using CSG water for irrigation depends on the presence, mobilisation potential and landscape constraints of soil salt stores.

2. METHOD OF ASSESSMENT

Coffey undertook a phased approach to the geology, landform and soils study. This involved the following:

- Phase 1.1 – collation and review of available existing studies, information, data, relevant legislation and mapping. These are listed in Section 11: References.
- Phase 1.2 – GIS geodatabase construction and preliminary constraints and sensitivity mapping.
- Phase 1.3 – Preliminary field reconnaissance to carry out high-level ground-truthing and to target areas for investigation during Phase 2.
- Phase 2 – Targeted field investigations of geology and soils, using test pits and geological mapping of existing rock exposures. Selected rock and soil samples were tested to assess their physical and chemical properties.
- Phase 3 – Impact assessment and mitigation/management recommendations.
- Phase 4 – Reporting.

Phases 1 and 2 were used to establish the existing environment of the study area (see Section 3: Existing Environment), and the environmental values and sensitivity of the landscape (see Section 4: Environmental Values and Landscape Sensitivity). Potential impacts, prior to management and mitigation measures, are assessed in Section 6: Environmental Impact Assessment. Additional information regarding Coffey's field investigation methodology is included in Appendix A.

Coffey mapped the geology, landform and soils of the study area. This mapping was based on Land Resource Areas (LRAs) mapped by the Queensland Government to provide information for agricultural planning and sustainable land management. To produce the LRA mapping, specialist government research teams (e.g. from CSIRO and DERM) carried out extensive field studies and interpretation of findings. These LRA studies used similar, but fundamentally different, classification systems. The classification systems are based on a combination of geology, landform and common/associated soils types (using the Australian Soil and Land Survey Field Handbook classifications; McDonald et al. 1990), and vegetation types. The LRA units are somewhat artificial, as they describe and divide a continuum of environmental conditions. Therefore, units are not homogeneous, with some having considerable variability, particularly soil and vegetation type.

Four different LRA studies cover the study area (see Section 11: References):

- Central Darling Downs (MCD), Harris *et al.*, 1999;
- Murilla, Tara and Chinchilla (MWD), Maher, 1996
- Waggamba Shire (WLM), Thwaites and Macnish, 1991
- Dawson Fitzroy Area (ZDD), Perry, 1968.

The ZDD LRA uses a slightly different approach to the other LRAs, being based on land systems which contain several different LRA-type units.

The LRA studies produced regional overview maps that are not suitable for site-specific assessment. Given the large (approximately 8,600 km^2) study area, it was felt that a regional assessment approach was appropriate to fulfil the ToR. Reinterpretation of the LRA mapping was not considered to be useful for the purposes of this study, except where specific constraints (e.g. steep landforms) were noted. The study methodology was designed to check the LRA mapping within the context of the study.

2.1 Study Area

As indicated in Section 1.5, the geology, landform and soils study area is defined by the limit of the EIS, i.e. the project development area (see Figure 1.1). A regional assessment (extent based on available LRA mapping coverage at a practical mapping scale) was also carried out to enable better understanding of the landscape within the study area.

2.2 Geological Assessment Methodology

The main aim of the geology assessment was to gain a broad overview of the near-surface rock conditions over the large study area. During the preliminary field reconnaissance visit, visual assessment of the large study area indicated that to obtain a broad overview of the near-surface rock conditions, isolated intrusive rock sampling at individual sites would be of limited value. Instead, many rock exposures were observed throughout the study area, and these existing exposures provided an excellent overview of the typical subsurface rock profile. Therefore, in lieu of individual sampling locations, a total of 109 locations were observed, including road cuttings, natural cliffs, river banks and existing borrow pits. A total of 37 rock samples were collected from selected locations, and laboratory strength testing of the rock samples was carried out. Coffey's geological logging and testing was supplemented by information from previous investigations supplied by Arrow.

2.3 Landform Assessment Methodology

Coffey assessed the study area terrain using a combination of aerial imagery, site observations and information from previous investigations (LRA mapping manuals; Titmarsh and Larkin, 2007; and references listed in Section 11.8: Reviewed for Background Appreciation of Study Area). Contours were available at an interval of 20 meters (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.

2.4 Soils Assessment Methodology

Soil mapping at a suitable scale has not been conducted in the study area. The only available soil-specific map was the 1:2 million Atlas of Australian Soils (CSIRO, 1960-1968). This mapping had insufficient detail for the purposes of the assessment. Land Resource Area (LRA) mapping was utilised to assess soil types across the study site. Each LRA unit can contain several different soil types.

A targeted field investigation was conducted to ground-truth the findings of the desktop study and collect samples for laboratory analysis, for physical, chemical and engineering property testing. A total of 16 test pits were excavated across the study area. Test pits were located based on review of the landscape unit mapping undertaken in the desktop review. Test pit sites were selected to target commonly occurring soil types within each landscape unit.

Samples were tested in National Association of Testing Authorities (NATA) accredited laboratories for physical, chemical and engineering properties.

The soils present within the study area have been described using the Australian Soil and Land Survey Field Handbook (MacDonald *et al*., 1998). Soil groups have been classified using texture grade and key features, in accordance with the Australian Soil Classification (Isbell, 2002).

GQAL and draft Strategic Cropping Land mapping was provided by DERM within the LRA GIS layers. GQAL mapping was based on the LRA mapping units and their different agricultural suitability. Draft Strategic Cropping Land mapping has been based on available soils, land and climate information, and is subject to revision by DERM. Ground-truthing of this mapping was not considered appropriate during this project, due to the large spatial extent of the study area and given that the policy has yet to be enacted. There is considerable overlap between land classified as GQAL and Strategic Cropping Land and these are generally considered in tandem throughout this report.

2.5 Terrain Mapping and Environmental Values Assessment Methodology

The different LRA landscape units were assessed with regard to environmental values which would affect landscape response to project activities. This assessment was then used to amalgamate and simplify the different LRA classifications, producing a consistent system across the study area. The study area was divided into “terrain units”, based on these different classifications, 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 (historic and current) and in the field. It was found that that unit boundaries did not exactly overlay the aerial photographs, partly due to errors in image rectification and partly to vegetation change since the original mapping was carried out. However, the units were observed to be accurate during the ground-truthing exercise. Part of the study area was not covered by the available LRA mapping. Aerial photography and observations from fieldwork were used to extend the terrain units to the limit of the study area. Jumpup features were also included, where necessary, as these were felt to be associated with significant potential impacts and constraints.

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 impact assessment outputs given the size of the study area and diverse landscape features. Consideration should be given to the variability of conditions which can occur within each terrain unit: localised areas may have markedly different properties and response to disturbance in comparison to the broadly defined characteristics.

2.6 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.

2.7 Impact Assessment Method – Significance of Impacts

The impact assessment method involved a multi-step process, following on from the assessment of landscape environmental values and sensitivity outlined in Sections 2.5 and 2.6, as listed below:

- 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 value (terrain unit) and the impact magnitude.

2.8 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 1.6: Legislative Context and Standards). Relevant management and mitigation measures are recommended in accordance with these guidelines and legislation. Given the variability of conditions within terrain units, and the different potential impacts of project activities, recommendations for site-specific assessments are indicated where relevant.

2.9 Residual Impact Assessment Method

The impact assessment was revised assuming successful implementation of the recommended management and mitigation measures.

2.10 Cumulative Impact Assessment Method

The aim of the cumulative impact assessment is to assess the combined effect of future developments that could interact with the Surat Gas Project, including the degree to which these projects contribute to the overall impact on the relevant environmental values.

The description of the existing environment includes existing developments constructed and operating in the Surat Basin region. The cumulative impact assessment only includes those projects that have documented evidence of a serious intent to develop (i.e. progressed beyond feasibility studies), including those that have taken a financial investment decision at the time of writing.

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.

The cumulative assessment approach considers the following:

- Projects or project activities that will lead to cumulative impacts and the mechanism of impact combination.

- The cumulative impact context, e.g. synchronised impact timing or spatial fragmentation of environmental values.
- Criteria that define the magnitude of the environmental value impacted (i.e. extent, duration and severity).
- Specific issues raised in the Terms of Reference.

3. EXISTING ENVIRONMENT

This section describes the geological evolution and the existing surficial geology, landforms and soils of the study area. The study area encompasses three physiographic regions associated with the major river catchments and each with appreciably different landscape characteristics. These are summarised in Table 3.1 and illustrated in Figure 3.1.

Table 3.1 Summary of Study Area Environmental Characteristics

Landscape Characteristics	River Catchment/Physiographic Region		
	Condamine River	**Dawson River**	**Border Rivers**
Surface Geology (Figures 3.1-3.3)	Resistant igneous rocks (granite and basalt) outcrop along the Great Dividing Range and isolated hills and plateaux to the south; sandstone outcrops along the Kumbarilla Ridge; with clay blanketing the Condamine River valley, overlain by more recent sandy alluvium and colluvium in places.	Sandstone, with resistant laterised sandstone and basalt capping plateaux. Clay blankets the valley floors, with sandy alluvial deposits along narrow river floodplains.	Sandstone with outcrops of locally resistant sandstone. Clay blankets the valley floors, with sandy outwash and aeolian deposits.
Relief (Figure 3.5 and Figure 3.6)	Relief is strongly linked to geology: steep slopes and higher elevations are associated with resistant igneous and sedimentary rocks of the Great Dividing Range and Kumbarilla Ridge.		
	300 m Australian Height Datum (AHD) at downstream end of Condamine River Valley; rising to 420 mAHD along the Kumbarilla Ridge; 600 mAHD isolated basalt outcrops; and over 800 mAHD along the Great Dividing Range.	260 mAHD within the Comorron Creek Valley to 380 mAHD along the Kumbarilla Ridge.	220 mAHD along the Juandah River Valley to 480 mAHD along the sandstone plateau to the south.
Topography (Figure 3.5 and Figure 3.6)	Extensive clay river plains flanked by the Great Dividing Range and Kumbarilla Ridge. To the south, remnant basalt mesas and sandstone jumpups form steep, rocky hills.	Laterised sandstone and basalt plateaux dissected by broad sandy alluvial river valleys.	Broad outwash plains flowing from the Kumbarilla Ridge. Remnant sandstone jumpup swarms occur along the foothills of the ridge. Elongated relict dunes are present along some valley floors.
Rainfall (Figure 3.7)	600-700 millimetres per year (mm/yr), with greater rainfall over the Great Dividing Range and eastern Kumbarilla Ridge and lower rainfall over rainshadow to the west.	600-700 mm/yr	500-600 mm/yr, within the rainshadow of the Kumbarilla Ridge
Soils Table 3.3 and Figure 4.1	Vertosols along the base of river valleys, with pockets of texture contrast soils. Texture contrast soils along the flanks and lower slopes of the Kumbarilla Ridge; shallow, gravelly soils at higher elevations.	Vertosols along the base of river valleys, with pockets of texture contrast soils. Texture contrast soils along the flanks and lower slopes of plateaux; shallow, gravelly soils at higher elevations.	Clay plain Vertosols; sandy and sandy-veneer texture contrast soils along river floodplains; texture contrast soils along sandstone outcrop flanks; shallow, gravelly soils at higher elevations.
Land-Use	Strongly related to soil type and relief: Intensive agriculture on river plain Vertosols; marginal agriculture along the flanks of higher-relief areas; state forest and forestry along the uplands of the Kumbarilla Ridge		
Erosion	Gullying and tunnelling on disturbed sodic/dispersive soils; stream channel erosion more common along low order streams and along outer banks of meander bends.		
	e.g. gullying west of Cecil Plains and Milmerran		

3.1 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.

3.1.1 Geological Evolution

An understanding of geological evolution allows a better understanding of the existing geological profile and contemporary landscape, particularly the likely pattern of geological outcropping and geology/landform interactions. The study area is geologically relatively simple. Basement rocks are overlain by deep sediments with volcanic intrusions. The geological evolution is summarised as follows (see Figures 3.1, 3.2 and 3.3):

Table 3.2 Summary Geological Evolution of the Study Area

Geological Era and Period		Associated Rock-type and Process of Formation
Palaeozoic	Ordovician-Permian 500-300 Million years ago (Mya)	Metamorphism of sedimentary and volcanic basement rocks created traprock of the Yarraman Block (Reiser, 1971; Harris *et al.,* 1999). East-west compression caused folding and downwarping to form the Yarrol Basin (which now underlies the Surat Basin).
	Permian 300-250 Mya	Granite was intruded into the traprock, causing regional uplift along what is now the Great Dividing Range (Reiser, 1971; Harris *et al.,* 1999). Deep marine and freshwater sediments were deposited within the downwarping Taroom Trough (to the east of the Yarrol Basin).
Mesozoic	Triassic 250-200 Mya	A long period of aridity and continued subsidence of the Taroom Trough resulted in deep red bed deposition (Rewan Formation). Uplift resulted in erosion and redeposition as coarse fluvial sandstones (Reiser, 1971; Perry, 1968).
	Jurassic 200-150 Mya	Several thick fining-upwards sequences were deposited during the Jurassic. Fast-flowing creeks deposited quartzose coarse sandstones (including the Precipice, Hutton (Surat Basin) and Marburg (Moreton Basin) Formations), grading to finer, more labile sediments (including the Evergreen Formation, Walloon Coal Measures[1] and late Jurassic to early Cretaceous Kumbarilla Beds[2]) deposited in lower-energy environments, e.g. as relief became more subdued (Reiser, 1971; Harris *et al.,* 1999; WDD LRA, Perry, 1968).
	Cretaceous 150-70 Mya	Erosion during the early Cretaceous was followed by marine transgressions, which deposited the fine-grained coastal plain sandstone and mudstone units of the Rolling Downs Group (WDD LRA; Kogan North EMP, 2003, Perry, 1968).
Cainozoic	Tertiary late Oligocene/ early Miocene 25-15 Mya	Volcanism along the Great Dividing Range produced extensive basalt flows and ash/dust deposits. Weathering and erosion of the basalts resulted in re-exposure of the Hutton/Marburg Sandstones and Injune Creek Group. Outcropping is unpredictable due to prior folding and dissection of these units (Harris *et al.,* 1999). Extensive erosion and weathering formed widespread clay plains through the Condamine River Valley. The period of landscape change was probably initiated by a major climatic change. Sheet flooding caused stripping, then broad cut and fill of the original surface, to form a wide valley, low slopes and lower clay plains. As the present drainage systems became established, the lower clay plains were then dissected by erosion and later partially refilled with more recent alluvium (Maher, 1996). Periods of prolonged, extensive deep weathering caused chemical and physical alteration of the surface layers, particularly silicification, kaolinisation and laterisation (Harris *et al.,* 1999).
	Pliocene 5-2 Mya	Fossiliferous Chinchilla Sands deposited by the Condamine River (Reiser, 1971)

Table 3.2 Summary Geological Evolution of the Study Area (cont'd)

Geological Era and Period		Associated Rock-type and Process of Formation
	Quaternary 2Mya – present	Periodic dissection of the landscape through drainage entrenchment (rejuvenation) and subsequent infilling occurred. Recently, creek/river headwaters and hilly areas have been eroding, with material re-deposited along the foothills of the Kumbarilla Ridge and within creek/river floodplains/channels. (Harris *et al.,* 1999, Perry, 1968). In the south of the study area, aeolian redistribution of sands has occurred.

[1]The Walloon Coal Measures are the predominant source of the coal seam gas to be extracted during this project. This unit is part of the Injune Creek Group (Reiser, 1971), overlying the Eurombah Formation and unconformably overlain by the Springbok Sandstone and Westbourne Formation (Scott *et al*., 2004).

[2] The Kumbarilla Beds are a unit equivalent to the stratigraphic interval between the Springbok Sandstone and the upper limit of the Bungil Formation (Reiser, 1971).

3.1.2 Geological Structure and Faulting

The study area lies within three major structural Mesozoic basins: The Surat Basin to the south and west, which unconformably overlies the Bowen Basin in the north and is separated from the Clarence/Moreton basin by the Kumbarilla Ridge anticline to the east. The Kumbarilla Ridge represents an anticlinal structure. Sedimentary sequences up to 2,500 m thick in the downwarped south-southeast to north-northwest trending Mimosa Syncline have been recorded where the Surat Basin overlies the Taroom Trough (Reiser, 1971; Arrow, 2003; URS, 2008; see Figure 3.1, Coffey Environments, 2011).

Major faulting within the Surat basin is generally an expression of boundary faults of the underlying Bowen Basin (Kogan North EMP, 2003). Minor Mesozoic faults (approximately 245 – 66.4 Mya) are also found to the west of the study area. Cainozoic faulting (approximately 66.4 Mya to present) has not been recorded.

Regionally, the Jurassic and Cretaceous sediments dip gently (<5°) to the southwest (Kogan North EMP, 2003). This is probably due to continuing basin subsidence and uplift associated with Tertiary volcanic activity (Reiser, 1971). Where Marburg sandstones onlap the Great Dividing Range igneous rocks, the local dip may be as steep as 10°.

3.1.3 Contemporary Surface Geology

A large portion of the study area is covered by a deep blanket of clay-rich colluvium and alluvium, which forms part of the Brigalow Belt bioregion (known as the Brigalow clay sheet (Harris *et al*., 1999)). Rock outcropping is confined mainly to the Kumbarilla Ridge (See Figure 3.3) in the western and south-western portions of the project development area. The majority of the stratigraphic sequence does not outcrop. The most commonly outcropping formations are the older sequences of the Kumbarilla Beds: the Springbok Sandstone and Westbourne Formation, which are late Jurassic members of the Injune Creek Group. These formations are unconformably overlain by late Jurassic/early Cretaceous Gubberamunda sandstone. Tertiary sandstone outcrops in the north of the study area. Laterisation of upland sandstone outcrops is common. Late Tertiary (Pliocene) fossil beds are associated with the Chinchilla Sands, which are found around Chinchilla and extending to the east and southeast.

The sedimentary formations outcropping within the study area are generally comparable in appearance, with similar geotechnical properties.

Minor outcrops of igneous rock are found within the study area. A small Triassic granite dome is present in the south of the study area, about 20 km south of Millmerran. Tertiary basalt caps the mesas close to Captain's Mountain (in the south) and Guluguba (in the north).

The characteristics of superficial deposits (alluvium and colluvium) reflect the nature of the source rocks. The Brigalow clay sheet blankets the valley floors of the major river valleys. Fine-grained deposits are also associated with erosion of more labile sandstones, siltstones, mudstones and shales. Sandy colluvium, occasionally containing gravels and cobbles, has been washed downslope along the fringes of the Kumbarilla Ridge. Sandy alluvial material is also found along watercourses.

3.1.4 Geotechnical Properties

Field Assessment

Coffey's field assessment of the geology in the study area is summarised in Appendix B and has enabled a more robust understanding of the geotechnical properties of the area. Observations confirmed the homogeneity and localised variability indicated by the available geological mapping. The majority of outcrops within the study area were variably textured sedimentary formations confined to the Kumbarilla Ridge (see Figure 3.4), with basalt outcrops near Captain's Mountain and, at a smaller scale, in the north of the study area. Rock outcrops were not observed between Dalby and Chinchilla.

Coffey's site observations indicated that the majority of sedimentary rocks were moderately to extremely weathered, medium to coarse-grained sandstones. These were characterised by distinct layers of very low (soil) strength, bleached, extremely weathered material, interbedded with medium to high strength, moderately weathered, ferruginised material. There were also a number of conglomerate outcrops. Sedimentary breccia was found at one location.

Numerous borrow pits were observed along the Kumbarilla Ridge, indicating that the rock has historically been used for construction purposes. Site observations indicated that crushed sandstone is the predominant road sub-base throughout the study area. These observations supported Coffey's field assessment of material properties: that the outcropping rocks were generally medium strength and, therefore, suitable for some construction purposes.

Laboratory Assessment of Rock Properties

Point Load Strength Tests were carried out on selected rock samples, giving a Point Load Index (I_{50}) and estimated Uniaxial Compression Strength (UCS) (see Appendix C). These were used to confirm field assessment of rock strength.

Test results were variable, ranging from low to very high in strength. More labile sediments were of low strength (I_{50} = 0.9 Megapascals (MPa) – 0.27MPa) and very high strength (I_{50} = 3.41MPa) is associated with conglomerates. Sandstones were generally low to medium strength (I_{50} = 0.31MPa – 0.82 MPa). One siltstone sample was tested, indicating high strength (I_{50} = 1.08 MPa).

The degree of weathering also affected the rock strength. Slightly and highly weathered samples were of lower strength than moderately weathered material. Ferruginisation is apparent in red and orange-stained moderately weathered rock, and generally increases rock strength.

3.2 Landform

3.2.1 Study Area-Specific Landform Features and Geomorphological Processes

There are several landforms and geomorphological processes that are specific (but not unique) to the study area, and which pose constraints to the project, as detailed below.

Upland Features

Plateaux are tablelands with elevated broad, level surfaces bounded by steep escarpments. Mesas are similar in appearance to plateaux but limited in extent. Within the study area, remnant basalt outcrops form prominent mesas (see Appendix B, Figures 112-115).

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. In the study area, the dip is sufficiently shallow that the cuestas take a plateau-like appearance (see Appendix B, Figure 117). These features may be found in the north of the study area, where resistant laterised sandstones cap the dip-slopes.

Landslides and Slope Stability

The study findings indicate that slopes within the study area do not exhibit signs of instability or landsliding. The material properties of the rock and soil, combined with the limited extent of steep slopes are such that landslides within the study area are considered unlikely, although rockfalls or landslides could occur along plateau or mesa clifflines, or cuesta escarpments.

Gilgai

The mineralogy of Vertosols (deep clay soils) causes swell/shrink during wetting and drying cycles, leading to the surface cracking typical of this type of soil. Shrinking causes cracking as the soils dry out. If material is washed into the cracks, the ground can be deformed during expansion on re-wetting. Over time, this can cause the formation of a continuous pattern of irregular mounds and depressions. These micro-relief features are known as “gilgai”.

Gilgai soils can have highly variable and complex soil morphology (Ahmad and Mermud, 1996). On the mounds, sediment tends to be coarser with shallow topsoils, with finer sediments and deeper topsoils found within the depressions.

On flatter ground, gilgai are roughly circular, whereas on steeper slopes, they become elongated. Large gilgai can be up to 2 m high and 50 m wide. The vertical interval between gilgai mounds and troughs is generally at least 300 mm (Isbell, 2002). Low-relief gilgai are locally known as “crabhole” gilgai (associated with Kupunn soils), whereas the larger features are known as “melonhole” gilgai (associated with Tara soils). Both types are common on the extensive clay plains of the study area. Appendix B, Figure 118 shows melonhole gilgai associated with terrain unit IIIb (Brigalow Plains and Uplands with melonhole gilgai).

Within the study area, gilgai are located on good agricultural land (GQAL class A). These undulations are unwelcome to farmers and many gilgaied areas have subsequently been levelled. This study, also found that topsoil elevations were consistent across the undulations: deeper beneath the mounds and shallower under the depressions.

Runoff (Sheetwash), Rill and Gully Erosion

Erosion is related to vegetation cover, rainfall intensity, soil type and slope steepness and length. Runoff erosion, or sheetwash, occurs when unconfined flow over bare or sparsely vegetated ground strips the surface soil layers. 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. Rills are similar to gullying, but at a smaller scale (rills are defined as minor trenches that can be ploughed out). 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 can occur upstream of gully headcuts, accelerating the gullying process. Therefore, prevention of gullying is considerably easier than its rehabilitation.

Queensland Main Roads Department found that over 60% of the annual erosion at Dalby occurs during the wet summer months, between November to February. Within the study area there are two mechanisms of gully formation (Titmarsh and Larkin, 2007):

- Rills and gullies can form in cultivated or heavily disturbed clay soils.
- Sodic texture contrast soils are dispersive in nature and highly erodible (see Section 3.3.2: Sodic and Dispersive Soils). The structure and chemical composition of this type of soil makes them susceptible to subsurface piping/tunnelling, and surface rill and gully erosion.

Clearance of vegetation and intensive agriculture on seemingly stable soils led to widespread gullying and soil loss between the mid-1800s and mid-1900s. Overgrazing and pasture burning had a similar effect, particularly in marginal soils. Structures and infrastructure (e.g. tracks) causing flow concentration were also responsible for severe erosion (Harris *et al.*, 1999). Gullies have a natural course of evolution which eventually results in self-stabilisation. This may be as much as 50 years after initiation (Titmarsh and Larkin, 2007).

Soil conservation measures, such as construction of contour banks, diversion banks and establishment of surface vegetation cover, have now been widely adopted and much of the erosion-damaged areas have now been treated (Harris *et al.*, 1999).

Within the study area, soils are typically sodic, and therefore prone to erosion in response to minor disturbances. The sodic Vertosols common to certain terrain units (specifically terrain units I and III, refer to Table 3.3) can have highly dispersive subsoils (see Appendix B, Figure 119). However, these soils tend to occur on low relief plains. Erosion, therefore, tends to be limited to where flows are concentrated, e.g. along access tracks, fencelines or compacted areas. Texture contrast soils (Sodosols and Chromosols) with sodic, dispersive subsoils are particularly found along the fringes of the Kumbarilla Ridge. This area has higher relief and gullying is, therefore, more common.

Wind Erosion

Strong winds do not generally occur within the study area. However, summer thunderstorms can create localised strong winds (Thwaites and Macnish, 1991). These can lead to aeolian erosion of susceptible soils, especially where surface cover has been removed.

River and Creek Erosion

The majority of watercourses within the study area are incised (see Appendix B, Figure 120), showing the incised Condamine River). Many show signs of historic and contemporary bank erosion and bed scour. Initiation of downcutting most likely occurred in much the same way as gully initiation. This incision has lead to many of the watercourses being dissociated with their floodplains: Only high-magnitude floods are able to inundate the formerly frequently inundated floodplains.

Erosion processes associated with watercourses and channel evolution are assessed in more detail in the Surface Water Section of the EIA (Alluvium, 2011).

3.2.2 Physiography, Topography and Geomorphology

The landscape within the study area is characterised by several major physiographic regions, which are strongly related to the underlying geology and geomorphological evolution of the area (see Figures 3.1, 3.5 and 3.6):

- Great Dividing Range highlands, to the northeast of the study area, comprising resistant igneous rocks (granite and basalt) overlying generally coarse-grained sandstones.

- Kumbarilla Ridge uplands, along the west of the study area, comprising resistant sandstones and finer-grained sedimentary rocks. This ridge is the physiographic expression of the Kumbarilla Ridge anticline. The crest of this structure cuts across the Condamine Valley close to Dalby, whereas the sandstone uplands extend north, to near Guluguba.
- Three major river valleys: the Condamine River, cutting between the Great Dividing Range and the Kumbarilla Ridge; the Dawson River, to the north; and the Border Rivers to the south.

The major river catchments each have appreciably different landscape characteristics.

Condamine River

The broad valley of the Condamine River divides the Great Dividing Range, to the east, and the Kumbarilla Ridge, to the west. The Condamine River flows northwards through the Darling Downs, turning west to eventually join the Murray-Darling Rivers. The valley, at its broadest, is approximately 50 km wide. Where the Condamine River has cut through the Kumbarilla Ridge, to the west of Chinchilla, the valley is appreciably narrower, at about 5 km wide. The valley floor is characterised by densely farmed alluvial and Brigalow plains, which are flat to gently undulating. Gilgai pockmark the plains in the north and south of the valley, where Brigalow clay soils are present. Broad expanses of gilgaied ground can be found on the valley floor around Brigalow, Chinchilla, Millmerran and Bringalily. Smaller crabhole gilgai have generally been levelled for agriculture, but larger melonhole gilgai are still evident.

Watercourses are generally incised, with well-defined channels that are dissociated from their floodplains, particularly along the fringes of the Kumbarilla Ridge. Downcutting of the watercourses has created a higher-elevation relict floodplain which is no longer inundated (Harris *et al.*, 1999) unless in higher-magnitide flooding events. Some watercourses within the catchment have exploited weaker fault zones, e.g. Mile Creek, which follows a lineament along the southern extent of the Burunga Fault, north-northwest of Miles.

Incision, bank erosion, channel migration and avulsion of the rivers and creeks have left palaeochannel meander scars and terraces within the more recent alluvial deposits. Meander scars are particularly evident on historic aerial images. Depositional features, such as levees and sandbars are also common. These features indicate that, in recent geological times, the watercourses have been dynamic systems.

Gully networks have formed in erosion-susceptible soils (erodibility is discussed further in Sections 3.3.2 and 4.2.3), e.g. west of Millmerran and Cecil Plains.

The uplands are composed of more resistant bedrock. The Great Dividing Range, rising to over 800 mAHD, forms the highest peaks of the region. The Kumbarilla Ridge, in contrast, is generally characterised by more gentle slopes, with maximum elevations of around 420 mAHD. To the north, Tertiary sandstone uplands form a broad cuesta dip-slope, rising to around 380 mAHD. Within the latter, pockets of gilgaied clays may be found.

Remnant basalt has formed steep-sided, generally elongated, mesas close to Captain’s Mountain. These features have a maximum elevation of over 620 mAHD and can rise approximately 150 m above the surrounding slopes. To the south of Millmerran, resistant sandstone remnants have formed small, steep, rounded hills, known as “jumpups”. These can rise approximately 50 m above the more gentle slopes of the Kumbarilla Ridge.

Dawson River

The Dawson River catchment is found in the north of the study area. The major watercourse, a tributary of the Dawson River, is the Juandah Creek, flowing northeast through Guluguba and Wandoan. The Juandah Creek valley is characterised by mesas and cuestas with convex gently to moderately sloping Brigalow plains leading to the valley floor. The mesas are generally capped by basalt, whereas the cuestas are capped by gently dipping laterised sandstone. Basalt does not outcrop widely in this area.

Watercourses are similar in morphology to those of the Condamine River catchment: they are generally incised, with well-defined channels. Sandy alluvium has been deposited along the valley floors adjacent to the creeks.

The catchment is not intensively farmed, instead characterised by grazing land.

Border Rivers

The Border Rivers catchment is found in the south of the study area. Major watercourses include Wyaga Creek and Commoron Creek, which flow southwest towards Goondiwindi. The catchment within the study area falls within two broad terrain types: uplands associated with the sandstone Kumbarilla Ridge falling to broad Brigalow clay and sandy alluvial plains.

Along the western flanks of the Kumbarilla Ridge, resistant sandstone has formed distinct ridges and swarms of jumpups. These ridges and individual hills can rise approximately 40 m to 100 m above the surrounding slopes (see Appendix B, Figures 83, 87 and 88). The valley floor is generally covered by the thick Brigalow clays. Pockets of melonhole and crabhole gilgai occur. Some gilgai have been levelled for agriculture, but many remain. Adjacent to the major watercourses, sandy alluvium has been deposited over the floodplain areas. Linear relict fans, terraces and levees composed of reworked alluvium indicate the dynamicism and downcutting of the watercourses in recent geological times (Thwaites and Macnish, 1991). Occasional low, elongated relict dune ridges may also be found on the valley floor.

The Border Rivers catchment, within the study area, is drier than the Condamine River and Dawson River catchments, being further inland and within the rainshadow of the Kumbarilla Ridge (see Figure 3.7). The lower rainfall, micro-relief and sandy soils of the area are not conducive to intense arable cropping and grazing predominates, despite the widespread GQAL Class A land.

3.3 Soils

3.3.1 Soil Types and Characteristics Within the Study Area

Soil characteristics are strongly related to parent material, formation process and relief (Maher, 1996). Within the study area, soils are linked to their parent material as listed below.

- Brigalow clay sheet was formed from intensely weathered mudstones.
- Sandy soils were formed from quartzose sandstone.
- Clays and finer soils were formed from labile (<75% quartz) sandstones and shales.
- Texture contrast soils and deep sandy soils were formed on predominantly upper plains and terraces.
- Deep cracking clay soils were formed on the lower alluvial plains subject to seasonal flooding, and originate from weathered basalt, shale and mudstones.

The desktop and field study found 7 broad soil types within the study area, each with typical characteristics, constraints and properties. The 7 broad soil types (1-7) are listed from most to least clay content as follows:

Soil Type 1. Gilgai Clays

Gilgai clays occur on level to gently undulating ground, generally on the older alluvial sediments subject to seasonal flooding. They were observed within the study area to the north of Warra and Chinchilla. They occur within pockets throughout the study area, particularly around Kupunn and further to the south in the Goondiwindi Shire (formerly Waggamba Shire). Large areas of gilgai have been levelled for agricultural purposes. Characteristics of this soil type are listed below.

- Deep to very deep (>1.5m).
- Medium clay to heavy clay surface soils, over medium clay to heavy clay subsoils.
- Hard, coarse block-structured subsoils, with variable surface soil structure, based on location within the gilgai. At the top of mounds, surface soils can have a thin crust and generally have a fine ped size, but tend to be massive or strongly structured within the depression.
- Poorly drained, with water often retained in the gilgai depression.
- Variable pH, but frequently acidic to neutral in the surface horizon and either moderately alkaline to strongly acidic in the clay subsoil. If alkaline, carbonate segregations may be present.
- Found in the *Brigalow Plains and Uplands (terrain unit III).*
- Classified as Vertosols.

Soil Type 2. Cracking Clays

Cracking clay soils are widespread throughout the study area. Two sub-groups of this soil type were identified within the study area.

2.1 Black Cracking Clays

Black cracking clays are the dominant soil type along the Condamine River valley around Dalby and to the south and east of Cecil Plains. These soils are of high value for agricultural production. Characteristics of this soil type are listed below.

- Generally deep to very deep.
- Surface soils can be grey to black in colour and may contain some coarse sand, giving a sandy, light clay to medium clay texture. This horizon is then underlain by a medium to heavy clay subsoil.
- Soils are generally well structured, with a self-mulching granular surface structure and a medium angular blocky subsoil structure which deteriorates with depth.
- Shrink/swell properties of the clay minerals cause these soils to swell when wet and crack when dry. Vertical cracks greater than 5mm wide can be evident when soils are dry.
- Surface soil pH levels range from acidic to moderately alkaline, with mildly alkaline field pH levels being common. Subsoils are moderately to strongly alkaline and commonly contain calcium carbonate nodules and soft segregations.
- Soils can be sodic and surface crusts can form.
- Found in the *Clay Alluvial Plains (terrain unit I)* and *Brigalow Plains and Uplands (terrain unit III).*
- Classified as Vertosols.

2.2 Uniform Cracking Clays

Uniform cracking clays are found throughout the study area, occurring in patches around Miles, Chinchilla, Kogan and Brigalow. They occur on gentle slopes on a range of materials derived from alluvium, basalt and deeply weathered materials. Characteristics of this soil type are listed below.

- Shallow to deep profiles.
- Uniform light to heavy clays, with cracking throughout the profile due to swelling and shrinking properties.
- Generally grey and brown in colour.
- Surface soils are generally friable and self mulching. They have poor internal drainage, although cracks can assist water penetration following the dry season.
- Found in the *Clay Alluvial Plains (terrain unit I)*, *Brigalow Plains and Uplands (terrain unit III) and Sandstone Ridge (terrain unit IV).*
- Classified as Vertosols.

Soil Type 3. Uniform Non-Cracking Clays

Uniform non-cracking clays occur on gently undulating plains and rises, and upper slopes of hills. These soils are present in the northern portion of the study area, in the Dawson River catchment. Agriculturally, these soils are generally highly productive, but require erosion control measures. Characteristics of this soil type are listed below.

- Generally deep uniform or gradational profiles, with medium to fine textured soils. Commonly occur with a dark brown surface of light to medium clay, overlying a brown or grey medium to heavy clay subsoil.
- Surface soils can be friable and highly erodible when cleared. Strong to coarse angular blocky structured subsoils.
- Found in the S*andy Alluvial Plains (terrain unit II), Brigalow Plains and Uplands (terrain unit III)* and *Basaltic Uplands (terrain unit V).*
- Classified as Dermosols.

Soil Type 4. Texture Contrast Soils

Texture contrast soils are characterised by an abrupt textural contrast between the surface and subsoil horizons. They commonly have sandy or loamy upper horizons, underlain by heavier textured (normally clay) subsoil. The boundary between the more clayey horizon and the overlying horizon must be classified as at least sharp (a boundary depth of less than 50 mm). In general, these soils have little agricultural value. However, they are used for low-density grazing in some areas. There are two types of texture contrast soils within the study area.

4.1 Dispersive Texture Contrast Soils

Dispersive texture contrast soils are widespread throughout the study area. They are commonly found on rises and plains, but are also found in the undulating hills. Characteristics of this soil type are listed below.

- Deep, generally with thick upper horizons (>0.3m) with organic humic loam surface textures; often over a pale or sporadically bleached horizon, underlain (with a clear or abrupt change) to predominantly mottled sandy clay to medium clay subsoil.

- Thinner upper horizons (<0.3m) on steeper slopes.
- Subsoils are generally sodic and may be acidic, with a massive through to columnar structure.
- Dispersive soils are prone to erosion and can be hardsetting. Subsoils are often more prone to erosion than surface horizons due to their chemical composition. This can lead to subsurface piping/tunnelling and gullying.
- Found in the *Clay Alluvial Plains (terrain unit I), Sandy Alluvial Plains (terrain unit II)*, *Brigalow Plains and Uplands (terrain unit III) and Sandstone Ridge (terrain unit IV).*
- Classified as Sodosols and Kurosols.

4.2 Non-Dispersive Texture Contrast Soils

Non-dispersive texture contrast soils are also common in the study area. They are found along the undulating to moderately sloping lands on the fringes of the Kumbarilla Ridge.

The physical attributes of these soils are similar to the dispersive soils described above:

- Moderately deep to deep profile (>0.5m). However, more shallow versions can occur on the margins of the sandstone uplands.
- Sandy or loamy surface texture, often underlain by a bleached subsurface horizon, with an abrupt, sharp or clear change to a finer (i.e. more clayey) subsoil.
- Subsoils can be yellow, brown, grey or red and are often mottled due to poorly drained conditions.
- Subsoils are generally well structured, medium to heavy clays with hard consistence. However, weakly structured soils do exist in some areas.
- Gravel is normally absent from the profile.
- pH levels can vary from strongly acidic to neutral.
- Firm hard setting surface layers can occur.
- Found in the *Clay Alluvial Plains (terrain unit I), Sandy Alluvial Plains (terrain unit II), Brigalow Plains* and *Uplands (terrain unit III)* and *Sandstone Ridge (terrain unit IV).*
- Classified as – Chromosols and Kurosols.

Soil Type 5. Uniform Loams and Clays

Two subgroups of this soil unit were identified within the study area based on their clay content.

5.1 Loams and Clay Loams

Loams and clay loams occur along the upper slopes and crests of the Kumbarilla Ridge and other uplands. Variants of these soils can also occur along alluvial drainage channels. In these locations, the soil comprises massive loamy sands over sandy clay or clayey loam subsoils. Characteristics of this soil type are listed below.

- Coarse to medium- textured profiles, with uniform or gradational texture throughout.
- Generally bleached massive loams and gravelly sandy loams with acidic subsoils, with a transitional zone into weathered rock.
- Found in the *Sandy Alluvial Plains (terrain unit II)* and *Sandstone Ridges (terrain unit IV) , Basaltic Uplands (terrain unit V)* and *Granite Uplands (terrain unit VI).*

- Classified as Tenosols and Kandosols.

5.2 Clay Loams and Clays

These soils occur on the lower slopes and edges of the sandstone uplands. They can also occur within depressions and along drainage channels. Characteristics of this soil type are listed below.

- Consist of gradational; loam to clay loam soil profiles with massive to moderately structured clay loam or light clay subsoils.
- Found in the *Sandy Alluvial Plains (terrain unit II)* and *Sandstone Ridges (terrain unit IV).*
- Classified as Rudosols, Tenosols and Kandosols.

Soil Type 6. Sands and Sandy Loams

Soils in this group have a uniform or weakly gradational, sandy texture. Two sub-groups of this soil unit were identified within the study area

6.1 Alluvial Sands

These soils comprise of alluvial and colluvial deposits. They are generally found along the sandy alluvial plains. Characteristics of this soil type are listed below.

- Moderately deep profile.
- Generally loose-grained sand soils.
- Found in the *Sandy Alluvial Plains* (*terrain unit* II).
- Classified as Rudosols and Tenosols.

6.2 Residual Sands and Sandy Loams

These soils are formed from quartzose sandstone. They occur on eroded plateau margins, uplands and occasionally on lower slopes. Characteristics of this soil type are listed below.

- Profile depth can vary from shallow to moderately deep, depending on erosion level and landscape position.
- Consist of sands and loamy sands with organic material (and staining), over an acidic sandy subsoil underlain by weathered rock.
- Found in the *Sandy Alluvial Plains (terrain unit II) and Sandstone Ridges (terrain unit IV)*.
- Classified as - Rudosols, Tenosols and Kandosols.

Soil Type 7. Skeletal, Rocky or Gravelly Soils

These soils occur in upland areas, generally adjacent to rock outcrops. Characteristics of this soil type are listed below.

- Shallow to moderately deep gravelly and stony soils.
- Typically >60% coarse fragments in a sandy, loamy or clayey soil matrix.
- Found in the *Sandstone Ridges (terrain unit IV), Basaltic Uplands (terrain unit V)* and *Granite Uplands (terrain unit VI).*
- Classified as Rudosols and Tenosols.

3.3.2 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 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 in 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).

The majority of soils within the study area have sodic subsoils, the exception being soils associated with the basalt or granite outcrops in the study area.

3.3.3 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. Many soils within the study area have saline subsoils; sodic soils are frequently saline due to their soil chemistry.

In the study area saline soils can arise from both natural and anthropogenic influences, as listed below.

- Weathering of natural rocks that contain high levels of sodium.
- Seepage of groundwater through naturally saline rocks.
- Irrigation onto soil with poor quality groundwater with high salt content (commonly referred to as irrigation salinity).
- Saline groundwater can rise following land clearance in recharge areas due to the reduction of water uptake from vegetation. As a result, ground water levels can rise, bringing subsurface salts to the surface (commonly referred to as dry land salinity). Within the study area, dryland salinity was observed to the west of Tipton and Cecil Plains.

The distribution of saline soils is similar to sodic soils.

3.3.4 Acid Sulfate Soils

Acid sulfate soils usually occur below 10 m AHD, and are associated with anoxic, highly organic environments close to saline water. Although these conditions do not exist within the project development area, acid sulfate soils can also occur at higher elevations inland, associated with anaerobic conditions along river and lake beds, irrigation channels, and in saline seepage areas where there are organic-rich deposits. Regional mapping provided by Arrow (based on the National Acid Sulphate Soils Atlas (Geosciences Australia)), shows areas of potential acid sulfate soils within the project development area. However, these areas are of limited extent and appear to represent areas where conditions may be suitable for the formation of acid sulfate soils (e.g., wetlands and watercourses), rather than groundtruthed, proven instances of acid sulfate soils within the project development area. Accordingly, it is reasonable for the project to progress on the assumption that acid sulfate soils will not be encountered during project activities.

3.3.5 Soil Distribution and Mapping

The assessment combined LRAs from four different data sets, to produce terrain units as described in Section 4.1: Terrain Unit Mapping and Environmental Values. Table 3.3 shows the typical soils associated with each terrain unit, Section 4.1: Terrain Units Mapping and Environmental Values discusses the characteristics and distribution of terrain units.

Table 3.3 Soil type and terrain unit (see Section 4.1) relationships across the study area

TU[1]	Typical Soils[2]	Associated Soils	Summary Description	Indicative Formation Process	Notes
Clay Alluvial Plains					
Ia	Condamine (2), Haslemere (4.1), Mywybilla (2), Anchorfield (2), **Arubial (4.1)**, *Keetah (5.1), Bengalla (4.1)*	Downfall (4.1), Combidiban (4.2), Waco (2), Cecilvale (2) **Bogandilla (4.1), Chinchilla (6.1)**	Deep cracking clays of various types ("black soils"), texture contrast soils on rises and low banks	Erosion/weathering of sandstone and basalt followed by long, deep weathering. Coarser topsoil associated with creeks	Associated with current river floodplain (actual channel is sandy alluvium)
Ib	Waco (2)	Anchorfield (2), Mywybilla (2), Cecilvale (2), Yargullen (2)	Deep cracking clays of various types ("black soils") - highly valued soils. Shallow Vertosols close to basaltic uplands	Basaltic alluvium eroded from Great Dividing Range to form broad plains	
Ic	Cecilvale (2), Millmerran (3)	Mywybilla (2), Haslemere (4.1), Downfall (4.1), Waco (2), Oakey (4.2), **Bogandilla (4.1)**	Deep cracking clays (grey) with texture contrast soils on rises (islands) within clay sheet	Mixed sandstone and basalt alluvium on the edge of the alluvial plains, possibly at the base of ridges between river valleys	
Sandy Alluvial Plains (cont'd)					
Id	Oakey (4.2), Haslemere (4.1), Waco (2)	Formartin (4.2), Cecilvale (2), Mywybilla (2)	Texture contrast soils with pockets of deep cracking clays in depressions/lower elevation areas	Remnant older mixed sandstone/basalt alluvial plains left (slightly) above more recent valley floor	Associated with Oakey Creek and dissected Basaltic uplands
Sandy Alluvial Plains					
IIa	Downfall (4.1), Leyburn (4.1), Haslemere (4.1), *Murra Cul Cu (4.1), Yambocully (4.1), Oonavale (4.1),* ***Retro (4.1)***	Milmerran (3), Cecilvale (2), Oakey (4.2), Condamine (2), Chinchilla (6.1), Davy, ***Taurus (4.1), Vermont (2), Warrinilla (5.1) Southernwood (4.2)***	Texture contrast soils with sandy soils on levees. Deep cracking clays at the base of basaltic uplands	Sandy/loamy alluvium washed from sandstone/basalt overlying sandstone respectively by rivers/creeks flowing from Kumbarilla Ridge	More loamy soils seem to be formed from sandstone underlying basalt
IIb	Davy (6.1), Combidiban (4.2), **Chinchilla (6.1), Bogandilla (4.1),** *Marella, Bendidee*	Leyburn (4.1), Downfall (4.1), Chinchilla (6.1), Nudley (4.2), **Arubial (4.1)**	Sandy soils close to creeks (floodplain) and texture contrast soils with sandy topsoil further away	Sandy alluvial plains/outwash fans/floodplains from the Kumbarilla Ridge	
IIc	*Wondoogle (6.1), Wai Wai (6.1)*		Deep sandy soils	Elevated sand ridges and relict dunes - probably originally creek bar deposits, then affected by aeolian processes	Within Weir River catchment. Sand deposits generally overlie clay alluvium
Brigalow Plains and Uplands					
IIIa	Kupunn (1), ***Teviot (2), Cheshire (5.1)***	Belahville (4.2), Haslemere (2), Tara (1), Langlands (1), **Arubial (4.1), Bogandilla (4.1), Rogers (4.1), Tandawanna,** ***May Downs (2), Rugby (7), Rolleston (3), Southernwood (4.2), Vermont, (2) Wyseby (4.1)***	Deep cracking clays, with texture contrast soils on levees/creek terraces; rises (islands) within Condamine floodplain and along the edge of (laterised) sandstone and in pockets along Juandah creek (North)	Coarser material washed over deep clays (formed by deep weathering of sandstone?) either through recent overbank flows or sheetwash from hills	Shallow gilgai (Kupunn), dissected by creeks
IIIb	Tara (1), *Wondalli, (1), Calingunee (1)*	Kupunn (1), Haslemere (2), **Bogandilla (4.1), Rogers (4.1), Arden (1),Tandawanna (4.2)**	Deep cracking clays with texture contrast soils (chromosols) on rises (islands) within floodplain	Coarser material may be remnant	Deep gilgai (Tara)

Table 3.3 Soil type and terrain unit (see Section 4.1) relationships across the study area (cont'd)

TU[1]	Typical Soils[2]	Associated Soils	Summary Description	Indicative Formation Process	Notes
IIIc	Moola (2), Gate (1), **Ulimaroa (2)**	Acland (3), Walker (4.2), Knoll (7), Edgefield, (2) Kenmuir (3), Downfall (4.1), **Bogandilla (4.1), Tandawanna (4.2)**	Deep cracking clays on lower slopes, moderately deep cracking clays on mid-slopes with texture contrast chromosols/ dermasols on steeper slopes and thin, rocky soils on ridgetops	Colluvium from steeper slopes washed over deeply weathered sedimentary rock (i.e. clays)	Moderate relief, with gilgaied clays in valleys and shallow soils over sandstone on higher ground (ridges) - texture contrast soils in between
IIId	Calingunee (1), Kurubmul (4.1), *Murra Cul Cul (4.1), Mt Carmel (3), Moruya (4.1), Wynhari (3),* ***Cheshire (5.1), Teviot (2), Retro(4.1), Taurus (4.1), Carraba (5.1)***	Arden (1), Tandawanna (4.1), ***Kinnoul (3), Southernwood (4.2), Ingelara (3)***	Texture contrast sodosols/chromosols with areas of deep cracking clays (sodic at depth) and brown earths	Erosion/weathering of sandstone has left remnant jumpups surrounded by deep cracking clays and texture contrast soils in south; similar pattern of weathering/erosion of fine-grained (shales/sandstones) in the north	Soils associated with weathering and erosion processes on Kumbarilla Ridge sedimentary rocks
Sandstone Ridge (cont'd)					
IVa	Leyburn (4.1), Downfall (4.1)	Haslemere (2), Nudley (4.1), Combidiban (4.2), Davy (6.1)	Deep sands close to creek channels, texture contrast soils (loamy topsoils) - chromosols on rises (islands), sodosols elsewhere	Thin sheet of coarser material washed over deep weathered deep cracking clays from sandstone ridge	
IVb	**Coalbah (4.1), Bogandilla (4.1), Weengallon (4.1), Braemar (4.1)**	**Cutthroat (4.2), Nudley (5.2), Kupunn (1), Arubial(4.1)**	Texture contrast soils with distinct sandy topsoils overlying clays. Patches of clay soils (in depressions)	Edge of Brigalow Clay Sheet and dissected laterised sandstone - sands washed over DCCs	Specifically at the edge of the Brigalow Clay Sheet at the foot of sandstone ridge
IVc	Weranga (4.1), Braemar (4.1), Channing (4.1), Cutthroat (4.1), *Uranilla (4.1)*	Knoll (7), Drome (6.2), Davy (6.1), Chinchilla (6.1), Combidiban (4.2), Hanmer (5.2), Flinton (5.2), Allan (4.1), Leyburn (4.1), Binkey (5.1), **Highmount (6.2), Minnabilla (7), Arubial (4.1)**	Sandy soils close to creeks; texture contrast soils with bleached sandy topsoils and/or bleached subsoils; shallow gravelly soils on steeper slopes/hilltops	Weathering and erosion of sandstone bedrock	Braemar on slopes above Cutthroat; Weranga located at top of slopes/rises; Davy/Chinchilla/ Drome located on levees/near creeks
IVd	Knoll (7), Cutthroat (4.1), Drome (6.2), **Minnabilla (7), Binkey (4.1),** *Weengalion (4.2), Flinton (6.2)*	Braemar (4.1), Hanmer (5.2), Allan (4.1), Davy (6.1)	Shallow, gravelly soils with texture contrast soils (bleached sandy topsoil) on shallower slopes and sandy soils close to creeks	Weathering and erosion of sandstone bedrock	Higher relief than IVc
IVe	*Flinton Shallow (6.2), Karbullah (7)*		Very shallow, very gravelly soils	Weathering and erosion of sandstone bedrock	Associated with sandstone jumpups at south end of Kumbarilla Ridge
Basaltic Uplands					
Va	Nungil (3), Kenmuir (3)	Beauaraba (3), Charlton (2), Purrawunda (2), Southbrook (3), Aubigny (3), Aberdeen (2), ***Cheshire (5.1), Rugby (7), Kinnoul (3)***	Shallow, gravelly dark/reddish non cracking clay and clay loam soils with deeper dark/reddish clays on lower slopes	Weathering and erosion of basalt bedrock	Only found in Dawson Fitzroy Basin

Table 3.3 Soil type and terrain unit (see Section 4.1) relationships across the study area (cont'd)

TU[1]	Typical Soils[2]	Associated Soils	Summary Description	Indicative Formation Process	Notes
Vb	Kenmuir (3), Beauaraba (3)	Charlton, (2) Purrawunda (2)	Non cracking clays on steeper slopes and higher elevations; moderately deep dark cracking clays on shallower slopes and at lower elevations	Weathering and erosion of basalt bedrock	Associated with basalt remnants in southern area of site
Granite Uplands					
VIa	Banca (5.1)	Cottonvale (4.2)	Sandy loam soils (shallow to moderately deep) on steeper, higher elevation slopes with moderately deep texture contrast soils on lower slopes	Weathering and erosion of granite bedrock	Banca located at higher elevation than Cottonvale

[1]TU = Terrain Unit.

[2]Soil classification key is based on the four LRA datasets as follows: MCD (Harris *et al*., 1999), **MWD** (Maher, 1996), *WLM* (Thwaites and Macnish, 1991), ***ZDD*** (Perry, 1968).

3.3.6 Soil Field Investigation Findings

Coffey's field investigation confirmed that soil types were consistent with those anticipated from the LRA and desktop assessment. Soil classifications are based on standard Australian classifications, which rely on physical and chemical property testing (see Section 3.3.1: Soil types and characteristics within the study area). However, the LRA soil classifications at the unit level are simplified versions of these. It was possible to encounter, for example, a Chromosol (<6.0% Exchangeable Sodium Percentage (ESP)) where the LRA unit indicated Sodosols (>6.0% ESP). Both sodic Chromosols and Sodosols have similar constraints and would be managed in the same way.

Test pit locations are shown in Figure 4.4. Summary information for Coffey test pits is as follows (see Appendix B and C for further details):

Table 3.4 Summary of Soil Types within Coffey Test Pits

Test Pit No.	GPS Coordinates		TU	LRA Soil Type*	Soil Type (after Isbell, 2002)	Appendix B Figure
	Northing	Easting				
CTP1	7096770	201401	IIId	Cheshire	Brown Dermosol	121
CTP2	7096534	199068	Va	Kinnoul	Brown Dermosol	122
CTP3	7099375	205401	IIa	Taurus	Brown Sodosol	123
CTP4	7050645	234212	IIIb	Tara	Grey Vertosol	124
CTP6	7023693	276537	Ia	Condamine	Grey Vertosol	125
CTP7	7023097	284766	IVb	Kupunn	Grey Vertosol	126
CTP8	6973292	334207	Id	Hazlemere	Brown Chromosol	127
CTP9	6961089	323209	IVd	Braemar (shallow)	Brown Sodosol	128
CTP10	6954231	341487	Ib	Mywybilla	Black Vertosol	129
CTP11	6963753	314607	IVa	Cutthroat	Yellow Chromosol	130
CTP12	6935155	320595	IIb	Leyburn	Red Chromosol	131
CTP13	6935557	324439	Ia	Condamine	Black Vertosol	132
CTP14	6935420	329659	Ia	Anchorfield	Black Vertosol	n/a
CTP15	6858413	270731	IIb	Marella	Yellow Tenosol	133
CTP16	6857279	275688	IIIb	Calingunee	Grey Vertosol	134
CTP17	6861232	266038	IIa	Murra Cul Cul	Red Sodosol	135

* Soil types taken from relevant LRA.

A summary of the physical and chemical soils testing is as follows:

- Gilgai Clay – CTP4 and CTP7. CTP4 was excavated through a melonhole gilgai. In CTP4 the surface soil sample was alkaline pH (7.8), while the subsoil was acidic (pH 4.6). The subsoil was also found to be sodic. CTP7 was located in an area where gilgai had been levelled. Samples from this test pit were alkaline. CTP7 is dispersive on remoulding and CTP4 is likely to be dispersive due to its high ESP, 8.9%).
- Black Cracking Clay – CTP6, CTP10, CTP13, CTP14, CTP16, occurring in a range of TUs. All samples were found to be alkaline throughout the profile. Only CTP13 was found to have strongly sodic subsoil (ESP 6.9%). Calcium was the dominant cation in CTP6, which is probably due to the presence of calcium carbonate segregations. Soils were generally dispersive, with CTP 14 dispersive on remoulding.
- Uniform Non-Cracking Clay – CTP1 and CTP2. Samples had an alkaline pH due to the presence of soil carbonate segregations in the subsoil. Soils in CTP1 were dispersive.
- Dispersive Texture Contrast Soils – CTP3, CTP8, CTP9, CTP11, CTP12 and CTP17. Soils in this category were found to have varying pH levels. Subsoils were generally found to be sodic to strongly sodic (ESP >6), with magnesium and sodium being the dominant cations. Samples were generally dispersive, with Emerson Classes of 1 or 2.
- Non-Dispersive Texture Contrast Soils – no non-dispersive texture contrast soils were encountered during the soil investigation program.
- Residual Sands and Sandy Loams – CTP15. Both the surface and subsurface horizons were found to have a slightly acidic to neutral pH level. The cation exchange capacity of the subsoil

was very low with magnesium and sodium being the dominant cations. The sodic nature of the subsoil (ESP 9.7%) indicates the potential for subsoil dispersion and erosion.

- Skeletal, rocky or gravelly soils – these soils were observed during the field reconnaissance but not assessed during the soil investigation program.

Geotechnical engineering properties of the soils are as follows (see Appendix B and C for further details):

Table 3.5 Summary of Soil Engineering Properties

Test Pit Number	TU	Depth of Sample m	% passing 75 µm sieve	Liquid Limit %	Plastic Limit %	Plasticity Index %	Standard Optimum Moisture Content %	Linear Shrinkage %	Swell %	Compactive effort	CBR @ 2.5mm %	Emerson Class
CTP1	IIId	1.0	87	59	20	39	21	18	5.5	Standard	1.0	2
CTP3	IIa	0.5	-	-	-	-	-	-	-	-	-	2
		1.0	-	-	-	-	-	-	-	-	-	1
CTP7	IVb	0.5	-	-	-	-	-	-	-	-	-	3
CTP10	Ib	1.0	95	104	39	65	31	25	10.0	Standard	1.0	2
CTP11	IVa	0.7-1.1	38	40	13	27	13.5	12	2.0	Standard	1.5	2
CTP12	IIb	0.5	57	39	13	26	13	12.5	4.0	Standard	3.5	2
CTP14	Ia	0.5	98	-	-	-	-	-	-	-	-	3
CTP16	IIIb	1.0	59	44	16	28	15	16.5	4.5	Standard	2.5	2

Note "-" indicates that samples were not subjected to the stated test.

The field assessments and laboratory testing information were used to supplement existing test pit data, obtained during previous geotechnical investigations within the study area (Coffey, 2006 and 2008; Stafford Adamson & Associates, 2007; Soil Surveys Engineering, 2008 and 2009; shown on Figure 3.4).

The laboratory testing of the soils sampled during this study indicates that, in general, the soils were composed of low-plasticity clay with Optimum Moisture Content close to Plastic Limit. However, soils were generally soft, with poor bearing capacities and CBR (California Bearing Ratio) values indicate that they will provide a poor subgrade for road pavements. All subsoils tested had Emerson Classes of either 1 or 2, indicating highly dispersive, erodible material. In addition, liquid limits and linear shrinkage values were generally high (>70% and >20% respectively), indicating cracking-prone materials. Shrink/swell amounts will depend on the quantity of fines in the material (Coffey, 2006). However, most test results, especially within clay soils, indicated that the material was moderately to very highly reactive to moisture i.e. significant ground movements could be expected in response to wetting and drying.

3.4 GQAL in the Study Area

The study area covers part of the Darling Downs, an area of national agricultural importance. This region is a traditional grain and cotton production area (Harris *et al.*, 1999). Clay soils are considered to have the highest cropping potential, while sands or shallow soils have limited cropping potential. This difference is a result of the higher water-holding capacity and fertility of the clay soils.

Cropping and stock grazing are the dominant land-uses across the study area. The relative area of GQAL within the study area is as follows (see Figure 3.8):

Table 3.6 Spatial Extent and Percentage of GQAL within the Study Area

GQAL Class	Area (ha)	% of Study Area	Agricultural Classification
Class A	438,000	52	GQAL
Class B	63,000	7	
Class C	347,000	41	Pasture land
Class D	400	Negligible	Non-agricultural land

The distribution and land-use of GQAL is visible on aerial photography and satellite imagery, as cropping patterns dominate the landscape. The majority of GQAL is located along the three major river valley floors, particularly the broad Condamine River valley with its deep cracking clays. GQAL is also present in the far north of the study area (between Guluguba and Wandoan). GQAL occurs in patches to the southwest of Captain's Mountain and becomes the dominant land class in the south of the study area, towards Goondiwindi.

Much of the GQAL within the study areas is currently used intensively. Advanced farming techniques are currently used giving opportunities for both winter and summer cropping and, occasionally, double cropping (Harris *et al.*, 1999). Irrigation water is abstracted from local creeks and rivers, particularly the Condamine River, as well as from bores accessing groundwater resources. Construction of large irrigation dams is common. Extensive areas of land have been laser levelled to achieve efficient flood irrigation. The irrigation systems often require significant capital expenditure.

Class C land occurs along the sandstone uplands of the Kumbarilla Ridge to the east and plateau areas to the north of the study area. This area is used extensively for cattle grazing. Many paddocks have undergone pasture improvements through fertiliser additions and establishment of improved pasture vegetation species (Harris *et al.*, 1999).

The predominance of highly erodible sodic soils within the study area has not been compatible with intensive agriculture and unsuitable land management practices. Therefore, GQAL is prone to erosion. Contour banks and strip cropping on sloping land are widespread. Stubble retention is also used to protect soil surface from rainsplash, runoff and wind erosion.

3.5 Strategic Cropping Land in the Study Area

The trigger mapping released by DERM indicates that the indicative areas of Strategic Cropping Land have a similar spatial extent to GQAL, covering 49% of the study area. Small areas of Agricultural Class C land have been included and small areas of GQAL not been included as candidate areas for Strategic Cropping Land. Draft Trigger mapping for Strategic Cropping Land is shown on Figure 3.8.

3.6 Specific Sites of Environmental Significance – Geoheritage

Several geology, landform or soils features have been registered or are indicative sites (i.e. not yet registered but nationally significant examples of a natural feature) on the Australian Register of the National Estate (although this has since been superseded by the Environmental Protection and Biodiversity Conservation Act (1999)) (DSEWPC, 2011). Indicative places are those which are (or were) being assessed to be included on the Register of the National Estate. The Register of the National Estate was frozen in 2007, and registered places are in the process of being transferred to the appropriate heritage register. Current information does not indicate whether the listed sites have been transferred. For the purposes of this report, the following sites are considered to be of environmental significance.

3.6.1 Lake Broadwater Conservation Park

Lake Broadwater, approximately 350 ha in area and 4 m deep when full, is located along the eastern flanks of the Kumbarilla Ridge, to the west-northwest of Tipton (DSEWPC, 2011). This water body represents an example of one of the few inland wetlands in southern Queensland. The 1200 ha Lake Broadwater Conservation Park (i.e. the lake and its immediate surrounds) has been protected by an environmental park status under the *Nature Conservation Act 1992* since 1994. The area surrounding the lake provides an example of vegetation communities typical of the Southern Brigalow Belt, supported on the heavy clay soils of the locality (DERM, 2011). The spatial extent of these soils, along with the associated vegetation communities, has been severely reduced by agricultural expansion. The lake soils and landscape also support a number of exotic plants and animals.

3.6.2 Chinchilla Sands Local Fossil Fauna Site

The Chinchilla Sands Local Fossil Fauna Site is the last remaining example of the Chinchilla Sands with an intact profile (DSEWPC, 2011). The sand profile remains relatively intact as it has not been altered by clearing or cultivation. The site is considered to be one of the most important Pliocene fossil sites in Australia and has been listed on the Register of the National Estate since 2002. The site extends over approximately 120 ha and is located approximately 3 km south-east of Chinchilla. The site comprises the Chinchilla Rifle Range (Reserve No.78), and a contiguous section of the Condamine River bounded on the south by its middle thread and on the east and west by the alignments of the adjoining sections of the rifle range (DSEWPC, 2011).

3.6.3 Barakula State Forest Area and Scientific Areas

The 31,000 ha Barakula State Forest Area (SF 302), located about 30 km northeast of Miles, represents a relatively intact example of Brigalow communities existing as part of a larger forest complex and is registered as an indicative place on the Register of the National Estate (DSEWPC, 2011). The conservation value of the area is based on the unique pattern of soils. Texture contrast soils are interspersed with sands along watercourses, with isolated gilgaied heavy clay soils. These isolated Vertosols support brigalow/belah open forest.

The 300 ha Barakula Scientific Area, north of Chinchilla, (particularly 80 ha No. 22) represents specific examples of brigalow/belah/softwood community associated with deep gilgaied clay soils. The areas are particularly valuable as they lie within a very large forest block of the Barakula State Forest, in contrast to the isolated situation of many remaining brigalow areas (DSEWPC, 2011). The Barakula Scientific Areas are also registered as indicative places on the Register of the National Estate. The location of the area is approximately 75 km north-north-east of Chinchilla and within State Forest 302 (area bounded by line commencing at AMG point: 9045-2 Durah - 870903, east to 890903, south to 890887, west to 870887, then north to commencement point; DSEWPC, 2011).

4. ENVIRONMENTAL VALUES AND LANDSCAPE SENSITIVITY

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

The broadly similar geological, landform and soil characteristics of each terrain unit represent the environmental values of the landscape, and govern the way in which the landscape responds to disturbance, i.e. its sensitivity. This response is controlled by a combination of the following:

- 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 than others.

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 DSEWPC Australian Heritage Database following assessment by the Australian Heritage Council and the Minister for Sustainability, Environment, Water, Population and Communities.

4.1 Terrain Unit Mapping and Environmental Values

The study area was divided into six broad terrain units, based on the findings of the existing environment assessment. The terrain units were defined and subdivided based on the following variables (see Section 2.5 and Figure 4.1):

- Geology: bedrock outcropping and engineering properties.
- Landform: slope steepness, topography, geomorphological process.
- Soils: physical, chemical and engineering properties.
- Properties: characteristics of the landscape which may cause adverse response.
- Processes: potentially adverse geomorphic processes.

The findings of this study were broadly consistent with the available LRA mapping. However, large areas of vegetation had been cleared and, in some areas, LRA vegetation types no longer applied. For example, areas mapped as Brigalow Forest with gilgai on the LRA mapping were observed as levelled agricultural fields during the field investigation.

Table 4.1 summarises the terrain unit characteristics, properties and processes that represent the environmental values of the study area. Typical vegetation for each unit is also presented, based on the LRA mapping observations (discussed further in 3D Environmental, 2011).

Table 4.1 Environmental Values of the Study Area: Terrain Unit Characteristics, Properties and Processes

TU	Landform	Geology	Soils	Vegetation	GQAL	Intrinsic Landscape Properties	Geomorphological Processes
Clay Alluvial Plains							
Ia Ia (f)	Contemporary Floodplain Area within 10 year flood zone	Quaternary Alluvium	Deep cracking clays with texture contrast soils within unfarmed elevated pockets	Poplar box or Queensland blue gum open woodland and blue gum/red gum/Moreton Bay ash woodland	A	• Soft soils • Prone to waterlogging, • Dispersive, sodic subsoils, • Agricultural land use	• Gullying and flooding within contemporary flood plain
Ib	Broad level plains of basaltic alluvium	Quaternary Alluvium	Black self-mulching deep cracking clays with texture contrast soils within unfarmed elevated pockets	Open grassland	A	• Intense agricultural land use	• Occasional erosive flooding
Ic	Broad level plains of mixed basaltic/ sandstone alluvium	Quaternary Alluvium	Grey deep cracking clays	Poplar box or Queensland blue gum open woodland with belah and wilga	A	• Prone to waterlogging • Soft soils • Surface crusting • Strongly sodic and alkaline subsoils	• Occasional erosive flooding • Wind/water erosion
Id	Broad level plains of mixed basaltic/ sandstone alluvium	Quaternary Alluvium	Texture-contrast soils with pockets of deep cracking clays	Poplar box open woodland or grassland	A	• Can be boggy at boundary of soil types • Surface crusting • Subsoils: strongly sodic, occasionally saline, strongly alkaline	• Wind/water erosion
Sandy Alluvial Plains							
IIa	Alluvial plains and stream terraces of mixed basaltic/ sandstone alluvium	Quaternary Alluvium	Bleached clay loams/sandy clay loams over dark clays	Poplar box and Moreton Bay ash woodland with wilga	B	• Hard-to-penetrate surface, especially after rain • Strongly sodic	• Wind/water erosion
IIb	Flat/gently undulating sandy alluvial plains	Sandy Alluvium/ Colluvium	Deep massive sands over mottled yellow/grey clays. Combination of texture contrast soils and deep sands	Cypress pine, rough-barked apple, blue gum, rusty gum and poplar box open forest	C	• Loose surface • Sodic relatively impermeable sub-soil with high bulk density • Highly erodible subsoil • Prone to waterlogging • Contains the Chinchilla Sands Local Fossil Fauna Site	• Wind erosion when cultivated (root structure removed)
Sandy Alluvial Plains (cont'd)							
IIc	Elevated sand ridges within Border River Valleys	Sandy Alluvium/ Colluvium	Deep aeolian sands	Mixed eucalypt and cypress pine	-	• Loose soils	• Water erosion • High/extreme wind erosion risk

Table 4.1 Environmental Values of the Study Area: Terrain Unit Characteristics, Properties and Processes (cont'd)

TU	Landform	Geology	Soils	Vegetation	GQAL	Intrinsic Landscape Properties	Geomorphological Processes
Brigalow Plains and Uplands							
IIIa	Flat to gently undulating clay plains with gilgai	Underlain by Sandstone	Very deep grey self-mulching cracking clays	Brigalow, belah and wilga forest, extensively cleared	A	• Shallow gilgai • Sodic and saline at depth • Intense agricultural land use • Fewer constraints than IIIb	• Occasional erosive flooding
IIIb	Flat to gently undulating clay plains with gilgai	Underlain by Sandstone	Very deep grey self-mulching cracking clays	Brigalow, belah open forest with some wilga and black tea tree	B	• Deep melonhole gilgai • Hard-setting surface crust • Highly sodic and saline at depth	• Water ponds within gilgai and gilgai remnants after levelling
IIIc	Gently undulating rises and plains on sandstone units within the Walloon Coal Measures	Underlain by Sandstone	Grey deep cracking clays	Brigalow, belah and wilga open forest	A/B	• Shallow/moderate gilgai • Sandstone cobbles/boulders may cause refusal during excavation • Strongly sodic and saline subsoils	• Severe water erosion
IIId	Undulating plains and rises	Underlain by Sandstone	Grey/brown deep cracking clays and texture contrast soils. Variable soil types	Belah or Brigalow open forest (with box or poplar box open woodland)	A/B	• Shallow gilgai • Strongly saline and sodic at depth. • Can have hard-setting surface	• Gully erosion
Sandstone Ridge							
IVa	Gently undulating plains on sandstone along the fringes of the Kumbarilla Ridge	Sandstone	Bleached sands/loams over brown/grey clays	Poplar box and bull oak open woodland	C/D	• Prone to waterlogging • Hard surface layer • Dense subsoils • Contains the Lake Broadwater Conservation Park	• Highly erodible (surface/subsurface)
IVb	Edge of Brigalow Plains or dissected laterised sandstone remnants	Sandstone	Texture contrast soils	Poplar box and false sandalwood shrubby woodland	C	• Prone to waterlogging due to impermeable subsoils and sandy surface soils • Dense subsoils	• Erosion
Sandstone Ridge (cont'd)							
IVc	Undulating plains and rises on sandstone	Sandstone	Texture contrast: bleached sands/loams over brown/grey clays	Narrow-leaved iron bark, bull oak, rusty gum, cypress pine and poplar box open forest	C/D	• Sodic, saline, dispersive subsoils • Prone to waterlogging due to impermeable subsoils and sandy surface soils • Dense subsoils • Hard-setting surface in places • Occasional rock outcrops	• Piping, gullying and surface/subsurface erosion

Table 4.1 Environmental Values of the Study Area: Terrain Unit Characteristics, Properties and Processes (cont'd)

TU	Landform	Geology	Soils	Vegetation	GQAL	Intrinsic Landscape Properties	Geomorphological Processes
IVd	Plateaus and low sandstone hills to undulating plains, lateritic scarps are common	Sandstone	Texture contrast soils with areas of shallow gravelly soils	Narrow-leaved iron bark, spotted gum and rusty gum open forest, or cypress pine, bull oak, rusty gum and iron bark open forest	C/D	• Highly sodic/saline • Waterlogging • Dense subsoils • Rock outcrops	• Gully/tunnel erosion • Wind erosion
IVe	Dissected uplands and scarps - jumpups	Sandstone	Shallow gravelly soils	Ironbark, poplar box and cypress pine woodland	D	• Shallow, gravelly soils • Slightly acidic • Steep slopes	• Water erosion
Basaltic Uplands							
Va	Level to gently undulating plains	Basalt overlying sandstone	Variable reddish brown to brown clays and loams	Poplar box open woodland	B/D	• Shallow soils • High gravel content • Aquifer recharge zone (potential for contamination) • Steep slopes • Lower slopes can be suitable location for building.	• Some sheet/rill and gully erosion • Wind erosion possible
Vb	Steep hills and mountains	Basalt overlying sandstone	Shallow gravelly clays	Mountain Coolabah and narrow-leaved iron-bark open woodland	D	• Shallow soils • High gravel content • Aquifer recharge zone (potential for contamination) • Steep slopes • High strength rock.	• Sheet/rill erosion
Granite Uplands							
VIa	Steep granite hills with rock outcrops	Granite	Sands over hard pan	New England blackbutt, tumbledown gum, ironbark and stringy bark woodland	D	• Shallow soils with hardpan • Rock outcrops • High quartz gravel/rock content • Steep slopes • Prone to waterlogging	• Rill and gully erosion

4.2 Landscape Sensitivity Assessment

This section of the report assesses the sensitivity of the environmental values within 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). The sensitivity of a terrain unit is controlled by the sensitivity of its attributes and defined by a combination of the following criteria:

Table 4.2 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 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 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 are 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</td><td>Rehabilitation can be successfully achieved</td><td>Rehabilitation is likely to be slow or only partially successful</td><td>Limited rehabilitation potential</td></tr>
</table>

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. Within the Study Area No Go areas are associated with very steep slopes along plateau and mesa edges and cuesta escarpments.

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.

4.2.1 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: This applies to most terrain units within the study area (i.e. those not listed under Moderate or High Sensitivity to disturbance of Conservation Status or Geoheritage Assets).
- Moderate – Sites classified by this study as being of importance from a geology, landform or soils perspective or indicative sites on the DSEWPC Register of the National Estate:
  - Lake Broadwater Conservation Park within terrain unit IVb.
  - Barakula State Forest Area spreading over terrain unit IVd, with Barakula State Forest Scientific Areas located within isolated areas of terrain unit IIIb.
- High – Sites listed on the DSEWPC Register of the National Estate or similar:

  Chinchilla Sands Local Fossil Fauna Site, within terrain unit IIb.

4.2.2 GQAL and Strategic Cropping Land

One of the major environmental values of the study area is its GQAL. This land is protected under Queensland State Law: SPP1/92. The susceptibility of terrain units to GQAL disturbance has been classified as follows (see Figure 4.2):

- Low – Class D GQAL; terrain units IIc, IVe, Vb, VIa; areas of terrain units IVa, IVc-d, upper slopes of Va
- Moderate – Class C GQAL; terrain units IIb, IVb; areas of IVa, IVc-d.
- High – Class A and B GQAL; terrain units Ia-d, IIa, IIIa-d, lower slopes of Va.

The susceptibility of Strategic Cropping Land to disturbance is similar to the susceptibility of terrain units to GQAL disturbance, as they have a similar spatial extent.

4.2.3 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. Erodible, sodic soils are a characteristic of the study area, common to terrain units I, IIa-b, III and IV.

Susceptibility to Water Erosion Processes – 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.

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.

The sensitivity of terrain units to erosion is as follows (see Figure 4.3):

- 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, sands/non-dispersive clays, slope angles <5°. This includes terrain units IIa and IIb adjacent to watercourses, IIc.
- High – Low to very low organic matter, dispersive subsoils, slope angles > 5°; or non-dispersive soils and slopes >10°. This includes terrain units Ia-d, IIIa-d, IIa-b away from watercourses, IVa-d, lower slopes of IVe, Va-b, VIa. Areas considered to be of particular susceptibility to erosion are those with very steep slopes (jumpups, plateaux/mesa edges or cuesta escarpments) within terrain units IVe, Va-b, VIa.

Soil Sensitivity to Wind Erosion

Soils with loose surface material are prone to wind erosion. Texture contrast soils, or soils which are prone to surface crusting, can be susceptible to wind erosion if mechanically disturbed (see Figure 4.4). The sensitivity classification for wind erosion is as follows:

- Low – Dense clay soils. This includes terrain units Ia-d, IIIa-c, IVe, Vb, Via.
- Moderate – Texture contrast soils with hard surface crusting. This includes terrain units IIId, IVa-e, Va.
- High – Loose sandy soils. This includes terrain units IIa-b adjacent to watercourses, IIc.

4.2.4 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.

The distribution of soils with saline subsoils within the study area is similar to those classified as being susceptible to erosion. Figure 4.3, therefore, provides an indication of the spatial distribution of soils which are susceptible to salinity. Saline subsoils are particularly associated with terrain units Id, IIIa-d and IVc-d.

4.2.5 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. . Waterlogging is a seasonal problem in the region. Sodic soils in the study area, 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 4.5):

- Low – Shallow, dense, gravelly soils. This includes terrain units IVe, Vb, VIa, and areas of terrain unit VId (these units have associated topographic constraint which may exacerbate sensitivity).
- Moderate – Moderate to deep clay or sandy soils which are less prone to waterlogging. This includes terrain units IIa, Va.
- High – Deep sodic clays and texture contrast soils, which are prone to waterlogging; or deep, loose sands. This includes terrain units Ia-d, IIb-c, IIIa-d, IVa-c and areas of IVd. Terrain unit Ia represents the floodplain of the Condamine River and susceptible to flooding.

4.2.6 Rehabilitation-Potential Sensitivity

The rehabilitation potential of soils in the study area reflects the susceptibility to disturbance of the rehabilitation potential of the terrain unit, i.e. the likelihood that the rehabilitation potential will be adversely affected. 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. GQAL has been considered to be of moderate sensitivity, despite the obvious fertility of the soils, as the soils are well-structured and will be difficult to reinstate to their pre-disturbance structure, compactive states and composition. Many soils classified as GQAL are gilgaied deep cracking clays with localised soil variability. Both topographic expression and soil pattern will be near-impossible to reinstate to pre-disturbance conditions.

The rehabilitation-potential susceptibility of a terrain unit is assessed as follows (see Figure 4.6):

- Low (i.e., high rehabilitation potential) – moderate to high fertility, weakly structured soils with a deep, uniform profile on shallow slopes (<5°). These characteristics are uncommon in the study area.
- Moderate – moderate fertility, well-structured gradational soils on moderate slopes (5°-20°); or GQAL/deep cracking-clays on lower slopes. This includes terrain units Ia-c, areas of terrain units Id and IIIa-d, and lower slopes of terrain unit Va.
- High (i.e., low rehabilitation potential) – low to very low fertility; texture contrast soils, particularly those with sodic subsoils; compacted soils; or shallow soils, especially those with thin topsoils; steep slopes (>20°). This includes terrain units II, IV, and VI and texture contrast soils of terrain unit Id, gilgai and texture contrast soils of terrain units IIIa-d, and upper slopes of terrain unit Va.

4.2.7 Effect of Slope Steepness on Landscape Susceptibility

The characteristics of slopes within a terrain unit directly influence the sensitivity of the landscape, particularly with regard to erosion, landslide susceptibility and rehabilitation potential. Slope steepness is one of the major factors controlling both erosion (water on steeper slopes tends to have higher velocity and, therefore, erosive energy) and slope instability (steeper slopes are more prone to landsliding). In addition, steeper slopes are likely to have shallow soils, with reduced revegetation potential and, therefore, rehabilitation success. Artificial steepening of slopes is likely to increase the susceptibility of a terrain unit to erosion, landsliding and poor rehabilitation success. Figure 3.6 indicates slope steepness across the study area.

4.3 Sensitivity Ranking Summary and Overall Terrain Unit Sensitivity

4.3.1 Sensitivity of Environmental Values within the Study Area

An overall classification has been assigned to each terrain unit, based on the relative susceptibility of the unit to change following disturbance and the way in which the environmental values interact within each unit. Overall sensitivity was assessed as follows:

Overall Sensitivity of Terrain Unit I – Clay Alluvial Plains

- Does not contain geoheritage features.
- Contains GQAL and Strategic Cropping Land.
- Contains sodic, saline subsoils which are susceptible to all forms of water erosion.
- Contains soft soils which are prone to waterlogging. Terrain unit Ia is susceptible to flooding as it forms the floodplain of the Condamine River.
- Soils are typically deep cracking clays which are well-structured, with areas of texture contrast soils. Although the soils generally have high fertility, they will be challenging to reinstate to their pre-disturbance condition. The texture contrast soils of sub-unit Id will be more difficult to rehabilitate due to lower fertility and distinct soil profiles.

Terrain unit I has **moderate** overall sensitivity to disturbance due to the presence of GQAL and Strategic Cropping Land; erodible, soft soils which are prone to waterlogging and which will be difficult to rehabilitate to pre-disturbance conditions. Sub-unit Id is considered to be of a slightly higher sensitivity due to the comparative difficulty of rehabilitation.

Overall Sensitivity of Terrain Unit II – Sandy Alluvial Plains

- Contains the Chinchilla Sands Local Fossil Fauna Site, which is listed on the Register of the National Estate is located within sub-unit IIb.
- Sub-unit IIa is classified as GQAL and Strategic Cropping Land.
- Contains sodic, saline subsoils which are susceptible to water erosion, except along watercourses, within sub-units IIa-b. Sandy soils which are susceptible to wind erosion in sub-unit IIc and along watercourses in sub-units IIa-b.
- Contains loose sandy soils or soft clay soils that are prone to waterlogging.
- Contains low fertility sandy soils with poor rehabilitation potential or high fertility, well-structured soils which are difficult to reinstate.

Terrain unit IIb has **high** overall sensitivity to disturbance associated with the Chinchilla Sands Local Fossil Fauna Site. The remainder of the area is categorised as being of **moderate to high** sensitivity to disturbance due to the erodible soft or loose soils and poor rehabilitation potential.

Overall Sensitivity of Terrain Unit III – Brigalow Plains and Uplands

- Contains the Barakula State Forest Scientific Areas, indicative areas on the Register of the National Estate, located within sub-unit IIId.
- Contains GQAL and Strategic Cropping Land.

- Contains sodic, saline subsoils which are susceptible to all forms of water erosion. Texture contrast soils within sub-unit IIId are moderately susceptible to wind erosion.
- Contains soft soils which are prone to waterlogging.
- Contains deep cracking clay soils that are gilgaied, in particular in sub-unit IIIb. Well-structured clay soils and gilgai present within the terrain unit will be difficult to reinstate. Texture contrast soils within sub-units IIIc-d will be more difficult to rehabilitate due to lower fertility and distinct soil profiles.

Terrain unit III has **moderate** overall sensitivity to disturbance due to the presence of GQAL and Strategic Cropping Land; erodible, soft soils which are prone to waterlogging; and well-structured gilgaied clay soils and texture contrast soils which will be difficult to rehabilitate to pre-disturbance conditions. The Barakula State Forest Scientific Areas locally increase the sensitivity of sub-unit IIId, but not sufficiently to increase the overall sensitivity classification.

Overall Sensitivity of Terrain Unit IV - Sandstone Ridge (including Kumbarilla Ridge)

- Contains Lake Broadwater, located within sub-unit IVa, and the Barakula State Forest, located within sub-unit IVd, which are both indicative areas on the Register of the National Estate.
- Sub-unit IVb and areas of IVa and IVc-d are classified as Agricultural Class C: Pasture Land. All other areas are classified as non-agricultural land.
- Contains texture contrast soils or shallow, gravelly soils that are susceptible to water erosion. Moderately susceptible to wind erosion and prone to waterlogging(other than the shallow soils of sub-units IVd-e).
- Steep slopes associated with jumpups, plateaux/mesa edges, and cuesta escarpments locally increase the sensitivity to disturbance within sub-unit IVe.

The soil profile and moderate to low fertility reduces rehabilitation potential.

Terrain unit IV has **moderate** overall sensitivity to disturbance due to the presence of sodic, erodible texture contrast soils which are prone to erosion, waterlogging and generally poor rehabilitation potential. Shallow, gravelly soils of sub-units IVd-e are less susceptible to wind erosion but rehabilitation of these thin soils will be challenging due to their low fertility and steep slopes. The presence of Lake Broadwater and the Barakula State Forest locally increase the sensitivity of sub-units IVa and IVd, respectively, but not sufficiently to increase the overall sensitivity classification.

Overall Sensitivity of Terrain Units V and VI – Basaltic and Granite Uplands

- Lower slopes of sub-unit Va are classified as GQAL and Strategic Cropping Land.
- Contains generally shallow, gravelly, erodible soils with rocky outcrops. Also contains deeper soils on lower slopes of sub-unit Va, which are also susceptible to water erosion. Sub-unit Va can also be susceptible to wind erosion.
- Contains steep slopes associated with mesa edges and isolated steep hills (other than lower slopes of sub-unit Va).
- Characterised by poor rehabilitation potential due to shallow, low fertility soils, with the exception of the fertile, well-structured soils of sub-unit Va, which are difficult to reinstate to their pre-disturbance condition.

Terrain units Vb and VIa and upper slopes of terrain unit Va have **moderate** overall sensitivity to erosion due to their shallow, erodible, low fertility soils and the steep slopes typical of these areas. Lower slopes of terrain unit Va also have **moderate** sensitivity to erosion, due to the presence of GQAL and Strategic Cropping Land.

4.3.2 Summary of Sensitivity of Environmental Values within the Study Area

Table 5.1 summarises the sensitivity to disturbance of the environmental values of the terrain units, as follows:

Table 4.3 Summary of Landscape Sensitivity within the Study Area

Terrain Unit	Geoheritage[1]	GQAL/ SCL	Susceptibility to Erosion		Soft Soils/ Waterlogging	Rehabilitation -Potential[2]	Overall Sensitivity
			Water Erosion	Wind Erosion			
Clay Alluvial Plains							
Ia	L	H	H	L	H	M	M_s
Ib	L	H	H	L	H	M	M_s
Ic	L	H	H	L	H	M	M_s
Id	L	H	H	L	H	M/H	M_s
Sandy Alluvial Plains							
IIa	L	H	M/H	M/H	M	H	M_s
IIb	L/H	M	M/H	M/H	H	H	M_s/H_s
IIc	L	L	M	H	H	H	M_s
Brigalow Plains and Uplands							
IIIa	L	H	H	L	H	M/H	M_s
IIIb	L	H	H	L	H	M/H	M_s
IIIc	L	H	H	L	H	M/H	M_s
IIId	L/M	H	H	M	H	M/H	M_s
Sandstone Ridge (including Kumbarilla Ridge)							
IVa	L/M	L/M	H	M	H	H	M_s
IVb	L	M	H	M	H	H	M_s
IVc	L	L/M	H	M	H	H	M_s
IVd	L/M	L/M	H	M	L/H	H	M_s
IVe	L	L	H	L	L	H	M_s
Basaltic Uplands							
Va	L	L/H	H	M	M	M/H	M_s
Vb	L	L	H	L	L	H	M_s
Granite Uplands							
VIa	L	L	H	L	L	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]Rehabilitation-potential indicates the susceptibility to disturbance of rehabilitation potential.

The majority of terrain units within the study area are considered to be moderately sensitive to disturbance given the widespread occurrence of GQAL/Strategic Cropping Land and sodic soils which are susceptible to water erosion and waterlogging; and the difficulty of successfully rehabilitating texture contrast or structured clay soils. Steep slope areas may have high localised sensitivity to disturbance.

5. 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 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.

A constraints ranking was assigned to each unit, which indicated the severity and manageability of the constraint, as follows (after Shields and Thompson, 2009):

- Negligible (N)– Little or no constraint associated within the unit.
- Low (L) – Slight constraint or impact that can be overcome, or controlled with standard management practices/mitigation measures.
- Moderate (M) – Substantial constraint or impact that can be overcome or controlled with a combination of standard and special management practices/mitigation measures.
- High (H) – Substantial constraint or impact that requires special management practices to be overcome or controlled/mitigation measures.
- Very High (VH) – Substantial constraint or impact that cannot usually be overcome or controlled, even with special management practices/mitigation measures. These areas are generally classified as “No Go” areas.

5.1 Faults and Seismic Hazard Constraints

There are few faults within the study area (see Figure 4.3). Relative to the remainder of Australia, the study area has a moderate level of earthquake activity, as indicated in AS1170.4-2007 Structural Design Actions Part 4: Earthquake Actions in Australia (Standards Australia, 2007). Any infrastructure within the study area would have a similar risk of being affected by earthquakes. Coffey considers that faults within the study area have a very low risk of reactivation during earthquake activity. Further study could be done to assess faults within the study area, but limited data is available. Fault movement is considered to have a low risk of affecting the study area during the proposed project design life.

5.2 Topographic Constraints

In general, the study area has gentle relief which is not anticipated to present constraints for the project. Major constraints are steep slopes associated with resistant geology: jumpups, plateaux and mesa edges and cuesta escarpments. Incised watercourses and gully networks may also present problems. These are considered to be “No Go” areas, since they are spatially limited and can be avoided without major changes to the project design. The **Surface Water** section of the EIS assesses the constraints posed by incised watercourses and, to an extent, by eroding gullies (Alluvium, 2011). Avoidance of these landforms should reduce sidelong ground issues within the study area.

The topographic data available during the study had a contour interval of 20 m or greater. Smaller landforms could, therefore, be indistinct (e.g. gully systems and smaller jumpups). It is recommended that more detailed surveys of infrastructure routes and facilities footprints be undertaken prior to their detailed design. The topographic constraints map provides general guidance, with the degree of constraint ranked as follows (see Figure 5.1):

- Negligible – Average slopes <2°, Maximum slopes <15°; associated with terrain units Ia-d, IIa-c, IIIa-b.
- Low – Average slopes between 2° and 5°, Maximum slopes <20°; associated with terrain units IIIc-d, IVa-b.
- Moderate – Average slopes between 5° and 10°, Maximum slopes <25°; associated with terrain units IVc-d.
- High – Average slopes over 10°, Maximum slopes >25°; associated with terrain units IVe, Va-b, VIa.
- Very High – Clifflines and escarpments associated with particular landform features in associated with terrain units IVe, Va-b, VIa.

5.3 Erosion and Sedimentation Constraints

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 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).

Erosion and sedimentation constraints are directly related to erodibility and erosion hazard, as discussed in Section 4.2.3 and mapped in Figures 4.3 and 4.4.

5.4 Cracking Clays and Gilgai Constraints

Cracking clays, in particular gilgai clays have particular constraints associated with them including uneven ground, differential soil clay composition, soil chemistry, and ground movements due to cracking, shrink/swell and heave.

Gilgai are prone to ground movement and heave. Unless pipelines and other buried services are buried at depths below the lower limit of ground movement and within a relatively stable subsoil moisture regime, this can lead to exposure of buried infrastructure.

These constraints have been ranked as follows (see Figure 5.2):

- Negligible – associated with terrain units characterised by texture contrast and non-cracking clay soils of any unranked terrain units.
- Low – Terrain units characterised by texture contrast and non-cracking clay soils; and cracking clay soils with no or limited gilgai. Associated with terrain units Ia-d, IIIc-d, and patches of IVb.
- Moderate – Cracking clay soils with crabhole gilgai. Associated with terrain unit IIIa.

- High – Cracking clay soils with melonhole gilgai. Associated with terrain unit IIIb.

5.5 Salinity Constraints

Salinity can have the following effects on the project:

- Saline soils can cause corrosion of footings and other susceptible surface infrastructure.
- 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 of saline soils.

The distribution of saline soils is similar to erodible soils due to the relationship between sodicity and salinity within the study area (see Figure 4.3), and is particularly associated with soils of terrain units Id, IIIa-d and IVc-d.

5.6 Trafficability Constraints

The sodic clay soils that dominate the study area become very soft (CBR between 1 and 3) and are prone to waterlogging during wetter months. During drier months, clay soils shrink and crack. Access tracks may require considerable sub-base thicknesses to avoid excessive deformation of the underlying subgrade. These soils are generally in GQAL, and temporary tracks will require careful location and design to limit subgrade compaction and long-term impacts, such as rutting.

The findings of this study indicate that trafficability will pose a constraint throughout the project development area during the wetter summer months.

The relative trafficability constraint posed by different soils is comparable to the sensitivity of terrain units to soft soils and waterlogging (see Section 5.2.6: Landscape Sensitivity from Soft Soils and Waterlogging and Figure 5.5). One exception is deep sandy soils (terrain unit IIc) and texture contrast soils with loose sandy surface layers (terrain unit IIb) that may cause trafficability problems (Soil Surveys Engineering, Daanden, 2008) when dry or waterlogged.

5.7 Trenchability and Trench Stability Constraints

Much of the study area is blanketed by deep clay soils, which are anticipated to be amenable to conventional trenching and excavation equipment. Areas where soils are shallow and rock is close to the surface are anticipated to be limited to sandstone ridges and uplands. It is anticipated that trenches and infrastructure will be located to avoid jumpups, basaltic and granite uplands, as these have associated topographic constraints.

Near-surface sedimentary rocks within the study area have generally been subject to differential weathering. This has resulted in bands of soil-strength rock interlayered with medium to high, or even very high strength rock. The geological mapping of rock structure and laboratory rock strength testing performed as part of this investigation has indicated that the majority of rock will require hard digging, with occasional easy ripping (see Table 5.1). In areas of more labile sandstones (which contain less quartz), easy digging may be possible.

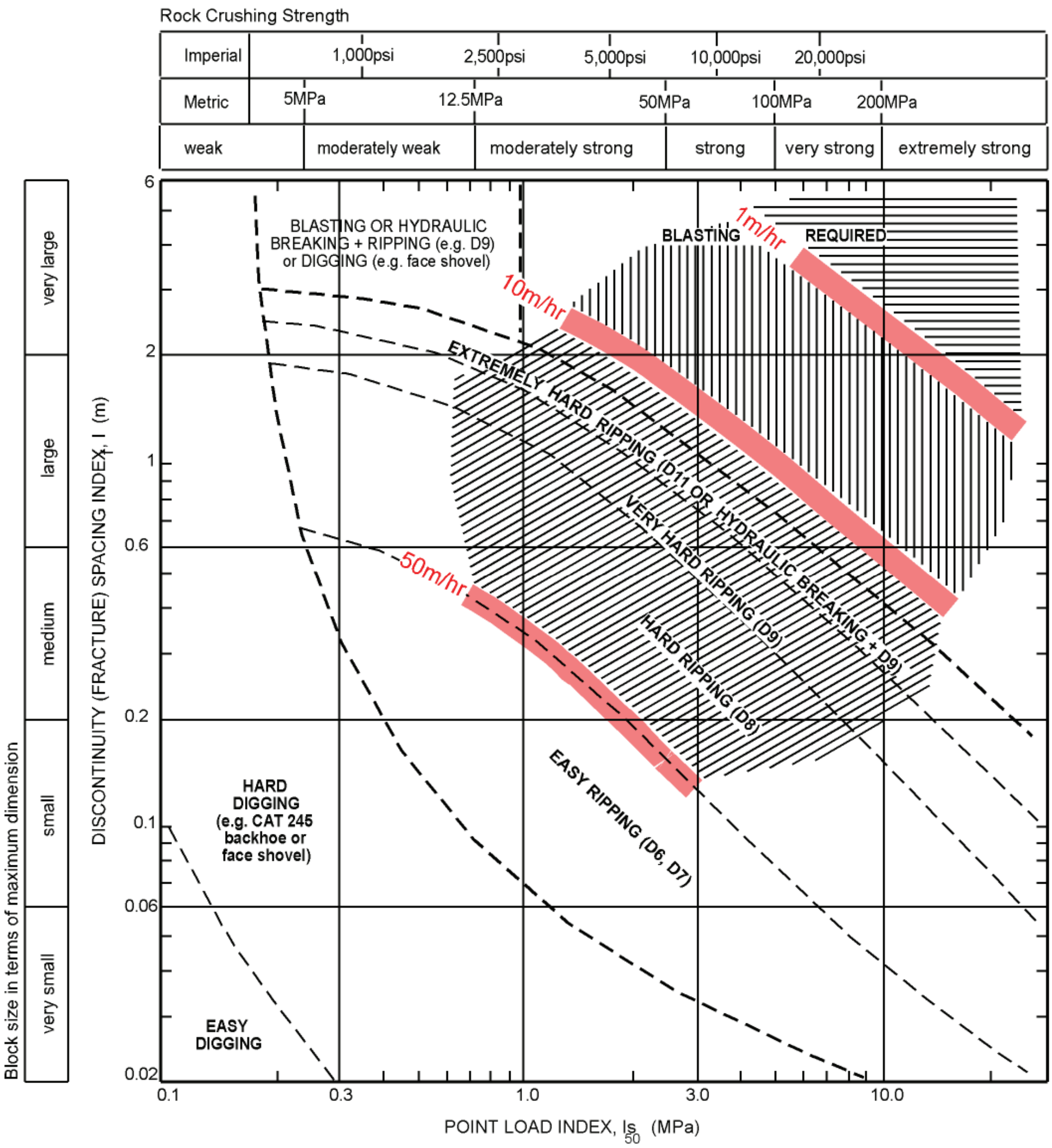
Soils containing appreciable quantities of gravel and cobbles can affect trenching rates.

An indicative trenchability ranking is as follows (see Figure 5.3):

- Negligible – Deep loose to dense soils, particularly geologically recent alluvium and colluviums associated with terrain units Ia-d, IIa-c, IIIa-d, IVa-b.

- Low – Gravelly soils and/or moderately deep soils, particularly residual clays associated with ridgelines within terrain unit IIIc and lower slopes of terrain units IVc-e, Va, Vb and VIa.

Table 5.1 Indicative Trenchability and Trenching Rates (After Pettifer and Fookes, 1994)



- Moderate – Shallow gravelly soils and sedimentary rock outcrops along the Kumbarilla Ridge. This includes rock outcrops within terrain units IVc-e (IVc has fewer outcrops than IVd, which has fewer than IVe).

- High – Basalt and granite outcrops. This includes mid-to upper slopes of terrain units Va-b and VIa.

In general, trench stability will be inversely related to trenchability, whereby rock typically forms stable trenches, whereas loose sands may require battering back or shoring to reduce the risk of trench collapse.

5.8 Construction Materials

Within the study area, borrow pits are common within the sedimentary rocks of the Kumbarilla Ridge. Crushed sandstone is used throughout the region for road pavements. It is anticipated that these materials could be suitable for construction of temporary and permanent access tracks.

Backfill padding for pipeline trenches should not contain material which is likely to damage the pipeline or its coating. Use of cracking and gilgai clays for backfill could also be problematic due to the potential for ground movement and pipeline heave. Similarly, sodic, dispersive soils could lead to tunnelling and gully erosion along the pipeline, particularly in higher-relief areas. As cracking clays are widespread throughout the study area, their suitability for backfill will require design considerations, especially on slopes. Importation of suitable backfill from other parts of the study area or treatment of backfill (e.g. stabilisation) may be required within more problematic soils and/or sloping areas.

The recommended classification of construction materials is as follows (See Figure 5.4):

- Suitable for backfill with design considerations (B1) includes:
  - Sodic soils from nearly all terrain units.
  - Cracking and gilgai clays from terrain units Ia-d, IIIa-d.
  - Dispersive texture contrast soils from Ia-d, IIa-b, IIIa-d, IVa-d.
  - Sandstone, basalt and granite crushed to pass a specified sieve size from rock outcrops in terrain units IVa-e; Va-b and VIa.
- Suitable for backfill (B2) includes non-cracking clays, sands and sandy loams, uniform loams and clays from soils within terrain units Id, IIa-c IIId, IVa-e, Va-b and VIa.
- Suitable for road sub-base (R) includes:
  - Sandstone from outcrops along the Kumbarilla Ridge.
  - Terrain units IVa-e.
  - Possibly basalt from terrain units Va-b and granite from terrain unit VI, although these have associated topographic constraints and are limited in size.

6. 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 7. Inspection and maintenance programmes to check that measures have been successfully implemented are discussed in Section 7.7. The residual potential impact, assuming successful implementation of the recommended management and mitigation measures, is discussed in Section 8.

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 operations and maintenance phase. Full rehabilitation will be carried out following decommissioning.

The impact that a project activity has 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.

6.1 Potentially Impacting Project Activities

The proposed project will include activities which may impact the geology, landform and soils of the project development area, as follows:

6.1.1 Facilities

For the purposes of this study, project activities which involve disturbance of a discrete parcel of land (i.e., rather than linear or fragmented disturbance) have been classified as “facilities”. The project will require construction of several types of facilities including gas processing facilities, power generation facilities, administration facilities (amenities and depots), and water storage and treatment facilities. Some facilities will be permanent for the lifespan of the project, such as Integrated Processing Facilities (IPF), (maximum of approximately 2.2 km^2). Other facilities will be temporary, e.g. construction camps (approximately 300 m x 200 m) and lay-down areas (approximately 200 m x 200 m).

Facilities will have the largest individual footprint of all project activities. Construction will involve large scale earthworks including potential cut and fill, construction of hard stands and importation of large quantities of construction materials. Impacts of facilities are discussed in Section 6.2: Generic Environmental Impacts. Management measures for these impacts are addressed in Section 7.1: Recommendations for All Activities and Section 7.2: Facilities Management Recommendations.

6.1.2 Wells

Well sites are likely to have intensive activity during construction, with a disturbance area of typically 70 m x 70 m (or 85 m x 85 m if a hybrid rig is used). This area may consist of lay-down areas for construction material, drill pads, truck turning areas, drill pits and temporary storage dams. Following construction, these well sites will be partially rehabilitated to reduce final footprint to about 10 m x 10 m. Wells will be constructed in parcels containing up to 100 wells, with a spacing of 700 m - 1,500 m. Approximately 7,500 wells are planned over the life of the Project.

The installation of wells will generally involve vegetation clearing, levelling of ground, excavation and construction of temporary pits to hold drilling spoil and groundwater. Coal seam water will be piped to IPF for longer term storage and treatment.

Well installation will include trafficking of heavy machinery to well sites. It is also likely to include the importation of construction materials (i.e., road base etc.).

Following construction, ongoing access will be required to well sites for maintenance. Therefore, permanent access tracks will be required.

Potential impacts of well sites are discussed in Section 6.2: Generic Environmental Impacts. Management measures for these impacts are addressed in Section 7.1: Recommendations for All Activities and Section 7.3: Well Site Management Recommendations.

6.1.3 Gathering Infrastructure

Arrow are currently conducting an ongoing exploration programme, which involves drilling of five or six test wells, spaced up to 200 m apart in a diamond-shaped layout. These wells are located following consultation with landowners and assessment of seasonal variations.

Networks of pipelines will be required to collect gas and associated water from well sites and provide electrical and telecommunications connections to the wells. The pipeline Right of Way (RoW) will be up to 20 m during construction. There may be sections of the RoW that are wider or narrower, depending on the type of pipeline, and local conditional and constraints.

Gathering infrastructure will also require establishment of temporary lay-down areas and access tracks during construction.

Pipelines will be installed using trenching equipment (backhoe, trench digger, etc.). The minimum depth of burial will be 750 mm, with the final depth of burial agreed with landowners to reduce disruption and infrastructure damage. Pipeline trenches will be backfilled, compacted to a level that is consistent with the surrounding land. The soil surface will be levelled using earthmoving equipment.

Potential impacts of gathering infrastructure are discussed in Section 6.2: Generic Environmental Impacts and Section 6.3: Subsurface Pipeline-Related Impacts. Management measures for these impacts are addressed in Section 7.1: Recommendations for All Activities and Section 7.4: Gathering Infrastructure (Pipeline) Management Recommendations.

6.1.4 Coal Seam Water

Coal seam water will be stored in surface dams and treated by reverse osmosis. Where possible, the water will be used for beneficial end use. Brine produced by reverse osmosis will be stored in surface dams for beneficial use or off-site disposal. Water pipelines will be located within the same easement as gas pipelines. The treated “beneficial use” water will be used within a 10 km radius of water treatment facilities. As per the DERM Healthy HeadWaters Guideline, prior to use on GQAL, Special Beneficial Use approval from DERM is required, which may involve the supplier (i.e., Arrow) having to register as a Water Service Provider (DERM, *in prep.*). Following prolonged rainfall or storm events, untreated coal seam water may be discharged to watercourses. Under such conditions, the additional input of fresh water is expected to be sufficient to dilute salinity to acceptable levels.

Coal seam water treated by reverse osmosis is stripped of its minerals. As the treated water percolates through the soil, it can leach nutrients, thus potentially resulting in a reduction in soil fertility and permanent alteration of the soil characteristics. Potential impacts of coal seam water are discussed within Section 6.2.8: Introduced Salinity. Management measures for these impacts are addressed in Section 7.5: Coal Seam Water Management Recommendations.

6.1.5 Supporting Infrastructure

For the purposes of this study, supporting infrastructure has been defined as the network of tracks and power lines that involve linear disturbance of the landscape surface. Anticipated access track dimensions are not known at the time of writing, but existing tracks will be used where possible. Power line easements will be up to 60 m wide, with a 10 m wide access track running along or adjacent to the easement centreline. Existing roads or tracks will be used, where possible, to access the easement. Vegetation will be cleared and maintained as per applicable electricity line safety clearance requirements.

Potential impacts of supporting infrastructure are discussed within Section 6.2: Generic Environmental Impacts. Management measures for these impacts are addressed in Section 7.1: Recommendations for All Activities and Section 7.6: Supporting Infrastructure Management Recommendations.

Many project activities have similar impacts, since the activities can involve similar tasks. For example, most construction tasks 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 facilities sites that will remain standing for several decades. Some invasive tasks, such as borrow pits and benching, will have a semi-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 task related to an activity is undertaken, e.g., large scale cut and fill associated with construction of facilities. The impact of these tasks is only related to these specific activities.

6.2 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. Management and mitigation measures to reduce land degradation impacts are discussed in Sections 7.1.1: Avoidance of High-Sensitivity Areas; Section 7.1.5: Land Degradation Management and Mitigation Measures; and Sections 7.1.6 – 7.1.11. Ground disturbance can cause the following land degradation:

6.2.1 Erosion

Any project activity which involves ground disturbance and/or vegetation removal has the potential to trigger or exacerbate erosion. 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 6.2.2 – 6.2.4 discuss project tasks which may increase or exacerbate erosion.

6.2.2 Vegetation Removal

Where vegetation coverage is less than about 70%, the risk of erosion is anticipated to increase appreciably. Vegetation removal is likely to have the following effect:

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

6.2.3 Soil Compaction

Project activities which subject the ground to loading can cause soil compaction, e.g. spoil placement and facilities, and vehicular trafficking of access tracks and lay-down areas. Once compacted, it can be difficult to return the material to its original compactive state.

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.

6.2.4 Introduction of Preferential Pathways for Runoff and Alteration of Natural Drainage

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. Similarly, other topographic alterations may cause disruption of natural overland flow paths, potentially leading to flow concentration. This is particularly problematic on slopes which cause acceleration of runoff. This concentration of flow could cause erosion, or flows away from dams and water collection points.

Gilgai act as small flood and runoff detention dams; their removal can increase the quantity and rapidity of overland flow (Maher, 1996).

6.2.5 Increased Sedimentation

Once eroded, sediment is transported downslope/downstream and deposited when flow velocities decrease (APIA, 2009). In these areas, sedimentation may cause burial of crops and vegetation, and reduce GQAL productivity (see also Alluvium, 2011; Gilbert and Sutherland, 2011).

Sections 6.2.1 – 6.2.5 often occur in combination. For example, loose, bare materials are particularly prone to erosion. Often, rills are initiated on bare surfaces, such as new spoil heaps. Consequent concentration of surface runoff, may increase the likelihood of further erosion and gullying. Eroded soil is then deposited down-system (i.e., downslope or downstream).

6.2.6 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 vegetation clearance, topsoil stripping, vehicle trafficking, track grading, pipeline trenching, benching and blasting, particularly if large-scale. 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 loose, fine silty or sandy surface are most prone to dust generation, in particular Soil Type 6: deep sandy soils in terrain unit IIb, and associated with watercourses in terrain units IIa and IIb.

6.2.7 Reduced Soil Quality

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

- Reprofiling of microrelief can cause patchy exposure of sodic and saline sub-soils, leading to increased erodibility and irregular vegetation growth. Inversion of the soil profile and backfill materials during reinstatement may also have a similar effect.
- Some project activities will require construction materials to be imported, e.g. road base. This material is considered poor quality material for agricultural production, and will require particular attention during rehabilitation.
- Some soils within the study area are typically shallow and gravelly, with low fertility (terrain units IVc-e, V and VI). Therefore, limited quantities of topsoil and/or subsoil may be available for rehabilitation. Stockpiling of these limited resources may further reduce their quality.

6.2.8 Introduced Salinity

Arrow will be operating on the fundamental assumption that coal seam water will be treated and used in accordance with relevant regulatory framework. As such, the direct introduction of salinity to the project area will be limited to coal seam water storage; treatment facilities and any beneficial use irrigation areas. Reference should be made to DERM Healthy HeadWaters Coal Seam Gas Water Feasibility Study: Assessment of the Salinity Impacts of Coal Seam Water on Landscapes and Surface Streams (*in prep.* Final Report, December 2010, but not yet policy or released to the general public). The outcomes of this assessment have not been included in this study, as impacts are not anticipated to be significant due to Arrow’s commitment to treat and monitor coal seam water.

Project activities that cause an increase in groundwater levels may cause dryland salinity, associated with soils which have saline subsoils (particularly associated with terrain units Id, IIIa-d and IVc-d). Increased soil salinity could reduce agricultural productivity long-term in GQAL areas.

- 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 of saline soils.
- Saline land can be susceptible to wind and water erosion, if vegetation cover is reduced. Runoff over eroding saline soils is likely to be saline.
- Soils with high salinity as a result of sodium chloride (i.e. soil sodicity) have a tendency to disperse in water due to weak sodium bonds between clay particles. This increases the risk of subsurface erosion.

6.2.9 Topographic Alteration and Landslides

Construction of some facilities may require semi-permanent, localised alteration of topography, should earthworks be required to level the sites. Topographic alteration is more likely to be required where facilities are located on steep slopes. Although landsliding is not considered to be a major issue within the study area removal of material at the base; addition of material at the head of a slope; removal of vegetation; or alteration of drainage may cause slope destabilisation and potential landsliding.

6.2.10 Disturbance or Accidental Damage of Fossils

The Chinchilla Sands Local Fossil Fauna Site is within the study area. The fossiliferous Chinchilla Sands crop out around Chinchilla, extending to the east and southeast (see Figure 3.3). It is possible that fossils could be uncovered outside the registered Fossil Site during excavations which intercept the Chinchilla Sands.

6.2.11 Use of Rock in Construction Activities

The project will require construction materials e.g. crushed rock for road pavements, granular soils for pipe bedding and backfill. 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.

6.3 Subsurface Pipeline-Related Impacts

Project tasks specific to the construction of subsurface pipelines (gas and water) may result in impacts not covered in the above generic impacts. Pipeline-specific management and mitigation measures are discussed in Section 7.4: Gathering Infrastructure (Pipeline) Management Recommendations. Pipeline construction-specific tasks include:

- Route preparation (vegetation clearance, earthworks, etc.).
- Trenching.
- Use of temporary lay-down areas.
- Reinstatement (backfilling, rehabilitation).

The following impacts should be considered in relation to pipelines:

6.3.1 Differential Settlement of Backfill and Padding

It is likely that backfilled and filled areas will not be returned to original density levels. Differential settlement of fill could cause depressions or mounds to form which could potentially lead to drainage concentration and gullying or waterlogging.

6.3.2 Activation of Preferential Pathways

Burial of pipelines in subsoil may create preferential pathways for subsurface flows. Groundwater which accumulates and flows alongside the buried pipeline may result in piping erosion (tunnelling). Collapse of the subsurface void may initiate gullying. Gullying may also be triggered as a result of trenching: the trench forms an artificial gully, with localised steep slopes, which may extend back (sub-perpendicular) from the trench edge. This type of impact is more likely in sodic, dispersive soils. In the study area these soils are associated with terrain units I, IIa-b, III and IV.

6.4 Specific Potential Impacts on GQAL and Strategic Cropping Land

The study area is dominated by GQAL, which covers about 500,000 ha (5000 km^2) and about 60% of the project development area, and Strategic Cropping Land, which covers nearly 50% of the project development area. GQAL-specific management and mitigation measures are discussed in Section 7.1.3: Protection of GQAL and Strategic Cropping Land. This assessment has identified the following potential impacts:

6.4.1 Loss of GQAL and Strategic Cropping Land

The proposed project involves the establishment of a network of wells, linear infrastructure and facilities. It is, therefore, possible that GQAL will be impacted by the installation of wells, infrastructure (pipelines, access roads, lay-down areas, construction camps etc.) and possibly facilities, removing these areas temporarily and, in some instances, permanently from agricultural production. The construction phase disturbance footprint will be greater than the footprint required for infrastructure once operational.

6.4.2 Fragmentation of GQAL and Strategic Cropping Land

Construction of infrastructure, such as pipelines and temporary/permanent access roads may fragment agriculturally productive soils characteristic of GQAL or Strategic Cropping Land.

6.4.3 Negative Changes to Physical and Chemical Properties of GQAL

Compaction of clay soils can significantly impact long-term crop productivity. Topsoil disturbance during construction (i.e. through excavation, erosion or trafficking) may result in a long-term reduction in fertility levels within footprint areas, if effective management and rehabilitation measures are not successfully implemented.

6.4.4 Impeding Surface Flow of Irrigation Water on Levelled Paddocks

Efficient flood irrigation on laser-levelled paddocks relies on the gravitational flow of water. Any hollows, gullies or mounds, caused by project-related infrastructure within these paddocks, have the ability to prevent water reaching the headwall of the paddock. This may lead to wetter and drier sections of the paddock, impacting crop growth and resulting in uneven crops

6.5 Potential Magnitude of Environmental Impacts

The anticipated magnitude of environmental impact of the project on the sensitive/significant areas discussed in Section 5: Environmental Sensitivity and Significance 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 7. Table 6.1 shows the description and classifications of each of the above considerations used to assess the magnitude of impact.

Table 6.1 Impact Magnitude Descriptors and Categories

Description	Anticipated 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)

6.5.1 Magnitude of Impact Associated with Project Activities

At the time of writing, the location of project activities had not been finalised. The magnitude of impact assessment has, therefore, been carried out based on the assumption that activities could be located in any terrain unit within the study area. Many impacts are similar for all activities; the major differentiation being the spatial extent and duration of impact.

The following sections describe the anticipated magnitude of impact of each of the project activities on the environmental values of the study area.

Magnitude of Impact Associated with Facilities

The magnitude of impact of facilities will be dependent on the size and longevity of the project activity. Small, temporary facilities are anticipated to have a lower magnitude of impact than large, permanent facilities. For the purposes of this assessment, the worst case scenario (i.e. large, long-term facilities), without implementation of management and mitigation measures, has been considered.

- Facility areas, particularly integrated processing facilities, will have the largest footprint (with a footprint area up to approximately 2.2 km^2), potentially impacting areas of GQAL/Strategic Cropping Land or heritage-listed sites.
- Impacts could extend outside the footprint of the facilities sites given the predominance of erodible soils within the project area, particularly if associated with natural or artificial steep slopes. Leakage of saline coal seam water from treatment dams may impact soil characteristics in areas outside the integrated processing facility;
- Facilities may require excavation to level the ground, resulting in potential fossil disturbance (terrain unit IIb) and semi-permanent topographic change, particularly if located on steep slopes.
- Some facilities will be in operation for the lifetime of the project (e.g. IPF and amenities), whereas others may be only temporary (e.g. construction camps and laydown areas). Recovery will be dependent on the degree of topographic alteration; length of disturbance time; degree of vegetation clearance; availability of topsoil (which may need importing) and

pre-disturbance characteristics of the landscape. Given the scale of activity, recovery is anticipated to take up to 25 years, if effective management and rehabilitation measures are not successfully implemented.

It is anticipated that, without successful implementation of effective management and rehabilitation measures, the large, long-term facilities will have a **high** impact magnitude on the environmental values of the study area. These activities will have a large spatial extent, potentially affecting areas of GQAL/Strategic Cropping Land or heritage-listed sites; may require semi-permanent topographic change and large-scale vegetation clearance of erodible soils, erosion is possible, particularly on steep slopes if effective controls are not implemented. Site levelling may deplete valuable topsoil leading to reduced productivity if topsoil stockpiles are not effectively managed and soil horizons reinstated during rehabilitation.

Magnitude of Impact Associated with Exploration and Production Wells

- Wells will have a moderate disturbance area of up to 85m x 85m which will be partially rehabilitated following construction to a footprint of 10 m x 10 m. The large number of wells proposed (approximately 140 exploration holes and 7,500 production wells) and during the life of the project and their construction spacing (in parcels of about 100 wells) means that their cumulative impact requires consideration, as the cumulative spatial disturbance will be around 65 ha. The structures could cause fragmentation of heritage-listed sites or GQAL/Strategic Cropping Land and adverse impacts to agriculturally productive soils. Drilling into the Chinchilla Sands geological formation (see Figure 3.3; associated with terrain unit IIb) may locally disturb the unique, fossiliferous geological structure, particularly within the heritage-listed Chinchilla Sands Local Fossil Fauna Site.

- Well construction will require intense activity and impacts are likely to extend outside the footprint of the sites given the trafficking of heavy machinery and excavation of pits; and predominance of erodible soils within the project area, particularly when associated with steep slopes.

- Wells may require excavation to level the ground, resulting in potential fossil disturbance, particularly within the Chinchilla Sands geological formation; and semi-permanent topographic change, particularly if located on steep slopes.

- Exploration wells may be temporary activities, whereas production wells will be in operation for the lifetime of the project. Recovery will be dependent on the degree of topographic alteration; degree of vegetation clearance; availability of topsoil (which may need importing) and pre-disturbance characteristics of the landscape. Given the scale of activity, recovery is anticipated to take up to 10 years, if effective management and rehabilitation measures are not successfully implemented.

It is anticipated that, without successful implementation of effective management and rehabilitation measures, wells will have a **moderate** impact magnitude on the environmental values of the study area, other than at the Chinchilla Sands Local Fossil Fauna Site, where the magnitude of impact will be **high**, due to subsurface disruption. The spatial extent of individual wells is not great, but the number and concentration of wells means that the cumulative extent will be large, potentially causing fragmentation of GQAL/Strategic Cropping Land or heritage-listed sites. Well construction may require small-scale semi-permanent topographic change and vegetation clearance (again, spatially extensive when assessed cumulatively over the study area), which will be likely to result in erosion, particularly on steep slopes. Recovery is anticipated to be medium-term without successful implementation of effective management and rehabilitation measures.

Magnitude of Impact Associated with Subsurface Gathering Infrastructure

- Pipelines will have a moderate disturbance area of up to 20 m wide. Although the width of the pipeline right of way is not great, the linear extent, depth of excavation and large number of proposed pipelines will create a cumulative impact. The linear ground disturbance could cause fragmentation of heritage-listed sites or GQAL/Strategic Cropping Land and adverse impacts to agricultural productivity.
- Impacts are anticipated to extend outside the pipeline easement, given the erodibility of soils and potential for differential settlement of backfill and padding; linear clearance of vegetation; trafficking associated with construction; and leaks or spills if pipelines are breached. Pipeline trenching and preferential erosion along the pipe could trigger gullying.
- Pipeline trenching may result in fossil disturbance (terrain unit IIb).
- Pipelines will be in operation for the lifetime of the project. Recovery is anticipated to be dependent on the pre-disturbance characteristics and local sensitivity of the landscape. Recovery times may, therefore, vary significantly, from short- to long-term (up to 25 years in soils which are highly sensitive to disturbance).

It is anticipated that cumulatively, without successful implementation of effective management and rehabilitation measures, pipelines will have a **high** impact magnitude on the environmental values of the study area. Disturbance of the ground due to trenching will have a limited lateral extent, but a large cumulative spatial impact when considered over the study area, resulting in disturbance, fragmentation and (if breached) contamination of the landscape, potentially including GQAL/Strategic Cropping Land or heritage-listed sites. Erosion is likely given the linear nature of excavations and vegetation clearance of erodible soils. Recovery is anticipated to be long-term in some areas without successful implementation of effective management and rehabilitation measures.

Magnitude of Impact Associated with Coal Seam Water

The magnitude of impact of coal seam water has only been considered in this study when used for dust suppression (discussed further in Section 7.1.5: Dust Control Measures), or when associated with storage and treatment facilities. Arrow intends to treat the coal seam water to reduce impacts: the assessment of magnitude below indicates potential impacts of untreated water, as a worst-case scenario.

- Use of untreated, saline coal seam water has the potential to result in a reduction in vegetation cover and rehabilitation potential, increased erosion (see Section 6.2.8: Introduced Salinity); and adverse impacts to the agriculturally productive soils supporting GQAL/Strategic Cropping Land; and heritage-listed sites.
- Runoff of untreated water from spraying during dust suppression, or leakage of pipelines or brine dams may result in adverse impacts outside the activity footprints. The saline water could enter watercourses and impacts may occur some distance downslope or downstream.
- Coal seam water will be produced for the lifetime of the project. Brine dams may be in use for long periods of time. Assessment of the potential impacts associated with the long-term use of brine dams, prior to consideration of appropriate management measures (e.g., impermeable

dam liners) indicates a long-term recovery (up to 25 years), as the soil chemistry may be significantly altered, with very low rehabilitation potential.

It is anticipated that use of coal seam water, without successful implementation of effective management and rehabilitation measures, will have a **high** impact magnitude on the environmental values of the study area. The highly saline nature of untreated coal seam water is likely to cause long-term damage to productive agricultural soils and reduce rehabilitation potential. Saline water could enter watercourses or be washed downslope, if effective controls are not implemented.

Magnitude of Impact Associated with Supporting Infrastructure

- Supporting infrastructure is anticipated to have a small footprint, but the linear nature of access tracks and large quantity of structures required will have a more extensive cumulative impact. These structures could cause adverse local impacts to GQAL/Strategic Cropping Land soils or heritage-listed sites. Tracks will be trafficked throughout the lifetime of the project.
- Impacts may extend outside the activity footprints, given the propensity for drainage concentration along linear infrastructure (particularly if wheel ruts are formed) and erodibility of soils in the study area, particularly in steep slope areas. Gullying may be triggered.
- Supporting infrastructure will be in use for the lifetime of the project, including the rehabilitation and post-project monitoring phases. Recovery is anticipated to be long-term (up to 25 years), as gully networks may become extensive, soils may be compacted and imported materials may require removal.

It is anticipated that, without successful implementation of management and rehabilitation strategies, supporting infrastructure will have a **high** impact magnitude on the environmental values of the study area. Long-term trafficking of tracks in soils which are susceptible to erosion means that gullying may occur. Compaction and imported materials may hinder rehabilitation.

6.5.2 Summary of Magnitude of Potential Impacts

Table 6.2 summarises the magnitude of the potential impacts of each of the project activities without successful implementation of effective management and rehabilitation measures, as follows:

Table 6.2 Summary of Magnitude of Potential Impacts

Project Activity	**Facilities**	**Wells**		**Gathering Infrastructure**	**Coal Seam Water**	**Supporting Infrastructure**
Magnitude of Impact[1]		**General**	**Chinchilla Sands Site**			
Geographical Extent	H	H	H	H	H	H
Severity	H	M	H	H	H	H
Duration	H	M	H	H	H	H
Overall	**H_m**	**M_m**	**H_m**	**H_m**	**H_m**	**H_m**

[1]Classification of the magnitude of impact is given in Table 6.1: Impact Magnitude Descriptors and Categories. The geographical extent is related to the footprint of the project activity and whether impacts are anticipated outside this footprint.

Table 6.2 represents a worst-case scenario, in the absence of any form of management strategies. The magnitude of potential impacts following the implementation of effective management strategies is discussed in Section 7: Management and Mitigation Recommendations.

6.6 Significance of Potential Impacts on Environmental Values Prior to Implementation of Management or Mitigation

The significance of potential impacts of the Surat Gas 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 6.2. The product of sensitivity and magnitude gives the significance of the potential impact, as per the matrix shown in Table 6.3.

Table 6.3 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)	Major (VH)

Table 6.4 Significance of Potential Impacts on Environmental Values Prior to Implementation of Management or Mitigation

Terrain Unit	Facilities	Wells	Gathering Infrastructure	Coal Seam Water	Supporting infrastructure
I – Clay Alluvial Plains	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H
IIa-IIc – Sandy Alluvial Plains	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H
IIb – Chinchilla Sands Local Fossil Fauna Site	H_sxH_m=VH	H_sx H_m=VH	H_sxH_m=VH	H_sxH_m=VH	H_sxH_m=VH
III – Brigalow Plains and Uplands	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H
IV – Sandstone Ridge	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H
V – Basaltic Uplands	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H
VI – Granite Uplands	M_sxH_m=H	M_sx M_m=M	M_sxH_m=H	M_sxH_m=H	M_sxH_m=H

The assessment of significance of potential impacts on the environmental values of the study area has indicated that, without successful implementation of effective management and rehabilitation measures, the impacts of the majority of the project activities on the majority of terrain units will be highly significant. Within terrain unit IIb, impacts on the heritage-listed Chinchilla Sands Local Fossil Fauna Site will be of major (VH) significance. Outside this heritage-listed area, potential impacts of wells are anticipated to be moderately significant. The following sections recommend appropriate management and rehabilitation measures to address these potential impacts (Section 7: Management and Mitigation Recommendations); and the residual risk following successful implementation of these measures (Section 8: Residual Impacts).

7. MANAGEMENT AND MITIGATION RECOMMENDATIONS

This section provides management recommendations for mitigation of environmental and project impacts. These recommendations fall into several categories as listed below.

- **Avoid**: design and plan the project so that the activity has no impact.
- **Eliminate**: remove the activity completely.
- **Accommodate**: consider designs which reduce the impact of the activity to an acceptable level.
- **Reduce**: implement measures to reduce the impact of the activity to an acceptable level.

7.1 Recommendations for All Activities: Standard Operating Procedures

The following measures apply to all coal seam gas infrastructure including wells, pipelines, infrastructure and facilities. These issues should be considered in all phases of the project, from construction, post-construction rehabilitation, operation and maintenance through to decommissioning. Project activity-specific mitigation measures are discussed in Section 7.2 onwards.

7.1.1 Avoidance of High-Sensitivity Areas

Where practicable, the project should be designed and planned to avoid areas with high sensitivity levels. This includes:

- Heritage-listed sites. These sites have limited special extent within the study area and can therefore, potentially be avoided.
- GQAL and Strategic Cropping Land. These land types are broad in their extent, and avoidance may not always be possible. Specific mitigation measures are noted in Sections 7.1.3 and 7.4.1. Specific mitigation measures associated with agricultural practices are contained in the Gilbert and Sutherland (2011) Agriculture report.
- Steep slopes. Steep slopes (>20°) and areas dissected by gully networks are anticipated to present particular issues associated with management, and surface water runoff and resultant soil erosion. These landforms have a limited spatial extent within the study area and can, therefore, potentially be avoided during the project.

7.1.2 Fossil Disturbance Management Strategies

As indicated above, the Chinchilla Sands Local Fossil Fauna Site should be avoided. However, it is possible that fossils may be uncovered during excavation or drilling works in the Chinchilla Sands (i.e., the geological formation). Identification of fossils may be challenging in the field. However, construction teams should be made aware of the potential existence of fossils in the Chinchilla Sands area. Should the discovery of fossilised materials be suspected, the following management strategies should be implemented:

- Excavation in the immediate vicinity should be stopped.
- A suitability qualified individual (i.e. palaeontologist) should be engaged to assess the find.

7.1.3 Protection of GQAL and Strategic Cropping Land

GQAL (Agricultural Class A and B, defined in Table 1.1: GQAL Descriptions) should be managed by following the management recommendations below:

- Project infrastructure and facilities should not be located centrally within cultivated paddocks or on GQAL. Where this is not practicable, this infrastructure should be located in non-cultivated areas or on the edges of cultivated areas, e.g. corners of paddocks, adjacent to paddock fence lines, sheds or other non-farmed land.
- Excessive watering should be avoided to reduce leaching, rising groundwater and saline soils. Vertosols, in particular, have good water-holding properties. Hard-setting and surface-crusting soils should not be spray-irrigated to avoid exacerbating crust formation (Harris *et al.*, 1999).
- Untreated coal seam water should not be used on GQAL or Strategic Cropping Land. Treated water should only be used if the water quality is comparable to that of typical irrigation water used in the locality.
- Existing access tracks should be used where possible. Where this is not possible, efforts should be made to reduce the impact of infrastructure and trafficking on paddocks and farming patterns e.g. running roads parallel to farming patterns.
- Any new or existing access tracks should be well-defined and construction traffic should remain within these boundaries.
- Temporary access tracks should be removed when no longer necessary, unless otherwise agreed with the landholder.
- Ground levels should be returned to pre-construction levels during rehabilitation, to avoid negative impacts on irrigation or concentration of drainage.
- Specialised backfilling techniques that incorporate specific compaction requirements over the full backfill profile maybe required.
- Rehabilitation should be sympathetic with the surrounding pre-disturbed land-use.
- Provision for ongoing maintenance programmes may be required to treat areas of differential settlement associated with buried infrastructure that interrupt the pre-existing surface water flow within intensively cultivated areas.

Specific mitigation measures associated with agricultural practices are contained in the Gilbert and Sutherland (2011) Agriculture report.

7.1.4 Landowner Consultation

Where practicable, project activities should be undertaken following discussion with landowners. Generally these landowners have extensive land management experience and may have invested considerable time and expense in implementing agricultural and management measures. Their knowledge of successful land degradation and soil damage control measures could prove invaluable in limiting impacts to the landscape. Landowner advice regarding crop scheduling and seasonal variability should be sought.

Project tasks where landowner consultation is recommended are as follows:

- Depth of excavations (to allow for any specific anticipated land-use practices, such as deep ripping);

- Backfilling of excavation in laser levelled paddocks;
- Restoration to pre-disturbance land-uses;
- Design of revegetation planting, seeding and fertilising plans

Specific mitigation measures associated with agricultural practices are discussed in Gilbert and Sutherland (2011).

7.1.5 Land Degradation Management and Mitigation Measures

Erosion is a widespread potential impact across a majority of the study area. 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 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 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 3.2.1: Landform Features). Management of aggressively eroding gully networks can require major engineering structures, which often only provide temporary solutions.
- Erodible soils and sensitive reaches of watercourses should be avoided where practicable. A buffer zone should be left around these sensitive areas. Buffer zones should be site-specific, dependent on ground and landform conditions, and scale, duration and timing of disturbance.
- Roads, tracks, fencing and buildings should be placed to avoid disrupting surface runoff, which tends to accumulate along topographic lows and within surface depressions (Harris *et al.*, 1999; IECA, 2008).
- Design or removal of flood banks and artificial levees should be undertaken with caution, as flood paths and flow regimes can be negatively impacted (Harris *et al.*, 1999).
- Disturbance of contour banks and strip cropping should be avoided.
- Grasses and other ground-cover vegetation should be re-established on bare areas as soon as possible following construction, especially during wetter summer months (3D Environmental, 2011; Gilbert and Sutherland, 2011). This can reduce overland flow velocities, act as silt traps and stabilise the soil surface (Harris *et al.*, 1999; 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 7.1.8: 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

- Sodic and dispersive soils should be avoided where possible, especially if reworking is necessary (e.g. for earthworks and backfill).
- Application of soil ameliorants such as gypsum should be considered for sodic soils as these can reduce dispersivity, waterlogging and crusting (Harris *et al.*, 1999; IECA, 2008).

Dust Control Measures

- Project 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 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).
- To improve the integrity of permanent access tracks, dust stabiliser additives may be required to improve structural stability.

7.1.6 Timing of Disturbance

Rainfall and, therefore, soil erosion in the Surat Basin is highly seasonal, with over 60% of erosion at Dalby occurring between November and February (Queensland Department of Main Roads, 2002). In addition, many of the soils within the study area are subject to moisture softening. Construction works and access to sites should be timed to avoid wetter periods, where practicable, to reduce the likelihood of erosion and project delays due to difficult access.

7.1.7 Soil Salinity Management Measures

Potential management strategies are as follows:

- Prior to major earthworks, ground investigations should be carried out in soils prone to salinity, to establish the depth at which saline conditions occur.

- In areas prone to salinity, removal of vegetation should be limited, to avoid the potential for groundwater levels to rise.
- If an area must be cleared, revegetation should be carried out as soon as is practicable.
- 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.

7.1.8 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 best-practice.
- 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.

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

- Exclude vehicular traffic from areas where soils are to be stripped, where practicable.
- Traffic should also be excluded 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.
- Stockpiling of 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:

- Project component-specific stockpile locations should be designated 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 throughout the project according to soil type and salinity levels (APIA, 2009).
- Topsoil stockpiles should be generally no more than 2 m 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 1 m, if practicable (Strohmayer, 1999). Stockpiles that are anticipated to be *in situ* for several years require intensive management to avoid loss of fertility.
- Where long-term soil storage stockpiles are required, stockpiles should be fertilised and seeded to maintain soil structure, organic matter and microbial activity.
- Stockpiles should be constructed with a “rough” surface to reduce erosion hazard, improve drainage and promote revegetation.
- Sediment 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. Stockpiles containing contaminated or saline soils may require covering with a separation layer (e.g. plastic sheeting).
- Stockpiles should be deep-ripped to create aerobic conditions prior to reapplication of the stockpiled soil for rehabilitation.
- Where necessary, an appropriate soil ameliorant should be applied to dispersive (sodic) soil stockpiles.

Indicative Topsoil Stripping Depths

Viable topsoil is one of the most important factors in successful rehabilitation. Ideally, soils from stripped areas should be preserved for use in rehabilitation. The suitability of topsoil for rehabilitation purposes varies with physical and chemical properties. The use of unsuitable topsoil can reduce rehabilitation success and increase environmental degradation.

The suitability of materials for use in rehabilitation during the project has been assessed from soil characterisation and indicative testing. Additional data has also been obtained from the LRAs.

Topsoil resources are mainly confined to the near-surface A horizon materials and the upper part of the subsurface horizon. Subsoil is generally not suitable for use as topsoil. However in areas where stripping occurs, subsoil should be retained for use in reprofiling the soil. Topsoil and subsoil should be stored separately, as discussed above.

The Queensland Main Roads Department Specification for Landscape and Revegetation (2006) has been used to rate soil suitability for rehabilitation, which indicates the following:

- Any soil material from sand to light clay is suitable, although amelioration may be required.
- Soils of medium to heavy clay texture are generally not suitable as they are too coarsely structured to maintain soil/seed contact, are very hard when dry and have low permeability. This can restrict vegetation re-establishment.

Indicative depths of topsoil suitable for rehabilitation within the soils identified in the study area are outlined in Table 7.1:

Table 7.1 Indicative soil resources

Soil Group	Indicative Stripping Depth (m)	Notes
1. Gilgai Clays	0	Unsuitable due to heavy clay texture.
2.1 Cracking Clays - Black Cracking Clays	0	
2.2 Cracking Clays - Uniform Cracking Clays	0.1	Likely to have light clay textured topsoil. Suitable for use in rehabilitation, but can be difficult to remove.
3. Uniform Non-Cracking Clays	0.1	
4.1 Dispersive Texture Contrast Soils	0.1-0.3	Suitable to use in rehabilitation. However stripping these soils would expose highly dispersive subsoil. Subsoil stabilisation may be required. Avoid collecting and mixing subsoil with topsoil.
4.2 Non-Dispersive Texture Contrast Soils	0.1-0.3	Suitable for use in rehabilitation. Topsoil depth is variable across the profiles within this group.
5.1 Uniform Loams and Clays - Loams and Clay Loams	0.2-0.3	Suitable for use in rehabilitation. Amelioration may be required to improve chemical properties and nutrient levels.
5.2 Uniform Loams and Clays - Clay Loams and Clays	0.2-0.3	
6.1 Sands and Sandy Loams - Alluvial Sands	>0.3	
6.2 Sands and Sandy Loams - Residual Sands	>0.3	
7. Skeletal, Rocky or Gravelly Soils	0	Skeletal soils have limited available topsoil

The scale of the investigation does not allow specific mapping of these resources. Soils and, therefore, topsoil depths, vary across the terrain units. A site-specific investigation of soil resources will be required in these areas prior to earthworks to assess stripping depths.

7.1.9 Backfilling Management Measures

Excavation backfilling should be managed as follows:

- In all locations, any excavated soil should be replaced in the order in which it was excavated. Soil profiles should be recreated and subsoil should not be present at the surface.
- The land surface should be replaced to pre construction levels. Mounding soils to allow for settling may be required in some areas. However in laser-levelled paddocks, this may not be possible, and backfilling should be carried out in consultation with the landowner. Specialised backfilling techniques that incorporate specific compaction requirements over the full backfill profile maybe required in GQAL.

Soils should be compacted to pre-construction levels, where possible.

Backfilled and filled areas should be inspected regularly for subsidence and re-filled if necessary.

7.1.10 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 topsoil is not locally available, soil with appropriate properties should be imported and placed over the ground surface to at least 0.25m depth to aid re-establishment of vegetation.
- Ground levels should be restored to their pre-existing elevation, where practicable.
- Drainage lines should be re-established.
- Medium to long-term erosion control measures should be implemented (see Section 7.1.5: Land Degradation).
- Areas should be restored to their previous land use, with landowner consultation.
- A planting and seeding plan should be established for re-establishment of vegetation, with landowner consultation.

7.1.11 Construction Materials – Borrow Pits

Borrow pits may be used as a source of construction materials during the project. These should be managed as follows:

- Borrow pits should be located away from problem soil areas (e.g. saline soils) and groundwater recharge areas (see Coffey Environments, 2011).
- If significant quantities of material are required, excavation slopes should be benched to direct surface water runoff to managed control points.
- Erosion control measures should be implemented.
- Pits which expose sodic or saline subsoils should be bunded.
- Rehabilitation of pits should be carried out as soon as is practicable. This should include:
  - Ground surface re-profiling avoiding the creation of steep, unstable slopes;
  - Topsoil respreading;
  - Revegetation, and
  - Erosion control measures, including erosion bunds and contour ripping.

7.2 Facilities Management Recommendations

The project will require construction of several types of facilities. Some facilities will be permanent for the lifespan of the project, such as IPFs (maximum of approximately 2.2 km^2). Other facilities will be temporary, e.g. construction camps and laydown areas.

7.2.1 General Facilities Management Measures

Facility locations require specific management measures, as these may involve long-term disturbance over large areas. The following management issues should be considered.

- 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 (see Section 7.1.8: Soil Management; Topsoil and Spoil Storage).
- In cracking clays, a relatively constant moisture content should be maintained to avoid excessive ground movements. Slab or piled foundations are recommended in these areas. If

necessary use gravel as a buffer to reduce the magnitude of differential shrink swell ground movement;

- Water and sediment control measures should be implemented, particularly during construction. In addition, long-term management measures should also be considered to control runoff and sediment load throughout the lifetime of the facilities, as follows (see Alluvium, 2011)
  – Sediment control dams at major development sites, to reduce the quantity of sediment entering watercourses;
  – Installation of energy dissipation structures at drainage outlets, especially those entering natural watercourses.

7.2.2 Rehabilitation of Facilities Areas

Facility areas are likely to require intensive management during decommissioning to achieve successful rehabilitation. Measures can be implemented which will increase the likelihood of successful rehabilitation, including the following:

- 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 and measures taken to promote vegetation establishment.
- 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.

7.3 Well Site Management Recommendations

Well sites are likely to have intensive activity during construction, with a disturbance area of up to $85m^2$. This area may consist of lay-down areas for construction material, drill pads, truck turning areas, drill pits and temporary storage dams. Following construction, these well sites can be partially rehabilitated to reduce final foot print to about 10 m x 10 m.

7.3.1 Handling of Drilling By-Products – Storage and Management of Groundwater

Drilling muds are typically saline due to a combination of contact with saline aquifers (i.e. including coal seam water) and soils, and saline drilling additives.

During drilling and dewatering, groundwater which is forced to the surface can be stored in temporary dams. Drilling muds can be stored either in onsite storage bins or excavated drill pits. Storage bins should be removed from the site on completion of drilling. Coal seam water will be piped to IPF for treatment (discussed further in Section 7.5: Coal Seam Water Management Recommendations).

7.3.2 Partial Rehabilitation of Well Sites

Following construction, specific rehabilitation of well sites should include:

- Removal of all waste and imported materials.

- Removal of hardstand and construction materials.
- Ripping of drill pad areas to reduce soil compacted during construction.
- Reinstatement of topsoil coverage over areas where access is not required during operation and maintenance phases of the project.
- Resurfacing, reseeding and fertilising in consultation with landowners, to return the area to pre-disturbance conditions, as far as is practicable.

7.3.3 Rehabilitation of Well Sites following Decommissioning

Site-specific rehabilitation plans should be implemented following decommissioning of well sites (see Section 7.1.10: Rehabilitation).

7.4 Gathering Infrastructure (Pipeline) Management Recommendations

Typically, the pipeline right of way (RoW) will be 20 m wide during construction. However, RoW dimensions are likely to depend on the type of pipeline and local conditions.

7.4.1 Gathering Infrastructure GQAL Management Measures

GQAL along the RoW should be managed by following the management recommendations below:

- Where practicable, pipelines should be located to avoid impact on irrigation flow and/or current farming practices (i.e. along field boundaries or existing tracks).
- If it is necessary for the RoW to cross actively-farmed arable land, soil cover above the pipeline should be deep enough to allow for normal cultivation practices. Deep ripping can disturb the ground to a depth of approximately 1m. In areas where deep ripping is conducted, minimum cover depths should be extended to prevent pipeline damage and subsequent leaks and spills into the environment. As discussed in Section 7.1.4, consultation with landowners regarding the depth of excavations is recommended. Avoid mounding of soil along pipelines in irrigated paddocks.

7.4.2 Gilgai Management Measures

In areas with gilgai microrelief or self-mulching cracking clays, pipelines should be buried below the lower limit of ground movement and within a relatively stable subsoil moisture regime to prevent damage and subsequent leakage into the surrounding environment. Weighting of the pipeline may also be required. These measures will limit the possibility of heave to the surface, potential rupture and uncontrolled releases to the surface.

7.4.3 Pipeline-Specific Erosion-Control Measures

Erosion potential can be reduced by adopting the management practices below:

- Vegetation should be cleared in sections to reduce the spatial extent of bare ground.
- Grading, trenching and backfilling should be carried out as rapidly as is practicable, to reduce erosion.
- During construction, vehicle access to the pipeline easements should be provided at regular intervals to reduce the possibility of compaction and formation of wheel ruts along the easement.

- Windrow any cleared vegetation along the edge of working areas to control runoff.
- Trench-breakers/plugs will reduce erosion and allow fauna and personnel escape.

7.4.4 Trench Stability Management

In areas of soft or loose soils, the trench walls may require battering back or shoring to limit the risk of trench collapse; both a safety and erosion issue.

7.4.5 Backfill and Padding Management Measures

Infilling of the pipeline trench should be managed as follows:

- Fauna should be removed before backfilling.
- Appropriately-sized trench bedding and padding material should be used to avoid damage to the pipe coating. This may require sourcing of appropriate material from borrow pits within the study area or further afield.
- 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, to reduce trench subsidence and concentration of flow.
- Subsoil should not be exposed at the ground surface following backfilling. Any subsoil left exposed should be capped with topsoil.

7.4.6 Rehabilitation of Pipeline RoW

The pipeline RoW should be rehabilitated as follows:

- Where practicable, mulched surface vegetation should be spread over the pipeline RoW following backfilling to reduce rainsplash erosion.
- Vegetation coverage should be maintained over the pipeline easement. Bare surfaces should be seeded with e.g., native grasses as per recommendations discussed in Section 7.1.10: Rehabilitation.

7.5 Coal Seam Water Management Recommendations

Management measures for dust control that are relevant for saline coal seam water are discussed in Section 7.1.5: Dust Control Measures. Measures for coal seam water storage and treatment ponds are discussed in Section 7.3: Well Site Management Recommendations.

Where coal seam water is to be used on GQAL/Strategic Cropping Land or within heritage-listed or indicative sites, the water quality should meet beneficial use license conditions. These conditions require the following:

- Balancing of nutrients and minerals in sterile reverse osmosis-treated water.
- Vegetation and soil structure should not be damaged.
- Water should not be allowed to pond on the ground surface.

- Deep drainage beneath the vegetation root zone should be appropriately managed to meet leaching requirements and avoid groundwater rise.
- Water quality should not adversely impact shallow aquifers.

7.5.1 Coal Seam Water Storage Recommendations

Specific management recommendations for onsite storage of saline coal seam water are as follows:

- Storage dams and excavated pits should be adequately sealed to prevent the leakage of saline water and drilling wastes into the subsurface. Use of artificial liners or imported clay will be required to provide an adequate seal. Concrete is susceptible to cracking and should only be used in conjunction with a suitable geotextile membrane such as HDPE liner.
- Storage dams and excavated pits should be located outside cultivated GQAL, have a suitable clay base and require only minor geotechnical cut and fill works.
- Dispersive clays should not be exposed by the cut and fill operations. Where this is unavoidable, appropriate measures should be implemented, such as capping with topsoil.

7.5.2 Salinity Control Measures

It is considered that well sites exhibit the greatest likelihood of inducing saline soil conditions within the project development area, as saline associated water and drilling wastes (muds and cuttings) will be pumped from depth during well construction and completion. Suitable associated water and waste storage techniques should be implemented to prevent the build-up of salts. The following should be considered in conjunction with DERM (*in prep.*) recommendations:

- Gathering lines used to transfer associated water from the wellhead to the temporary dam should be water-tight to prevent spillage onto the soil surface.
- Drilling waste and associated water should be immediately placed in designated locations and managed to reduce salt contamination of non-saline soil.

7.5.3 Rehabilitation of Coal Seam Water Storage Sites

Rehabilitation of coal seam water storage and treatment dams should include excavation and removal of saline material. Ideally saline material should be stored in landfill-style cells lined with low-permeability clay or other suitable liner. Alternatively, the saline material should be disposed of at registered landfill facilities. This is particularly important in GQAL areas, as any saline soil spread over the surface can lead to adverse changes in soil chemistry.

7.6 Supporting Infrastructure Management Recommendations

Management measures for the construction, operation and rehabilitation of permanent and temporary infrastructure, such as access tracks, have been outlined in Section 7.1: Generic Recommendations. The only element-specific measures are as follows:

- Tracks should be graded regularly to maintain their integrity;
- Construction and rehabilitation should be carried out following discussion with stakeholders (particularly landowners). It may be possible to upgrade existing tracks or locate tracks in areas which will be of long-term benefit, reducing impact and decommissioning requirements.

7.7 Inspection, Monitoring and Maintenance Programme

Erosion is a natural process which is likely to occur throughout the life of the project. A baseline erosion monitoring program should be undertaken in the study area to establish pre-disturbance erosion rates. It is recommended that permanent 10 m x 20 m monitoring plots are established over a range of project activity areas (e.g. pipeline right of way, well sites, facilities areas in different terrain units) and adjacent areas which are not likely to be impacted.

Disturbed and rehabilitated areas should be monitored regularly for both short- and long-term adverse landform change, particularly in areas of intensive agriculture or areas which are particularly sensitive to erosion. Defects should be reported and 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 schedule should, therefore, reflect the likely rate of change and vary accordingly. Site-specific assessments prior to commencement of tasks should indicate the frequency and timing of monitoring.

Monitoring events should include:

- Location and type of erosion (with photographic records of site visits).
- Settlement of backfill over pipelines and other buried services.
- Soil tests (EC) in sensitive areas to assess operations-related salinity, in particular adjacent to coal seam water treatment facilities in accordance with DERM recommendations (Section 7, DERM, *in prep.*).
- Erosion rates.
- Effectiveness and integrity of erosion control measures.
- Runoff water quality.

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

- Repair of erosion control structures.
- Removal of sediment build-up behind erosion control measures involving damming of water, to maintain retention capacity.
- Reinstatement of eroded soil or landforms.
- Re-levelling within areas of differential settlement over 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 stable, safe, non-polluting landform with self-sustaining soil fertility.

It is recommended that rehabilitation performance criteria should include:

- Creation of stable landforms which reduce erosion as far as is practicable. Erosion control measures must remain effective in the long-term.
- A safe 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 of soil chemistry such that soil nutrient levels can support vegetation and pre-disturbance soil pH and EC levels can be achieved.
- A GQAL target to achieve pre-project agricultural production levels, particularly in areas of intensive agriculture and adjacent sensitive non-disturbed areas. Specific mitigation measures associated with agricultural practices are contained in Gilbert and Sutherland (2011).

A holistic approach is recommended when defining and monitoring performance criteria within the context of this study. This will assist in the creation of a balanced rehabilitated landform and environment. The findings and recommendations of other specialist reports should also be considered.

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.

8. RESIDUAL IMPACTS

This section of the report assesses the significance of the impacts of the Surat Gas Project on the environmental values of the study area, assuming successful implementation of the recommended management and mitigation measures outlined in Section 7: Management and Mitigation Recommendations.

The sensitivity of the environmental values within the study area will remain constant throughout the project, except where project activities require site levelling. 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 change in sensitivity is anticipated to be negligible.

Successful implementation of the management and mitigation measures will reduce the magnitude of potential impacts, as follows:

Magnitude of Residual Impact Associated with Facilities

- GQAL/Strategic Cropping Land or heritage-listed sites will be avoided where practicable. However, given the extent of the former, it is likely that some areas of cropping land will be impacted. However, Arrow has indicated that landowners will be consulted regarding timing and location of project activities to reduce impacts. Therefore, the spatial extent of disturbance is not anticipated to be extensive.
- Impacts will be limited to the footprint of the facilities sites.
- Facilities may require excavation to level the ground, resulting in potential fossil disturbance (terrain unit IIb) and semi-permanent topographic change, particularly if located on steep slopes. However, fossil finds will be reported when found and managed appropriately. Topographic change will aim to produce a stable, safe, non-polluting landform with self-sustaining soil fertility.
- Recovery will be dependent on the degree of topographic alteration; degree of vegetation clearance; availability of topsoil (which may need importing) and pre-disturbance characteristics of the landscape. Even given the scale of activity, with appropriate management, recovery times should be short-term, rather than medium-term.

It is anticipated that the facilities will have a **low** residual impact magnitude on the environmental values of the study area. Although the activities will have a large spatial extent, their location will be such that GQAL/Strategic Cropping Land or indicative heritage sites are avoided or impacts will be slight, and heritage-listed sites avoided altogether. Erosion control measures and an effective rehabilitation plan will reduce land degradation and recovery times to low levels.

Magnitude of Residual Impact Associated with Exploration and Production Wells

- The number of wells proposed (approximately 140 exploration holes and approximately 7,500 production wells) during the life of the project and their construction spacing (in parcels of about 100 wells) means it will be unlikely that adverse impacts to GQAL/Strategic Cropping Land will be avoided. However, Arrow has indicated that landowners will be consulted regarding timing and location of wells to reduce potential impacts.
- Impacts will be limited to the footprint of the well sites.

- Facilities may require excavation to level the ground, resulting in potential fossil disturbance (terrain unit IIb) and semi-permanent topographic change, particularly if located on steep slopes. However, fossil finds will be reported when found and managed appropriately. Topographic change will aim to produce a stable, safe, non-polluting landform with self-sustaining soil fertility.
- Recovery will be dependent on the degree of topographic alteration; degree of vegetation clearance; availability of topsoil (which may need importing) and pre-disturbance characteristics of the landscape. Even given the scale of activity, with appropriate management, recovery times should be short-term, rather than medium-term.

It is anticipated that wells will have a **low** residual impact magnitude on the environmental values of the study area. Although the network of wells will be extensive, sympathetic location selection will reduce the significance of impacts in GQAL/Strategic Cropping Land or indicative heritage sites, with heritage-listed sites avoided altogether. Erosion control measures and an effective rehabilitation plan will reduce land degradation and recovery times to low levels.

Magnitude of Residual Impact Associated with Underground Gathering Infrastructure

- The linear extent and large number of proposed pipelines means it will be unlikely that adverse impacts to GQAL/Strategic Cropping Land or indicative heritage sites will be avoided. However, consultation with landowners will enable sympathetic locations, chosen to reduce impacts. Heritage-listed sites will be avoided
- Impacts will be limited to the pipeline right of way.
- Any fossil finds will be reported when found and managed appropriately.
- Recovery is anticipated to be dependent on the pre-disturbance characteristics of the landscape, and is anticipated to be short-term.

It is anticipated that, cumulatively, pipelines will have a **low** residual impact magnitude on the environmental values of the study area. Sympathetic routing, design, construction techniques, erosion-control measures and rehabilitation plans will reduce the magnitude of impacts to low levels.

Magnitude of Residual Impact Associated with Coal Seam Water

- Coal seam water will be treated to reduce salinity levels to that of water typically used in the locality, particularly on GQAL/Strategic Cropping Land. The water treatment will also involve nutrient and mineral balancing. Heritage-listed sites will be avoided.
- Brine dams will be lined with impermeable material, in accordance with statutory requirements. Therefore, impacts will be limited to the footprint of brine dams.
- Recovery will be short-term, following appropriate disposal of saline soils/water and rehabilitation.

It is anticipated that coal seam water will have a **low** residual impact magnitude on the environmental values of the study area. Appropriate transport, storage, disposal and rehabilitation of coal seam water and salt-affected soils will result in adverse impacts being unlikely to occur.

Magnitude of Residual Impact Associated with Supporting Infrastructure

- GQAL/Strategic Cropping Land or heritage-listed sites will be avoided where practicable. However, given the extent of the former, it is likely that some areas of agricultural land will be impacted, given the cumulative spatial extent of supporting infrastructure. The extent of disturbance is not anticipated to be extensive, as existing tracks will be used where practicable, and the location of new tracks will be based on the advice of landowners.
- Impacts will be limited to the footprint of the supporting infrastructure.
- Recovery is anticipated to be short-term.

It is anticipated that supporting infrastructure will have a **low** residual impact magnitude on the environmental values of the study area. Sympathetic routing, design, construction techniques, erosion-control measures and rehabilitation plans will reduce the magnitude of impacts to low levels.

8.1.1 Significance of Potential Residual Impacts

The sensitivity of the environmental values remains constant, except where earthworks have resulted in topographic change. However, in these areas, rehabilitation will produce a stable, safe, non-polluting landform with self-sustaining soil fertility and, thus, long-term adverse impacts will be mitigated.

Despite the variability of ground conditions and project activities, successful implementation of the recommended management and mitigation measures should reduce the magnitude of impacts to low levels, as summarised in Table 8.1.

Table 8.1 Significance of Potential Residual Impacts on Environmental Values

Terrain Unit	Facilities	Wells	Gathering Infrastructure	Coal Seam Water	Supporting infrastructure
I – Clay Alluvial Plains	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L
IIa-IIc – Sandy Alluvial Plains	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L
IIb – Chinchilla Sands Local Fossil Fauna Site	Site will be avoided				
III – Brigalow Plains and Uplands	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L
IV – Sandstone Ridge	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L
V – Basaltic Uplands	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L
VI – Granite Uplands	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L	$M_s x L_m$=L

The assessment of significance of residual impacts on the environmental values of the study area has indicated that the impacts of the project activities on the study area will be of low significance, once the recommended management and mitigation measures have been successfully implemented.

9. CUMULATIVE RESIDUAL IMPACTS

This section discusses the potential combined effect of future developments (either approved or proposed) that could interact with the Surat Gas Project. This study has only assessed those projects that have synchronous timelines to the Surat Gas Project and that have the potential to impact the environmental values relevant to the geology, landform and soils within Arrow's defined project development area. As such, projects that are outside the project development area have not been considered. This assessment of cumulative impacts assumes that recommended management and mitigation measures are successfully adopted throughout the lifetime of the project.

9.1 Projects Considered for Cumulative Residual Impact Assessment

Table 9.1 indicates the projects that fall within the cumulative impact assessment criteria.

Table 9.1 Projects considered for the Cumulative Impact Assessment

Project and Relevant Study	Activities Anticipated to Interact with Surat Gas Project	Assessed Residual Impact
Arrow Surat Pipeline (formerly Surat-Gladstone Pipeline) Pty Ltd AECOM (2009) Arrow Energy website (2011)	Buried gas pipeline running from 20 km east of Kogan northwest to Miles and then north through the project development area.	Potential impacts include: • Erosion associated with sodic and dispersive soils, particularly associated with steep slopes and high-banked watercourses, necessitating effective erosion control measures • Temporary disruption of land-use and GQAL during construction. Management and mitigation measures are recommended to address these issues. Residual impacts are not specifically addressed. It is inferred that the significance of residual potential impacts will be low.
Australia Pacific LNG Project (APLNG) WorleyParsons (2010)	Buried gas pipelines running east from southwest of Guluguba and north from just east of Miles, joining about 40 km north of Miles before running north through the project development area across the northern extent of the Kumbarilla Ridge.	Potential impacts include • Topographic alteration • Poor rehabilitation potential (low fertility topsoils and saline soils) • Erosion, especially associated with steep slopes, watercourses and dispersive subsoils. Special stormwater control plans are recommended to reduce the likelihood of slope destabilisation and flow concentration. • Dust creation • Disturbance of GQAL Management and mitigation measures are recommended to address these issues, The report takes a constraints and risk-based approach, and residual impacts are not specifically assessed. It is inferred that the residual risk of impact is medium for erosion and GQAL disturbance, but low for other potential residual impacts.

Table 9.1 Projects considered for the Cumulative Impact Assessment (cont'd)

Project and Relevant Study	Activities Anticipated to Interact with Surat Gas Project	Assessed Residual Impact
Queensland Curtis LNG Project (QCLNG) Houghton Environmental (2009)	Buried gas pipeline running from south of Kogan northwest to Miles and then north through the project development area across the northern extent of the Kumbarilla Ridge.	Potential impacts include: • Erosion, especially associated with steep slopes, watercourses and sodic or dispersive subsoils. • Issues with trenching through rock. • Dust creation • Disturbance of GQAL Management and mitigation measures are recommended to address these issues, but the residual impact is not specifically assessed. It is inferred that residual impacts will be of low significance.

9.2 Cumulative Impact Triggers

Project activities or tasks are not specifically listed in the above reports. It has been assumed that the following activities and associated tasks will contribute to the cumulative impact within the project development area:

- Pipeline construction activities:
  - Route preparation (vegetation clearance, earthworks, etc.)
  - Trenching.
  - Use of temporary laydown areas.
  - Reinstatement (backfilling, rehabilitation).
- Construction and maintenance vehicle access tracks:
  - Use of existing tracks where possible.
  - Route preparation (vegetation clearance, earthworks, etc.), generally within the RoW.
  - Maintenance during use.
  - Rehabilitation.

It is also possible that facilities, such as construction camps, may be required within the project development area.

9.3 Significance of Cumulative Residual Impacts

The pipelines of the above projects appear to run along combined or adjacent corridors through the Kumbarilla Ridge, north of Miles. The proposed routes avoid heritage-listed and indicative heritage areas.

The activities and tasks listed are anticipated to trigger cumulative impacts within the project development area, as follows:

9.3.1 Land Degradation: Erosion

The combined projects will require linear ground disturbance through highly erodible soils during pipeline and track construction. A small area of the project development area will be disturbed by other proponents. Soils within the northern extent of the Kumbarilla Ridge are typically sodic, dispersive texture contrast soils, with isolated patches of gilgaied cracking clays. The project-specific studies recommend special erosion control measures, similar to those recommended by this study. Successful implementation of these measures will limit impacts to the footprint of the pipeline corridor(s), reduce the likelihood of extensive land degradation and facilitate short recovery periods. WorleyParsons (2010) indicates that the APLNG pipeline has a medium risk of impacting soil resources. However, the approach used is different to that used in this study and the inferred significance of residual impacts appears low. Therefore, the cumulative residual erosion impact is assessed to be low.

9.3.2 Disruption and Damage to GQAL

The named projects impact the project development area from Millmerran to the north, crossing the northern extent of the Kumbarilla Ridge. Therefore, only minor areas of GQAL (and Strategic Cropping Land) are likely to be disturbed by other proponents within the project development area. Implementation of management and mitigation measures, including discussion with landowners regarding location of activities and successful rehabilitation, will reduce the significance of the cumulative residual impact to low levels.

9.3.3 Topographic Alteration

In areas of high or undulating relief, earthworks may be required to level the ground, resulting in temporary to semi-permanent alteration of landforms. Where possible, reinstatement to pre-disturbance topography should be an aim. It is not anticipated that major topographic alteration will be required for the proposed pipelines through the project development area. The cumulative residual significance of impacts is, therefore, anticipated to be low.

9.3.4 Impacts Associated with Poor Rehabilitation Potential

WorleyParsons (2010) indicates that the rehabilitation potential of soils along the pipeline corridor may be an issue. However, adoption of the recommended management measures (e.g. addition of suitable nutrients), and given the pipeline corridor will result in a relatively small area of disturbance (compared to the size of the Surat Gas project development area), the significance of cumulative residual impact is anticipated to be low.

9.3.5 Dust Creation

Trafficking during the construction (and maintenance) phase of the combined projects is anticipated to create dust, particularly in areas with loamy surface soils. The texture contrast soils of the Kumbarilla Ridge are moderately sensitive to dust creation (i.e. susceptible to wind erosion on disturbance). However, successful implementation of dust control measures will reduce the cumulative residual impact to low levels.

9.3.6 Impacts Associated with Trenching through Rock

Houghton Environmental (2009) has indicated that construction may be prolonged and rehabilitation potential may be adversely impacted where the pipeline requires trenching through rock. It is likely that rock will be encountered through the northern extent of the Kumbarilla Ridge, as rock is close to or at the surface in places. However, implementation of the recommended management strategies, including effective stripping/storage of soils and successful rehabilitation, should reduce the cumulative residual impact to low significance levels.

9.3.7 Altered Landforms

Construction of underground pipelines for projects considered as part of this cumulative impact assessment is anticipated to cause limited landform disturbance along their narrow, linear pipeline corridors. It is, therefore, likely that impacts within the project development area will be limited. Conversely, in a broader context, the Surat Gas Project is anticipated to have a greater impact on the general landforms and landscape than these other pipeline projects. The number and spatial extent of infrastructure components and associated land disturbance activities associated with the Surat Gas Project are anticipated to be greater than those associated with the other pipeline projects considered.

10. CONCLUSION

The environmental values of the study area should be a constant consideration for the lifetime of the project. Artificial alterations may cause an increase in sensitivity, for example when associated with increases in slope steepness; or soil profile inversion, causing exposure of sodic or saline soils.

In contrast, the impact of each project element will differ according to the footprint size, activities involved and the landscape characteristics: Large integrated processing facilities will have a longer-term impact over a larger area than, for example, smaller well sites. Invasive activities, such as ground levelling and pipeline trenching will have a semi-permanent impact on the landscape and landuse. The magnitude of impact can be successfully reduced from moderate to low in most cases by appropriate implementation of management and mitigation measures.

This study has indicated that, despite the variability of landscape sensitivity and impact magnitude, providing the recommended management and mitigation measures are successfully implemented, the significance of residual impact should be reduced to acceptable levels. Successful reduction of potential residual impacts requires avoidance or consideration of the following:

- Heritage-listed Chinchilla Sands Local Fossil Fauna Site and indicative heritage areas (Lake Broadwater Conservation Park, and the Barakula State Forest and Scientific Areas). These areas are relatively limited in extent and should be avoided without major impact to the project;
- Steep slopes associated with specific landforms, including cuesta and mesa escarpments and jumpups. These areas are limited in extent and should be avoided without major impact to the project;
- Erosion in susceptible soils on steeper slopes. Erodible soils are present throughout the study area. However, it is considered that erosion mitigation will be possible on shallower slopes. On steeper slopes, higher velocity surface water flows are likely to require intensive management strategies, including avoidance where possible, to limit soil erosion to acceptable levels.
- Given the large area of high quality agricultural land within the study area and the quantity of project activities, impacts to GQAL and Strategic Cropping Land are unavoidable. However, sympathetic location of activities following landowner consultation and successful rehabilitation will reduce the significance of this impact to low levels.

Potential residual impacts as a result of these projects included in the cumulative impact assessment include land degradation (erosion), disruption of GQAL, topographic alteration, dust creation; and impacts associated with poor rehabilitation potential of soils, trenching through rock and altered landforms. Successful implementation of management and mitigation measures should reduce the significance of these impacts to acceptable (i.e. low) levels with the exception of impacts to landforms. The number and spatial extent of infrastructure components and associated land disturbance activities associated with the Surat Gas Project is anticipated to be greater than those associated with the other pipeline projects considered. The impacts of these pipeline projects on the environmental values of the geology, landform and soils within the project development area will be limited to narrow, linear, disturbance along the pipeline corridors within the project development area.

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11.7 GIS Metadata

Information	Source	Date	Scale
Topographic relief maps	DERM Geosciences Australia	1998 1990	1:100,000
Queensland geological mapping	DME geological exploration and mining data layers for Queensland (DVD)	Feb 2007	1:100,000
Queensland rainfall mapping	Department of Natural Resources and Water	Collected between 1915 – 2001, published 2004	Accuracy – approx. 268m
Aerial photography	Arrow Energy	Supplied 2011	1:1,200,000
Historical aerial photography	Arrow Energy	Supplied 2011	1:1,200,000
Atlas of Australian Soils*	CSIRO	1960-1968	1:2million
Land Resources Mapping	DERM, full references in “Government Reports”:	MCD - 2005-2007 MWD - 1996 WLM - 1990 ZDD - 1968	MCD, MWD and WLM – 1:250,000 ZDD – 1:500,000
GQAL Mapping	DERM	2007	ranges from 1:2500 to 1:250000
Cadastre/LGA Boundaries	DERM	30/10/2009	ranges from 1:2500 to 1:250000
Infrastructure	Arrow Energy	Supplied 2009/2010	unknown

* 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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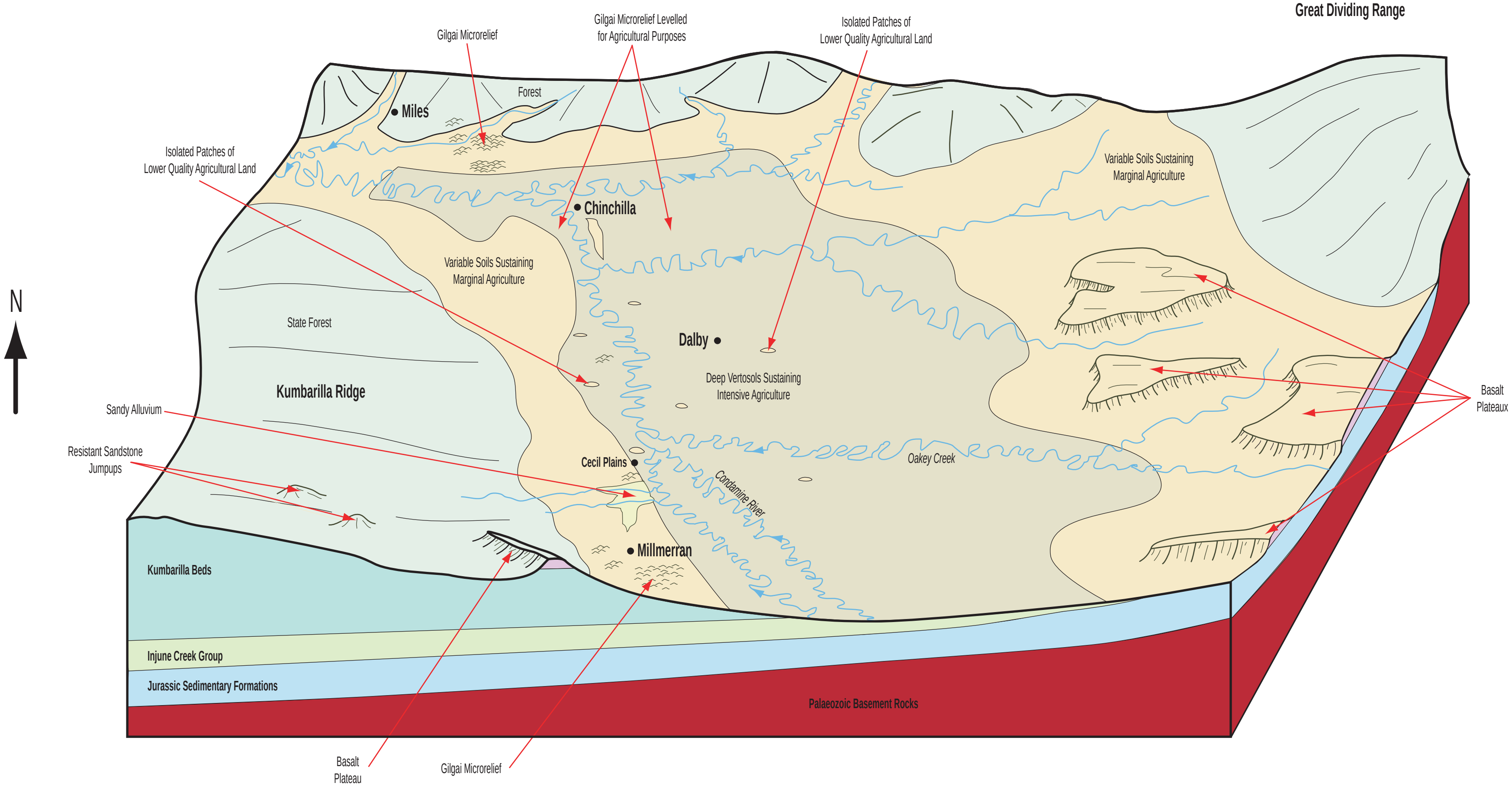
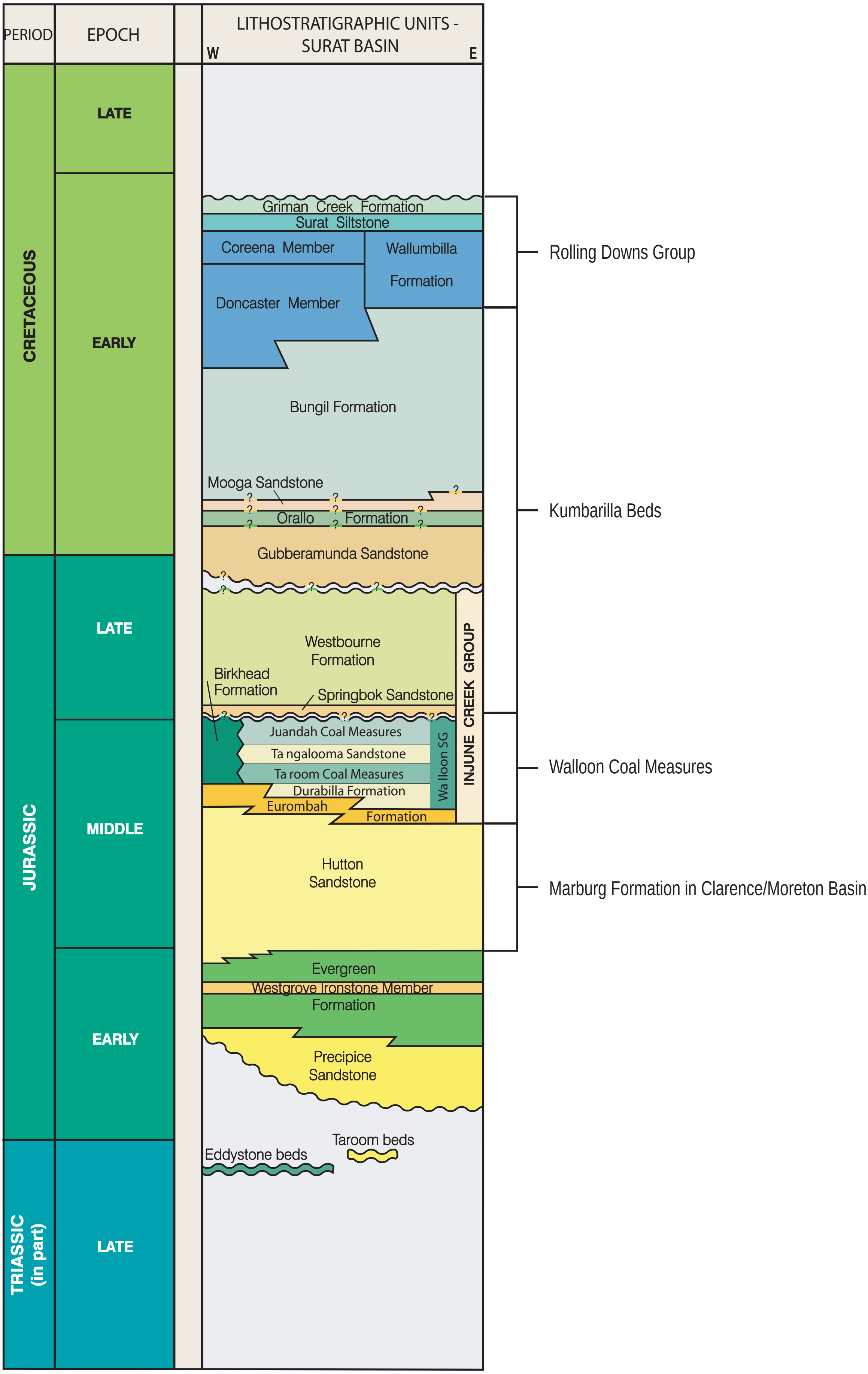
Figures

coffey geotechnics	Date: 16.11.2011 MXD: 7040AC_GLS_GIS001_v1_1 File Name: 7040_GLS_F01.01_GIS_HU	Arrow Energy Surat Gas Project	arrow energy go further	Location Map of the EIS Project Development Area	Figure No: 1.1



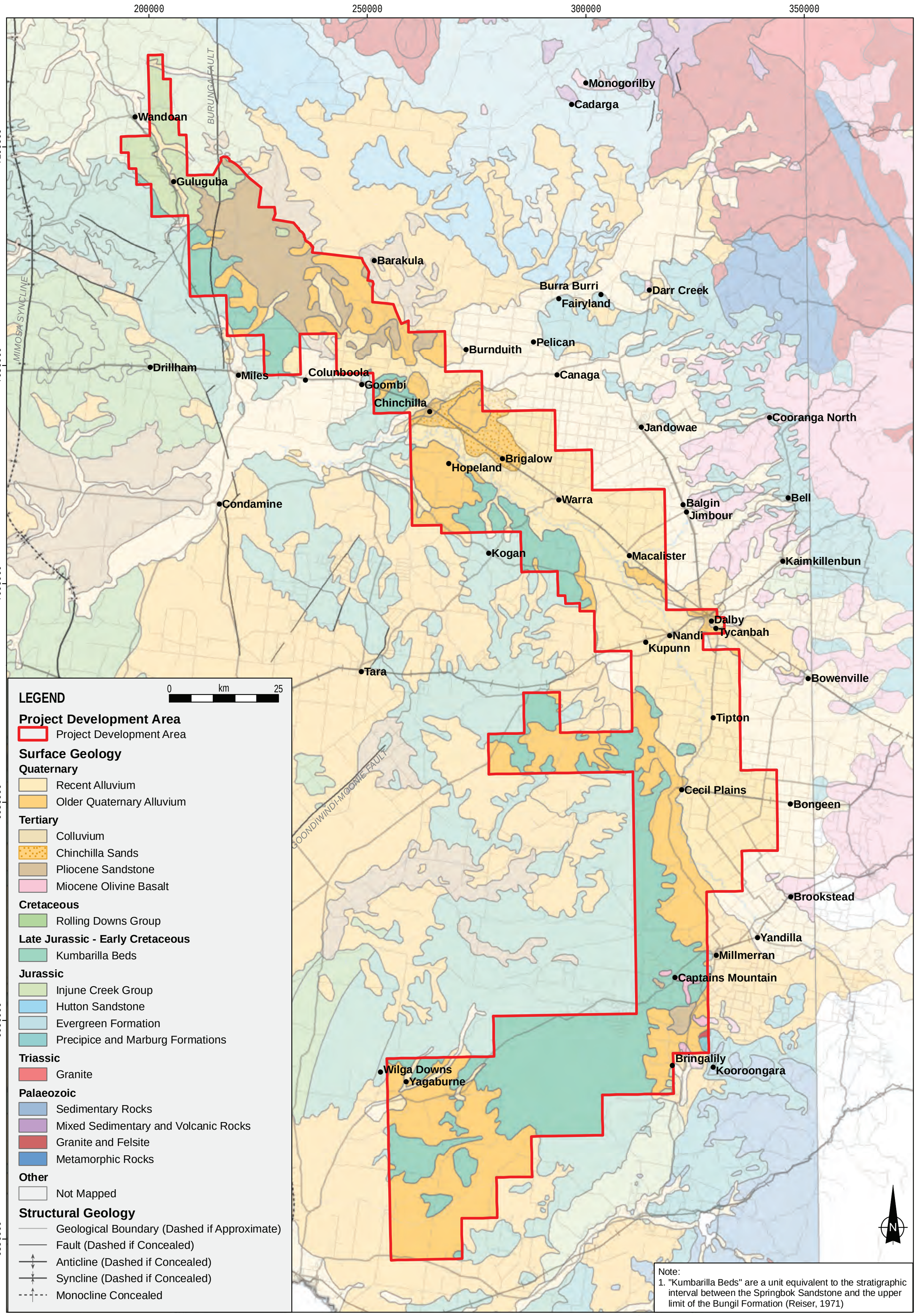
Not to Scale

coffey geotechnics	Date: 01.06.11 AI: Arrow_Condamine.AI File Name: ENAUBRIS07040AC_9097_F3.1_GLS	Arrow Energy Geology, Soils and Landform	arrow energy go further	Environmental Characteristics of the Condamine River Valley	Figure No: 3.1



After McKellar, 1999; Scott et al., 2004

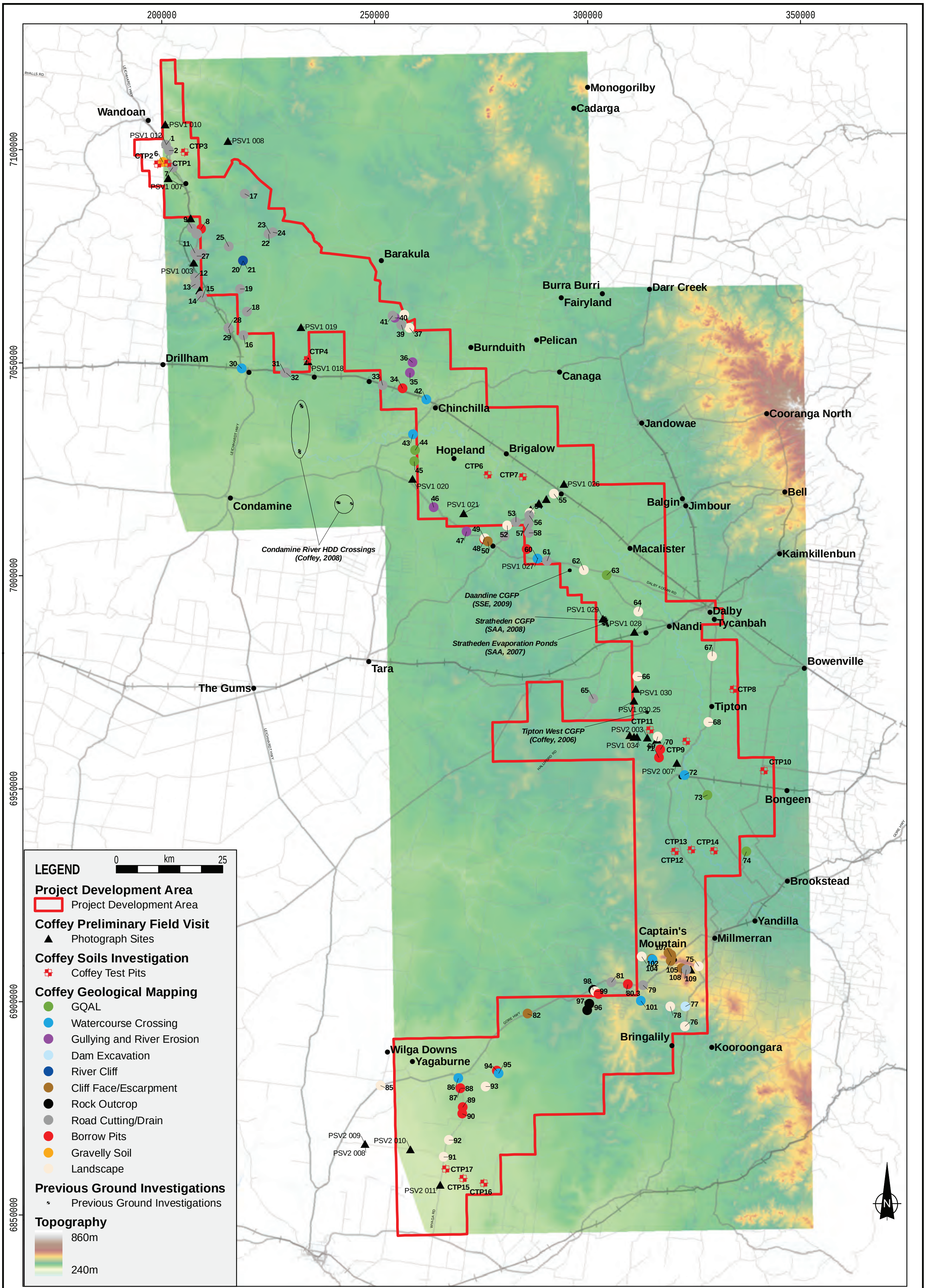
coffey geotechnics	Date: 01.06.11 AI: Arrow_Stratigraphy.AI File Name: ENAUBRIS07040AC_9097_F3.2_GLS	Arrow Energy Geology, Landform and Soils	arrow energy go further	Stratigraphic Profile of the Study Area	Figure No: 3.2



Source: 1:100,000 Queensland DME (2007) underlain by Geosciences Australia Geological Mapping

Scale 1:1,200,000 | Page size: A4 | Projection: GDA 1994 MGA Zone 56

coffey geotechnics SPECIALISTS MANAGING THE EARTH	Date: 01.06.11 MXD: Arrow_Geological Map.mxd File Name: ENAUBRIS07040AC_9097_F3.3_GLS	Arrow Energy Geology, Soils and Landform	arrow energy go further	Surface Geology of the Study Area and Environs	Figure No: 3.3



Source: Coffey GSL Team Field Mapping

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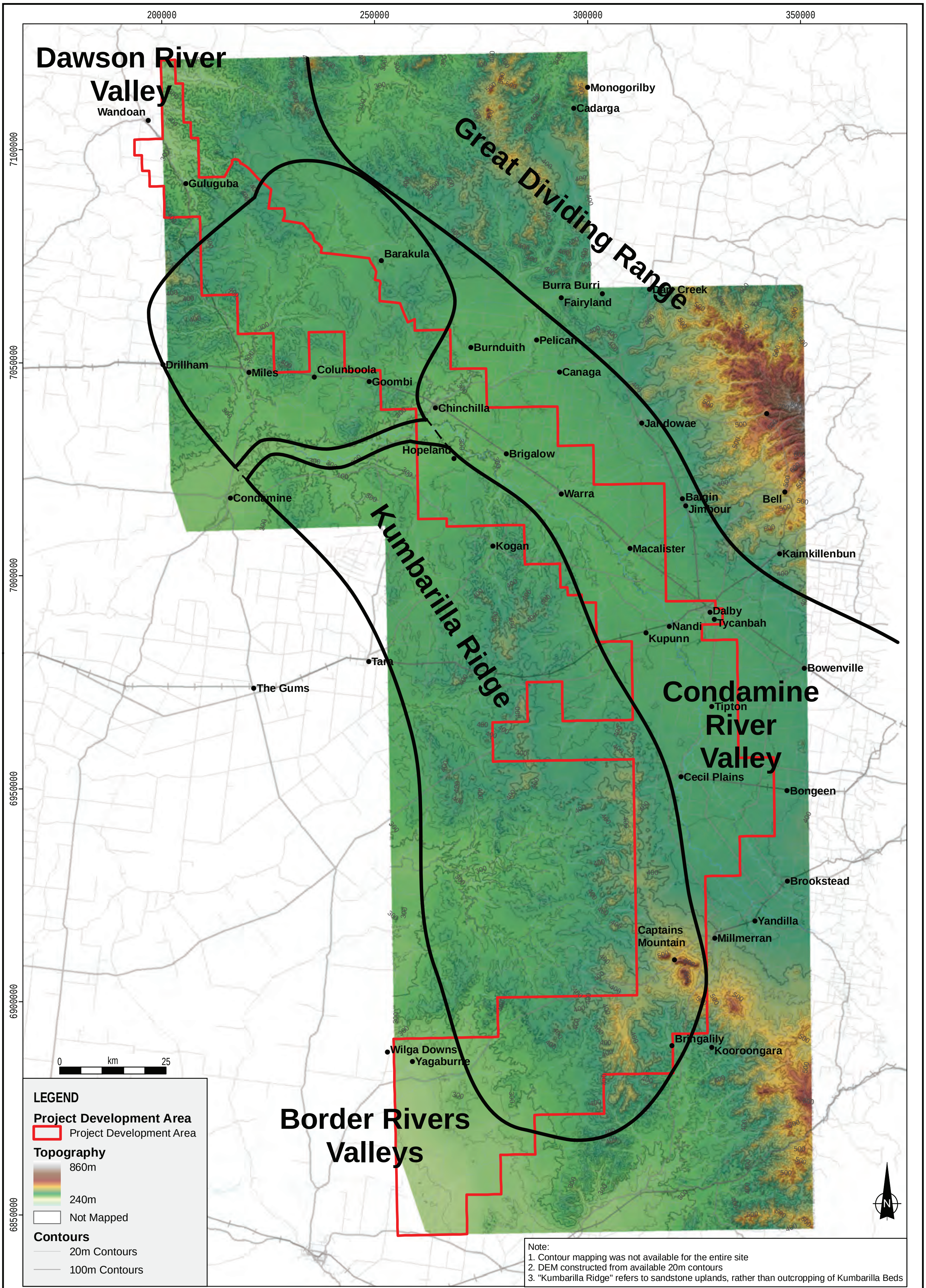

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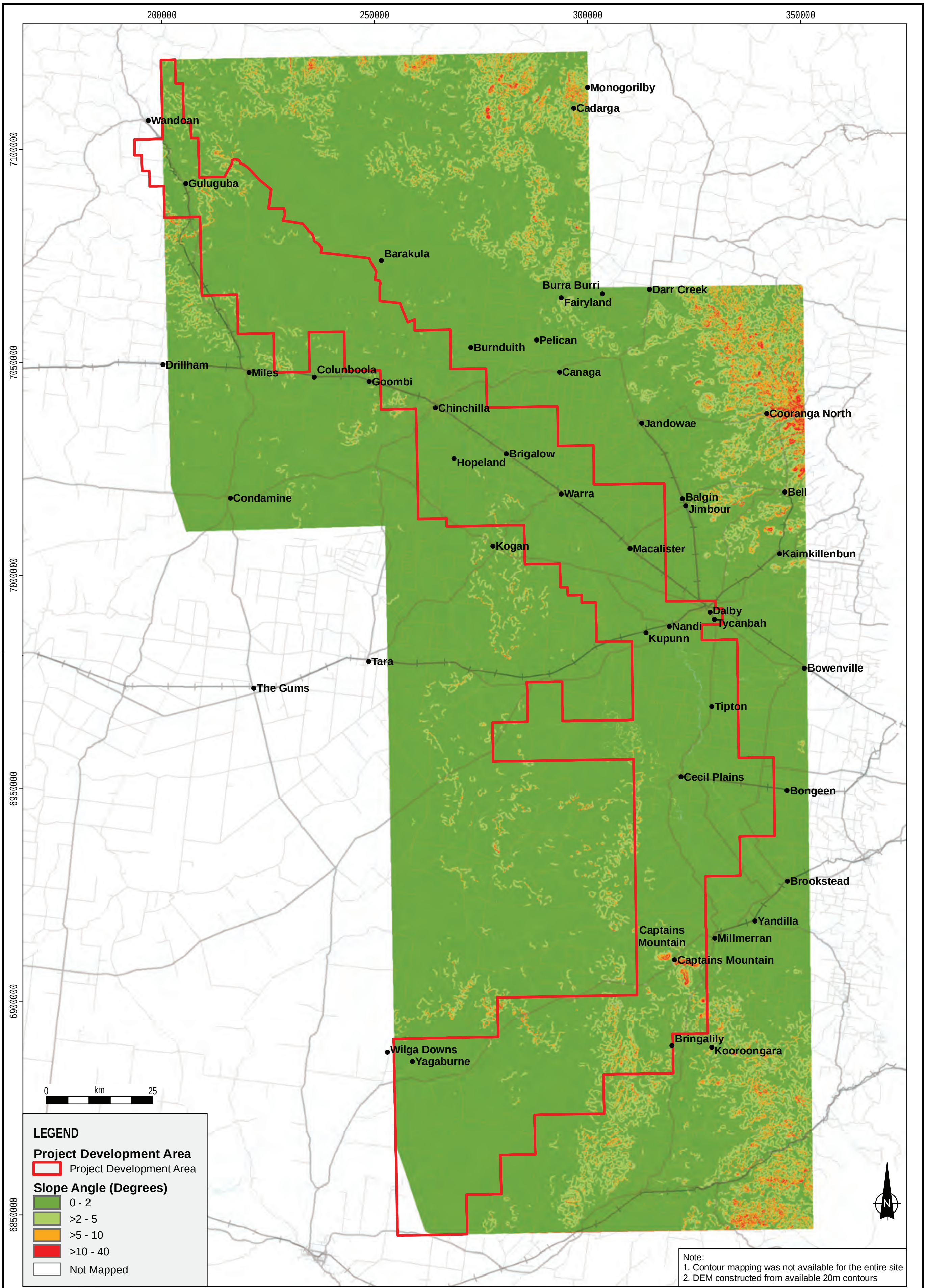

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coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Date: 01.06.11
MXD: Arrow_Slope.mxd
File Name: ENAUBRIS07040AC_9097_F3.6_GLS

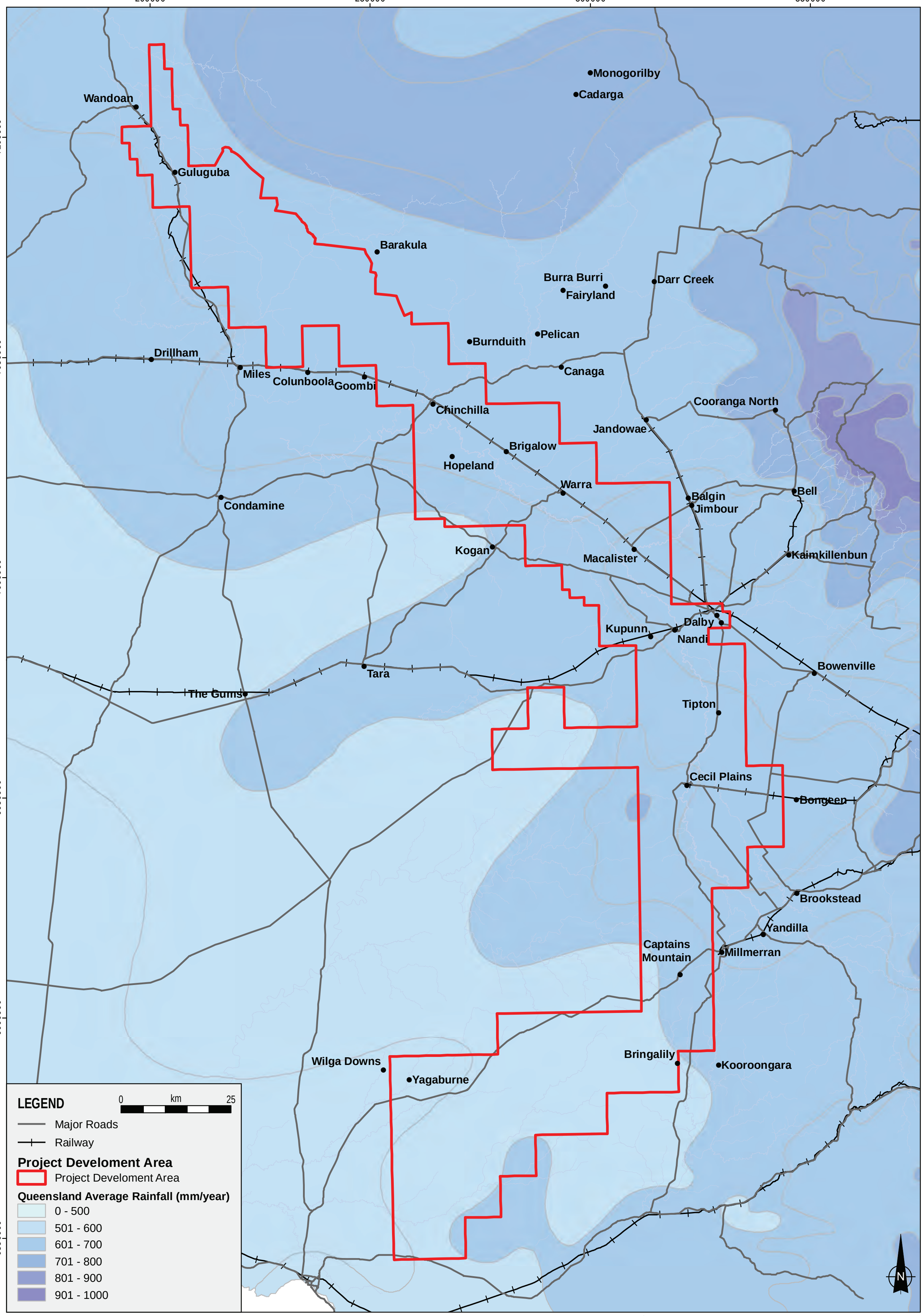
Arrow Energy

Geology, Landform and Soils

arrow energy
go further

Slope Steepness of the Study Area and Environs

Figure No: 3.6



Source: Australian Bureau of Meteorology

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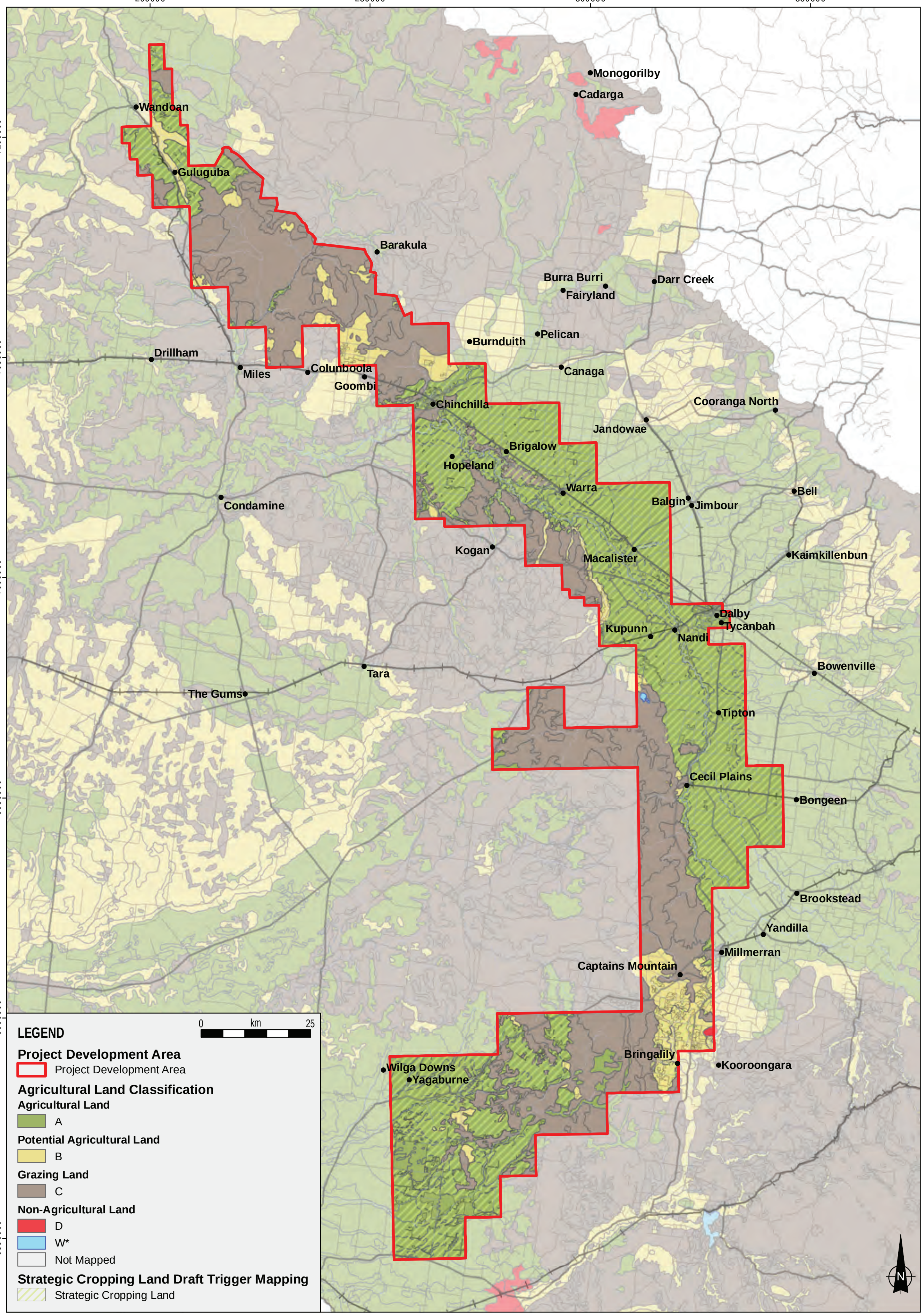

Source: 1:100,000 Queensland Southwest Region Agricultural Land Data (DPI)

Scale 1:1,200,000 Page size: A4 Projection: GDA 1994 MGA Zone 56

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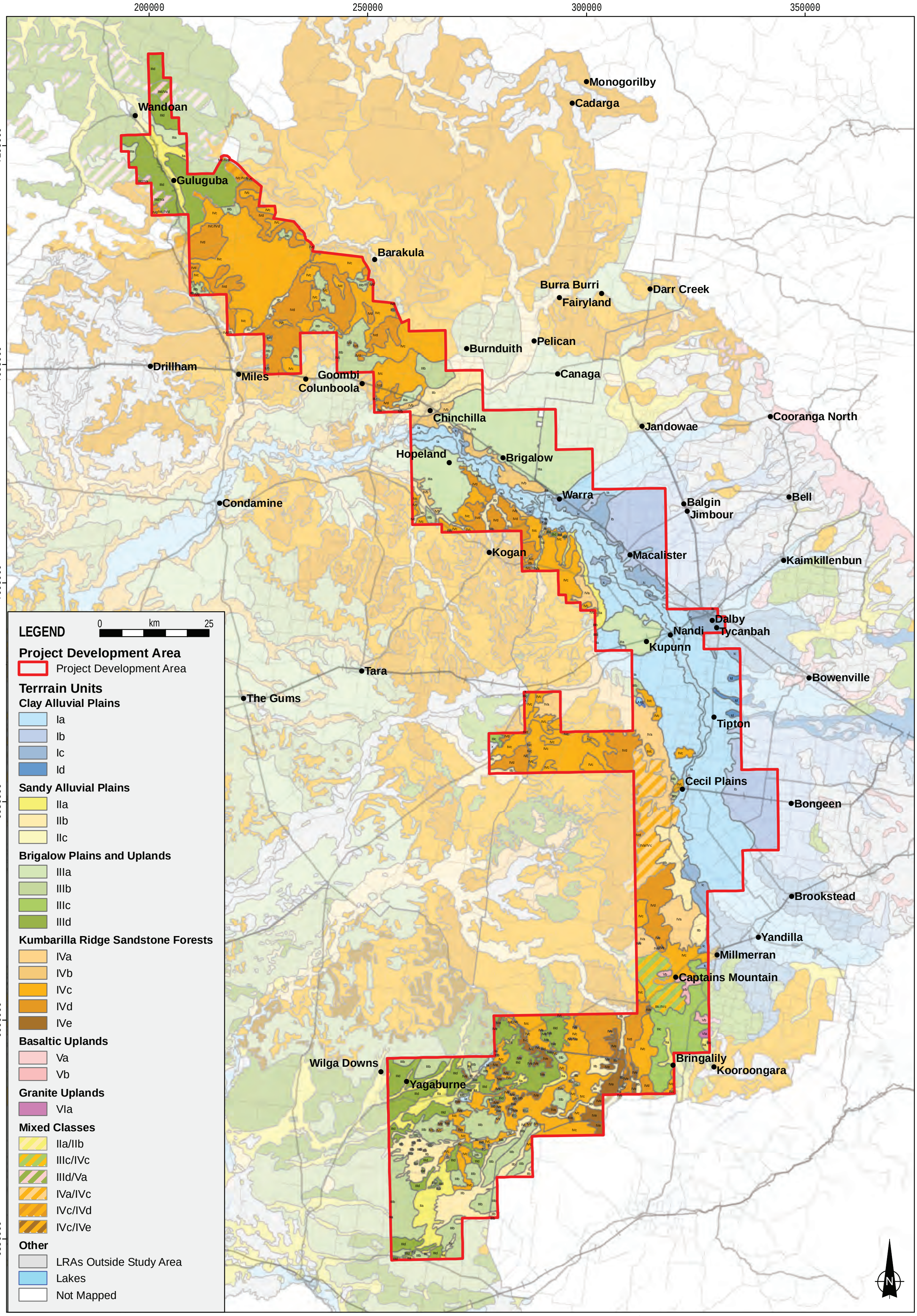

Based on DERM Land Resource Area Mapping (details provided in Reference list)

Scale 1:1,200,000 | Page size: A4 | Projection: GDA 1994 MGA Zone 56

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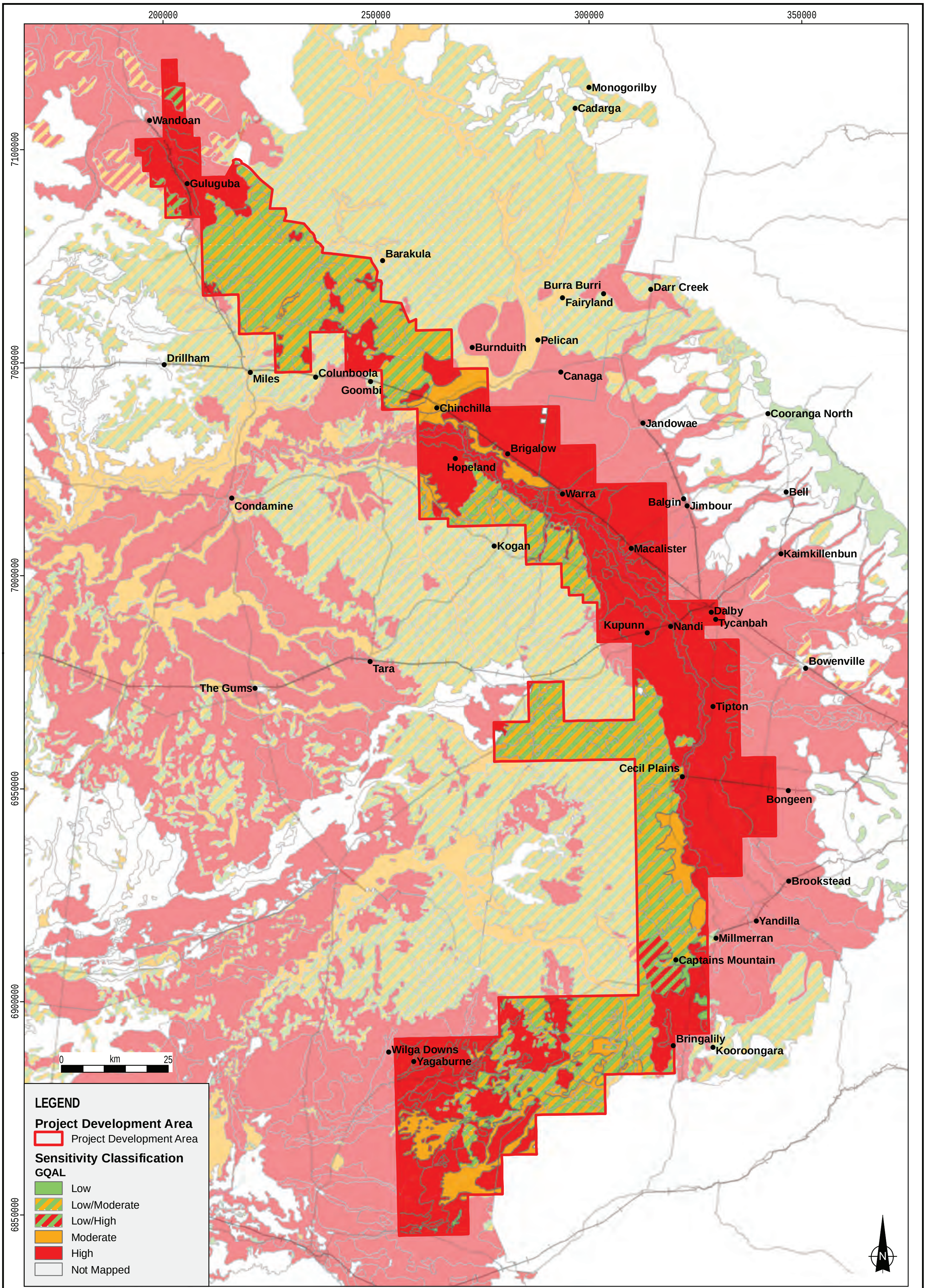

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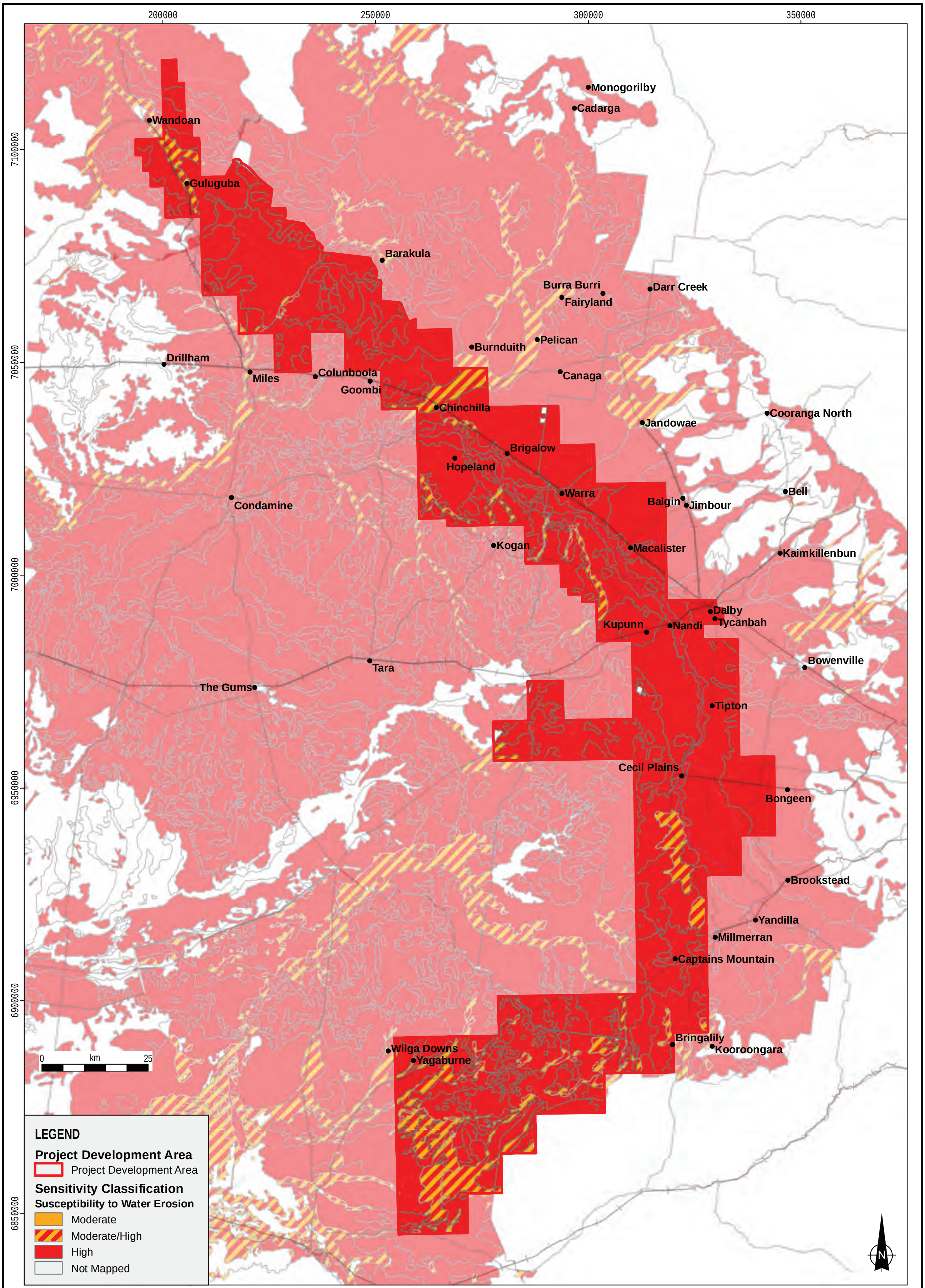
coffey geotechnics SPECIALISTS MANAGING THE EARTH	Date: 01.06.11 MXD: Arrow_GQALSens Map.mxd File Name: ENAUBRIS07040AC_9097_F4.2_GSL	Arrow Energy Geology, Landform and Soils	arrow energy go further	Sensitivity of Agricultural Soils in the Study Area	Figure No: 4.2



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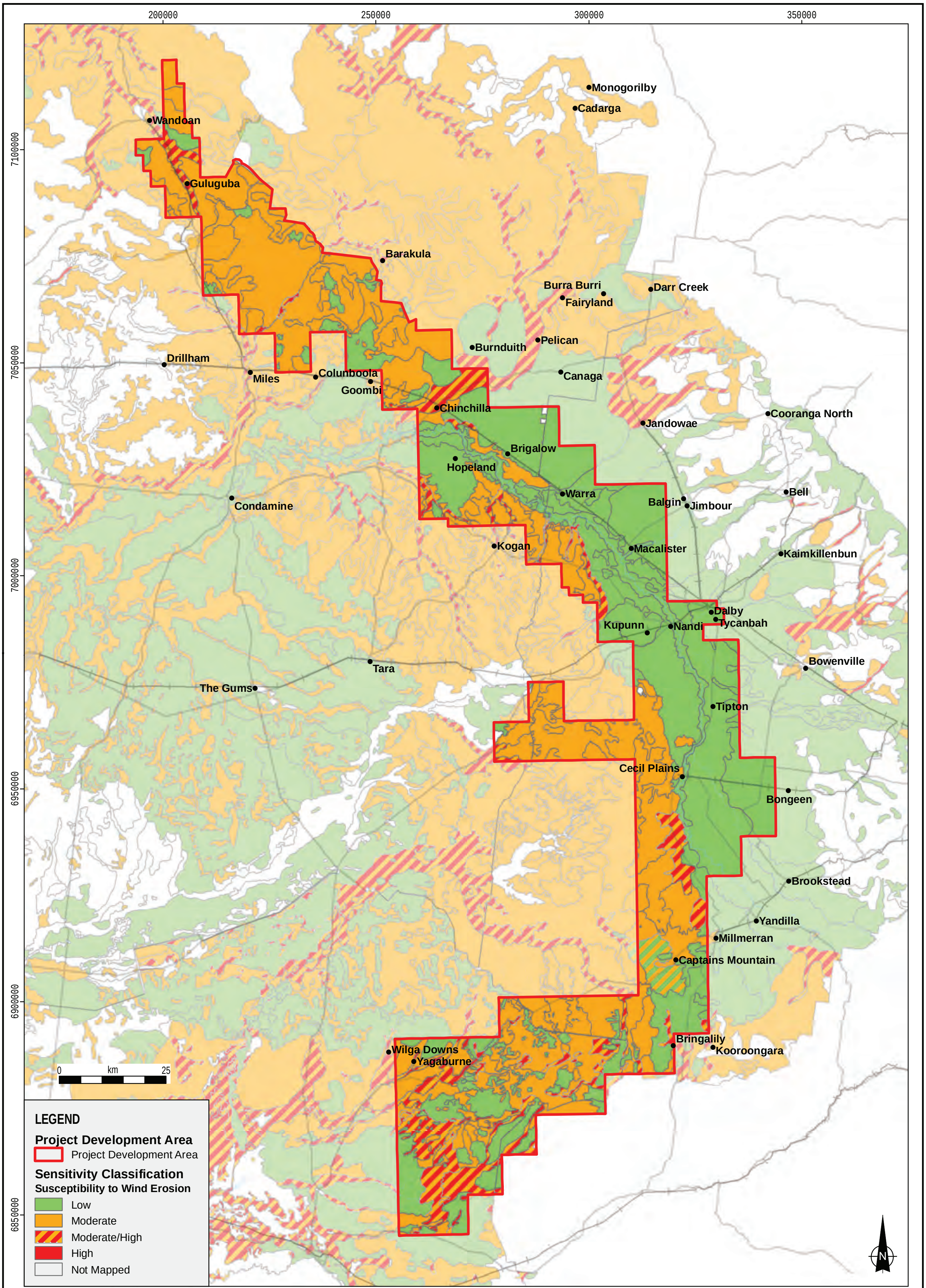

Based on DERM Land Resource Area Mapping (details provided in Reference list)

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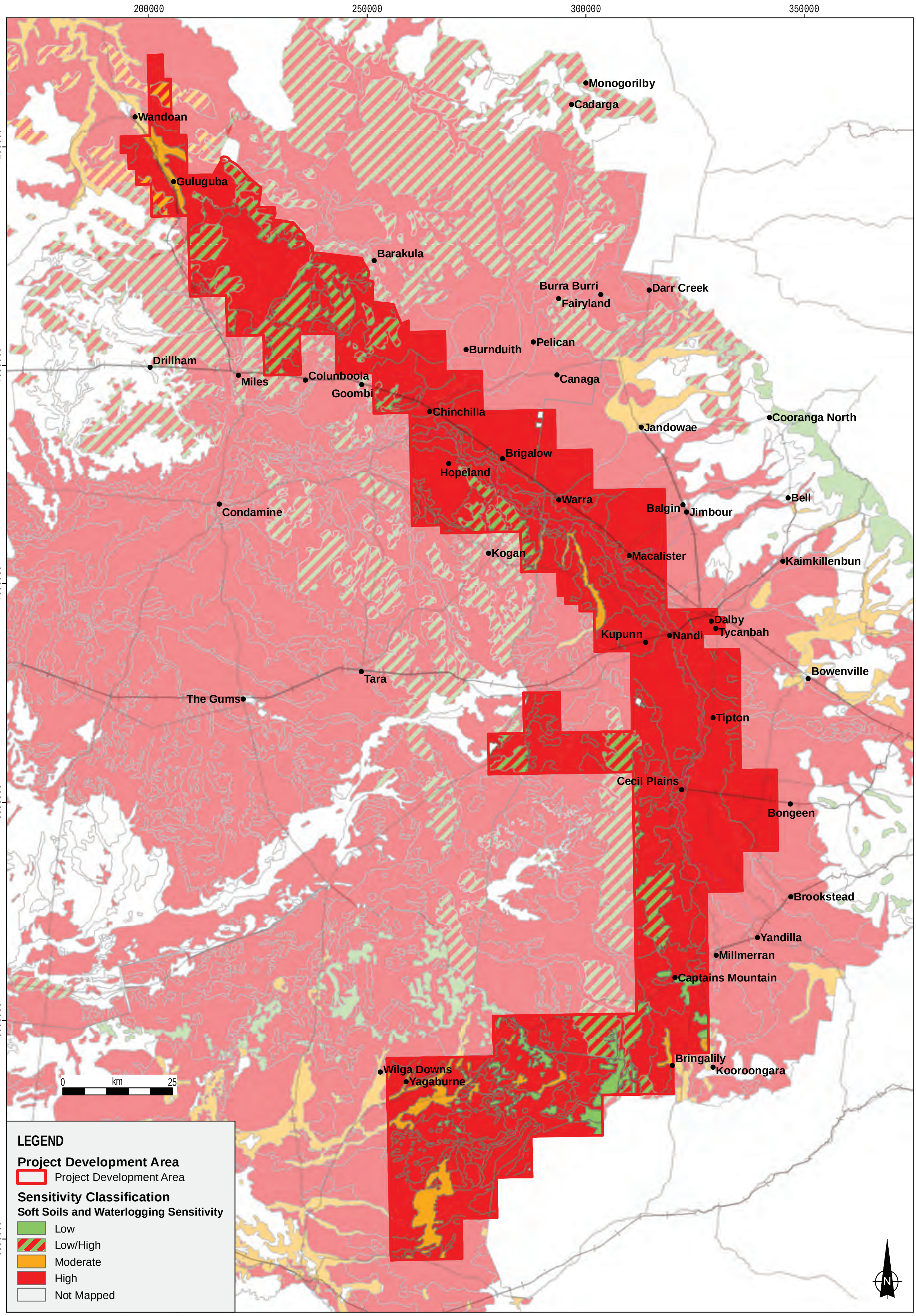
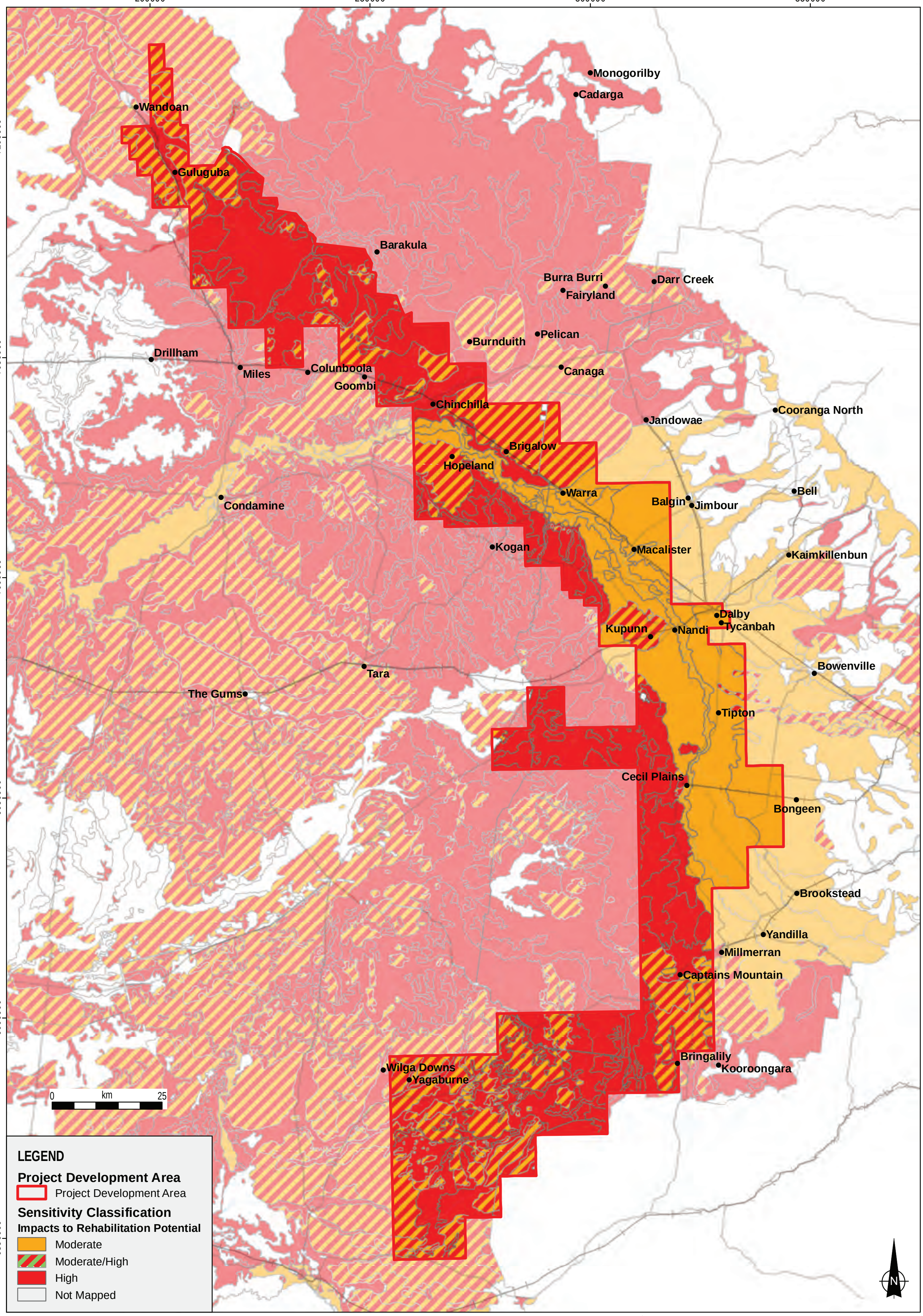
Date: 01.06.11 MXD: Arrow_WindSens Map.mxd File Name: ENAUBRIS07040AC_9097_F4.4_GSL	Arrow Energy Geology, Landform and Soils	Soil Susceptibility to Wind Erosion in the Study Area	Figure No: 4.4



Based on DERM Land Resource Area Mapping (details provided in Reference list)

Scale 1:1,200,000 Page size: A4 Projection: GDA 1994 MGA Zone 56

coffey geotechnics SPECIALISTS MANAGING THE EARTH	Date: 01.06.11 MXD: Arrow_SoftSSens Map.mxd File Name: ENAUBRIS07040AC_9097_F4.5_GSL	Arrow Energy Geology, Landform and Soils	arrow energy go further	Sensitivity from Soft Soils and Waterlogging in the Study Area	Figure No: 4.5



Based on DERM Land Resource Area Mapping (details provided in Reference list)

Scale 1:1,200,000 Page size: A4 Projection: GDA 1994 MGA Zone 56

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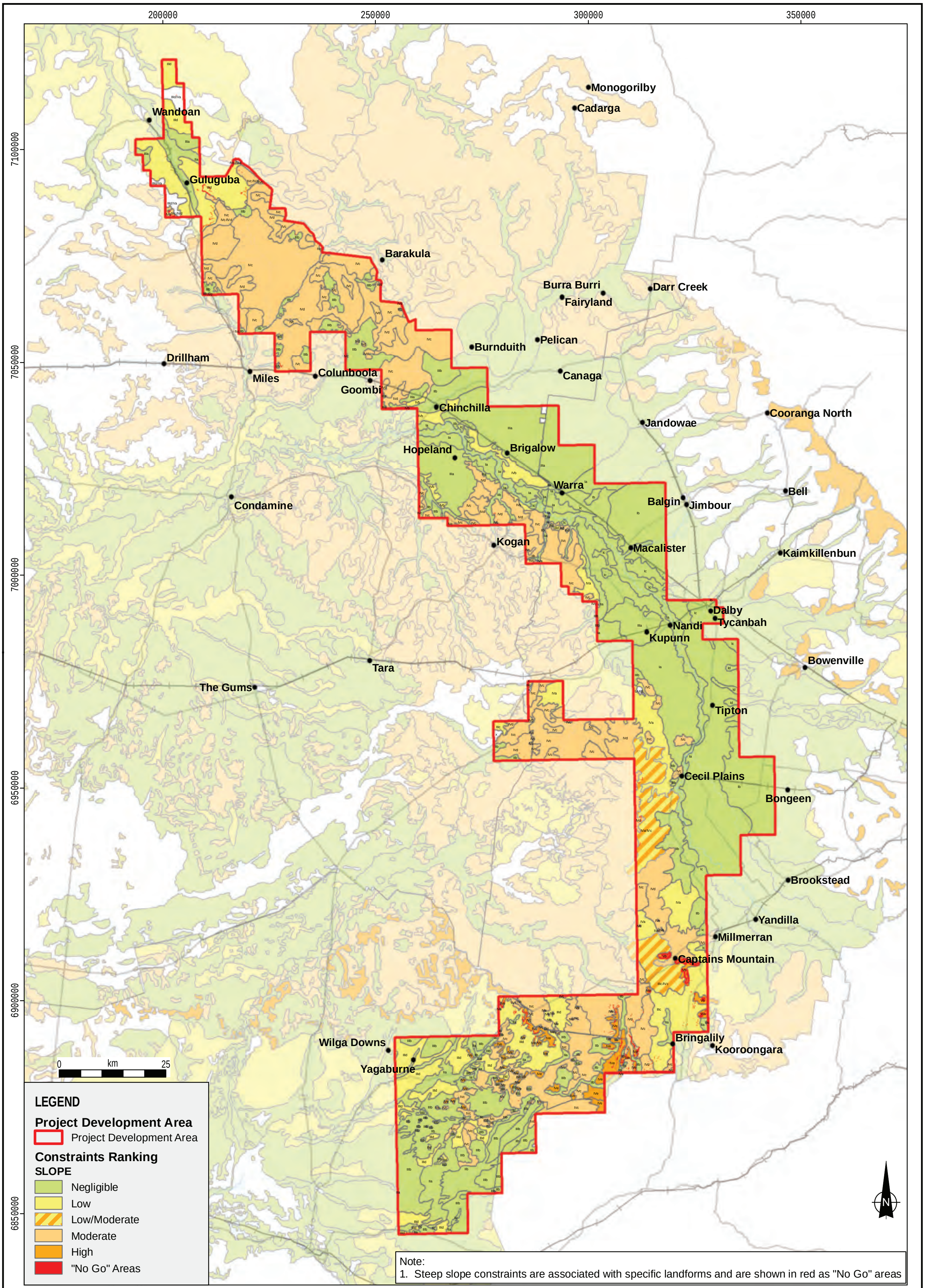

Scale 1:1,200,000 Page size: A4 Projection: GDA 1994 MGA Zone 56

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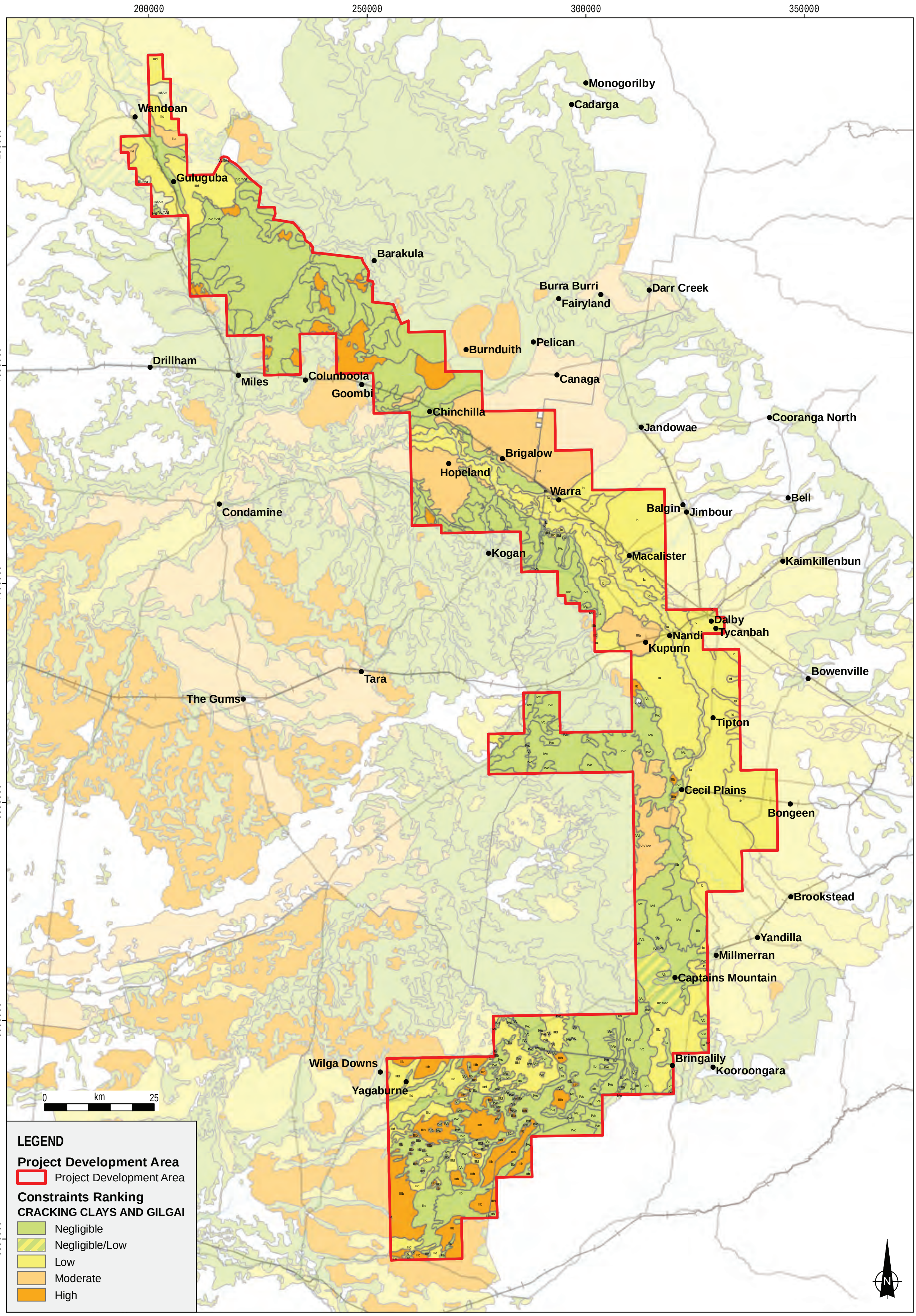

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Scale 1:1,200,000 Page size: A4 Projection: GDA 1994 MGA Zone 56

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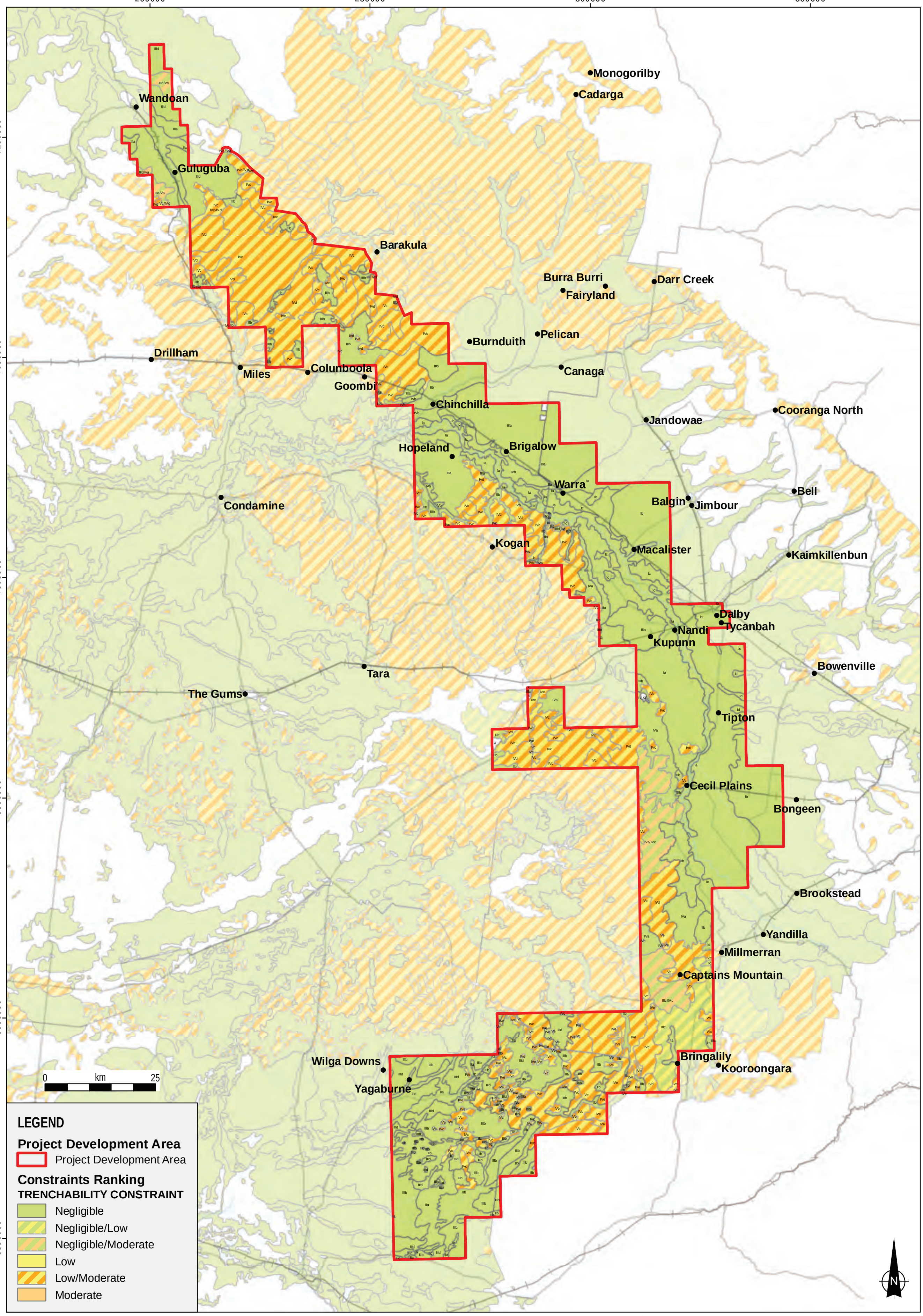
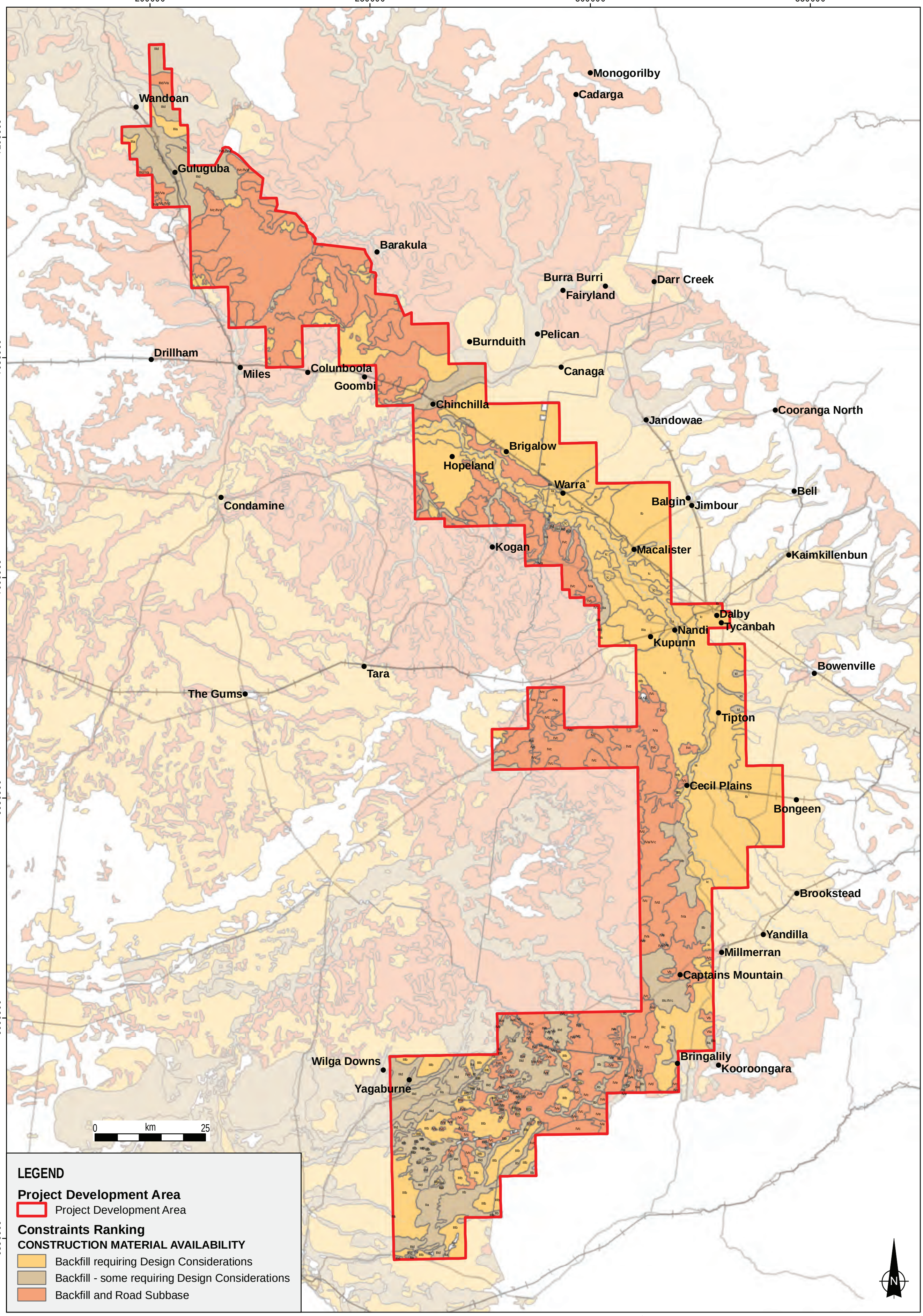


Based on DERM Land Resource Area Mapping (details provided in Reference list)

Scale 1:1,200,000 | Page size: A4 | Projection: GDA 1994 MGA Zone 56

coffey geotechnics SPECIALISTS MANAGING THE EARTH	Date: 01.06.11 MXD: Arrow_Trenchability Map.mxd File Name: ENAUBRIS07040AC_9097_F5.3_GLS	Arrow Energy Geology, Landform and Soils	arrow energy go further	Trenchability Constraint of the Study Area and Environs	Figure No: 5.3



Based on DERM Land Resource Area Mapping (details provided in Reference list)

Scale 1:1,200,000 | Page size: A4 | Projection: GDA 1994 MGA Zone 56

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Date: 01.06.11
MXD: Arrow_Construction.mxd
File Name: ENAUBRIS07040AC_9097_F5.4_GLS

Arrow Energy

Geology, Landform and Soils

arrow energy
go further

Construction Material Availability of the Study Area and Environs

Figure No: 5.4

Appendix A

Terrain Evaluation and Field Assessment Methodology

Method of Assessment

Coffey used a phased approach to the Geology, Landform and Soils Study. This involved the following:

DESKTOP ANALYSIS

Phase 1.1 – Collation and Review of Available Existing Studies, Information, Data, Relevant Legislation and Mapping.

The initial phase of the desktop analysis involved collating available information related to geology, landform and soils within the study area. This included review of publically available EIS, reports, articles and maps.

All digital mapping data used for this study was provided by Coffey Environments, under appropriate license agreements from data owners. Descriptions for mapping units were obtained from associated datasets.

The following data sets were used for mapping, description and assessment of the study area:

- Colour aerial photography provided by Arrow Energy.
- Geological mapping sourced from the Queensland Department of Mines and Energy vector coverage of the study area at a scale of 1:100 000 (February, 2007)
- Topography mapping derived from the Queensland Department of Environment and Natural Resources (1998) at a scale of 1:25,000 and Geosciences Australia (1990) at a scale 1:100,000
- Land resources digital data sets including CSIRO Land Research Series – the Central Darling Downs (MCD), Murilla, Tara and Chinchilla (MWD), Waggamba Shire (WLM), the Dawson Fitzroy Area (ZDD).
- Queensland Department of Natural Resources and Water (NRW – 2004) regional compilation of and mapping (1:250 000) Central West Region – Good Quality Agricultural Land (GQAL).

Since specific soil mapping was not available, land resource area (LRA) mapping was used to assess soil types across the study site. An LRA is made up of a series of common and associated soils with key geology, landscape and vegetation characteristics. The study area is covered by 4 separate LRA maps, each with their own legends:

- Central Darling Downs (Harris *et al.*, 1999)
- Murilla, Tara and Chinchilla (Maher, 1996)
- Waggamba Shire (Thwaites and Macnish, 1991)
- Lands of the Dawson-Fitzroy Area (Perry, 1968)

In order to achieve common landscape unit characterisation across the study area, a common key was created for the 4 LRA maps. The resulting map became the base of the landscape unit mapping used for this investigation.

While the geology and the landform within each LRA are fairly uniform, the soils within them can differ substantially. To account for this, soils occurring within the study area have been divided into major soil units and described in detail in this report.

Phase 1.2 – Preliminary Constraints and Sensitivity Mapping

Preliminary maps of geology, elevation and combined LRAs were managed using a GIS Geodatabase. The preliminary maps and associated data were then reviewed to identify any trends and anomalies between the layers. Aerial photographs were used to assist this process.

The LRA units were then assessed with regard to constraints which would affect the project. This assessment was then used to amalgamate and simplify the different classifications, producing a consistent system across the study area, which are have termed "Terrain Units" for the purposes of this assessment report.

FIELD INVESTIGATIONS

Phase 1.3 – Preliminary Field Reconnaissance

A field reconnaissance survey of parts of the study area was undertaken on 26 – 28 August 2009. The reconnaissance involved a drive-through with a soil scientist, geomorphologist and geologist to gain a general appreciation of the soils, geology and land characteristics of study area.

Phase 2 – Targeted field investigations

Soils Field Investigation

Ground Observations

Coffey's Soil Scientist visited the study area on 30 November – 4 December 2009.

Site reconnaissance was undertaken prior to the fieldwork program in order to provide preliminary confirmation of the desk study findings and to help assess the field investigation requirements. Test pit locations were selected by targeting areas identified as having specific soil attributes from the desktop review and preliminary mapping. The aim of the field investigation was to encounter a range of geology-landform-soil-vegetation combinations and to record specific site information for those assigned in the constraint units during the desktop analysis.

A total of 16 test pits (CTP1-4 and CTP6-17) were excavated using a 10 tonne excavator. Test pit locations were recorded using a hand-held GPS receiver with an accuracy of ±5-10 m. Test pits were 0.45 m wide (width of excavator bucket) and approximately 2 m deep or to refusal. Test pits were backfilled following sampling and logging, to reduce permanent environmental damage.

Test pits were described in accordance to the Australian Soil and Land Survey Field Handbook (McDonald *et al*., 1990) and classified using the Australian Soil Classification (Isbell, 2002). Landscape position, vegetation, ground surface features and substrate material (where evident) were also recorded at each site to assist in mapping.

Photographs of the typical soils encountered during the fieldwork are presented in Appendix B. Test pit logs showing the soil types encountered and depths at which samples were collected are included in Appendix C.

Sampling

Samples from each horizon were collected during the test pitting. All samples were set to the laboratory, however only 14 were selected for laboratory analysis.

Chemical laboratory testing comprised of the following:

- pH
- Electrical Conductivity

- Cation Exchange Capacity
- Exchangeable cations
- Exchangeable Sodium percentage (ESP)
- Acid generating potential:
- Physical laboratory testing comprised of the following:
- Particle size distribution:
- Dispersivity (Emerson Testing):
- California Bearing Ratio (CBR)
- Atterburg Limits

Physical soil testing was conducted by Coffey Information. Chemical soil testing was conducted by MGT Environmental Consulting. Both laboratories are NATA accredited. Laboratory certificates are presented in Appendix C. Split samples were assessed at the laboratory as part of the QA/QC procedures. Results of this are considered acceptable for uses in this study and are included in the laboratory certificates.

Geology Field Investigation

Ground Observations

Coffey's Geologist visited the study area on 14 – 16 December 2009.

The objective of the geology field investigation was to gain a broad overview of the rock characteristic and engineering properties of near-surface rock across the study area.

Detailed logging of exposed rock at locations and visual assessment of the rock and soil properties throughout the study area was undertaken.

Rock logging locations were recorded using a hand-held GPS receiver with an accuracy of ±5-10 m. Photographs of the typical rocks encountered during the fieldwork are presented in Appendix B.

Sampling

37 rock samples were collected, with 12 selected for Point Load Strength Testing.

Data Analysis

Soil profile descriptions and analytical data were used to confirm field soil classifications.

Profile descriptions and analytical data were used to confirm and refine the constraints units and adjust boundaries where necessary. In this assessment, maps have been produced with clear boundaries, however it should be noted that soil and landscape units exist as a continuum, slowing changing from one type to another. As a result the data produced in this study will not necessarily accurately describe individual sites. The findings have been presented at a scale appropriate for a regional overview, and to meet the Terms of Reference.

Appendix B

Geological Mapping and Site Photographs

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
1	Road Cutting	56	0200955	7101128

Description
Extremely weathered material comprising SAND, fine to medium grained, pale brown to pale grey With Interbedded SANDSTONE, fine to coarse grained, pale brown, assessed highly weathered and low strength to medium strength, cross bedded

Figure 1: Road cutting, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
2	Road Cutting	56	0201704	7099848

Description
Extremely weathered profile comprising clayey SAND, fine to medium grained, pale brown, low to medium plasticity clay With Interbedded SANDSTONE, medium to coarse grained, pale brown to pale orange with some black, assessed highly weathered and low strength, crossbedded

Figure 2: Road cutting, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
3	Road Cutting	56	0201838	3098775

Description
Alluvial profile, comprising Cobbles, Gravels, Sands and clayey Sands

Figure 3: Road cutting, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
4	Outcrop	55	0799369	7097103

Description
SANDSTONE, medium grained, pale brown to pale orange, some black, assessed moderately weathered and medium to high strength, some interbedded coarse grained sandstone horizons

Figure 4: Rock outcrop, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
5	Borrow Pit	55	0799767	7097043

Description
Gravels and Cobbles (weathered conglomerate)

Figure 5: Borrow pit, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
6	Landscape	56	0200289	7097035

Description
Gravels and Cobbles (weathered conglomerate)

Figure 6: Landscape, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
7	Road Cutting	56	0202674	7095883

Description
SANDSTONE, medium to coarse grained, pale brown – pale orange – pale grey, assessed highly to moderately weathered and very low to medium strength, with some extremely weathered material and residual soil

Figure 7: Road cutting, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
8	Small borrow pit	56	0209195	7081444

Description
Between old road and existing road, possible FILL material: Residual soil (weathered Conglomerate) comprising Cobbles/Gravels/ Sands and clayey Sands

Figure 8: Borrow pit, view to North - Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
9	Road Cutting	56	0207141	70815008

Description
Extremely weathered material with interbedded SANDSTONE, pale orange and pale grey, assessed highly to moderately weathered and low to medium strength, crossbedded, some palaeo channels observed

Figure 9: Road cutting, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
10	Road Cutting	56	0208170	7080330

Description
Extremely Weathered material comprising SAND, fine to medium grained, pale brown to pale grey, With Interbedded SANDSTONE, fine to coarse grained, pale brown, assessed highly weathered and low to medium strength, crossbedded

Figure 10: Road cutting, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
10	Road Cutting	56	0208188	7080321

Description
Colluvium

Figure 11: Colluvium in road cutting, view to North - Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
10	Road Cutting	56	0208335	7080187

Description
Conglomerate, fine to coarse gravel and cobble clasts in medium to coarse grained sand matrix, pale brown – pale grey – white

Figure 12: Conglomerate in road cutting, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
11	Road Cutting	56	0207758	7075771

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey – white, assessed moderately weathered and medium to high strength With CONGLOMERATE, fine to coarse gravel clasts in medium to coarse grained sand matrix, pale brown – pale grey - white

Figure 13: Road cutting and road drain, view to North – Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
12	Road Cutting	56	0207770	7069948

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey – white, assessed moderately weathered and medium to high strength

Figure 14: Road cutting, view to North West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
13	Road Cutting	56	0207925	7068435

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey – white, assessed moderately weathered and medium to high strength, defects < 200mm, joints, graded bedding, some cross bedding

Figure 15: Road cutting, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
14	Road Cutting	56	0209225	7065698

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey – white, assessed moderately weathered, medium to high strength, defects < 200mm, joints, graded bedding, some cross bedding

Figure 16: Road cutting, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
15	Road Drain	56	0209584	7065274

Description
CONGLOMERATE, gravel and cobble clasts in medium to coarse grained sand matrix, pale grey and white with some orange ironstaining, assessed highly to moderately weathered and medium strength

Figure 17: Road drain, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
16	Road Drain	56	0219139	7056417

Description
Gravelly SAND, fine to coarse grained, pale brown – pale orange – pale grey – white, with ironstaining, fine to coarse grained gravel, some low plasticity clay With Interbedded SANDSTONE, medium to coarse grained, pale brown, some pale orange ironstaining, assessed highly weathered, very low to medium strength And CONGLOMERATE, fine to coarse gravel clasts and some cobbles in fine to coarse grained sand matrix, pale brown – pale orange ironstaining – pale grey, assessed highly weathered and very low to medium strength Defects in SANDSTONE are <100mm; at least 3 sets of joints

Figure 18: Road cutting, view to North – Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
17	Road	56	0219500	7089720

Description
Landscape view of road

Figure 19: Road view to North – Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
18	Road Drain	56	0219990	7061897

Description
SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale brown to pale grey, some ironstaining, assessed highly to moderately weathered and low to medium strength

Figure 20: Road drain, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
19	Road Drain	56	0218360	7067314

Description
SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale brown to pale grey, some ironstaining, assessed highly to moderately weathered and low to medium strength

Figure 21: Road drain, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
20	Borrow Pit	56	0219043	7073933

Description
CONGLOMERATE, fine to medium gravel clasts in fine to medium grained sand matrix, pale grey and white with some ironstaining, assessed moderately weathered and medium to high strength, some honeycomb weathering

Figure 22: Borrow pit, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
21	River Bank/Cliff	56	0219043	7073933

Description
Cliff line

Figure 23: River bank view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
22	Road Drain	56	0225117	7080179

Description
SILTSTONE, pale grey to white with some ironstaining, assessed moderately to slightly weathered and medium to high strength, no signs of honeycomb weathering, defects <100mm; multiple sets (Possible CLAYSTONE)

Figure 24: Road drain, view to West - Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
23	Road	56	0225516	7080293

Description
Road

Figure 25: Road view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
24	Road	56	0226087	7080584

Description
Road

Figure 26: Road, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
25	Road	56	0215742	7077293

Description
Road

Figure 27: Road, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
26	Road Drain	56	0209473	7075585

Description
CONGLOMERATE, medium to coarse gravel and cobble size clasts and petrified wood (extremely high strength) in fine to medium grained sand matrix, pale grey with some iron staining, assessed moderately to slightly weathered and high to very high strength

Figure 28: Road drain, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
27	Road Cutting	56	0208225	7075018

Description
Extremely weathered material comprising fine to medium grained SAND, pale brown to pale grey And Interbedded SANDSTONE, fine to coarse grained, pale brown, assessed highly weathered and low to medium strength, crossbedded

Figure 29: Road cutting, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
28	Road Cutting	56	0215668	7058188

Description
Lithic SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale grey to white with some ironstaining, assessed highly weathered and very low to medium strength, some honeycomb weathering

Figure 30: Road cutting, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
29	Borrow Pit	56	0215715	7058005

Description
Lithic SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale grey to white with some ironstaining, assessed highly weathered and very low to medium strength, some honeycomb weathering

Figure 31: Borrow pit, view to North – Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
29	Road Cutting	56	0215715	7058005

Description
Lithic SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale grey to white with some ironstaining, assessed highly weathered and very low to medium strength, some honeycomb weathering

Figure 32: Road cutting, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
30	River Channel	56	0218780	7048625

Description
Extremely weathered material apparent as: Gravelly SAND, fine to coarse grained, pale brown – pale orange – pale grey – white, with ironstaining, fine to coarse grained gravel, some low plasticity clay With Interbedded SANDSTONE, medium to coarse grained, pale brown with some pale orange ironstaining, assessed highly weathered and very low to medium strength And CONGLOMERATE, fine to coarse gravel clasts and some cobbles in fine to coarse grained sand matrix, pale brown – pale orange (ironstaining) – pale grey, assessed highly weathered and very low to medium strength Defects in SANDSTONE are <100mm, at least 3 sets of joints

Figure 33: River channel, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
31	Road Cutting	56	0228903	7047634

Description
CONGLOMERATE, medium to coarse gravel, cobble and some boulder clasts in medium to coarse grained sand matrix, pale brown – pale orange – red – pale grey, assessed highly to moderately weathered and low to medium strength Interbedded medium to coarse grained SANDSTONE horizons

Figure 34: Road cutting, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
32	Road Cutting	56	0229230	7047614

Description
SANDSTONE, medium to coarse grained with some fine grained gravel sized clasts, pale brown to pale grey with some ironstaining, assessed highly to moderately weathered and low to medium strength

Figure 35: Road cutting, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
33	Highway	56	0251885	7044657

Description
Highway

Figure 36: Highway, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
34	Borrow Pit	56	0256566	7043982

Description
SANDSTONE, medium to coarse grained, pale grey to white, assessed moderately to slightly weathered and medium to high strength

Figure 37: Borrow pit, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
35	Gully/Creek Bed – Erosion	56	0258333	7047615

Description
No rock observed– alluvial profile

Figure 38: Creek bed, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
36	Gully – Erosion	56	0258899	7050109

Description
No rock observed – alluvial profile

Figure 39: Gully, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
37	Landscape	56	0258183	7058209

Description
Imported rock fill for bund

Figure 40: Landscape, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
38	Landscape	56	0256945	7061183

Description
No rock observed

Figure 41: Landscape, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
39	Road Drain	56	0256255	7058847

Description
SANDSTONE, medium to coarse grained, pale grey with some ironstaining, assessed highly to moderately weathered and low to medium strength, defects <100mm; at least 2 sets

Figure 42: Road drain, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
40	Gully – Erosion	56	0254726	7060567

Description
No rock observed

Figure 43: Gully view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
41	Road Drain	56	0254267	7061045

Description
SANDSTONE, medium to coarse grained, pale grey with some ironstaining, assessed highly to moderately weathered and low to medium strength, defects <100mm; at least 2 sets

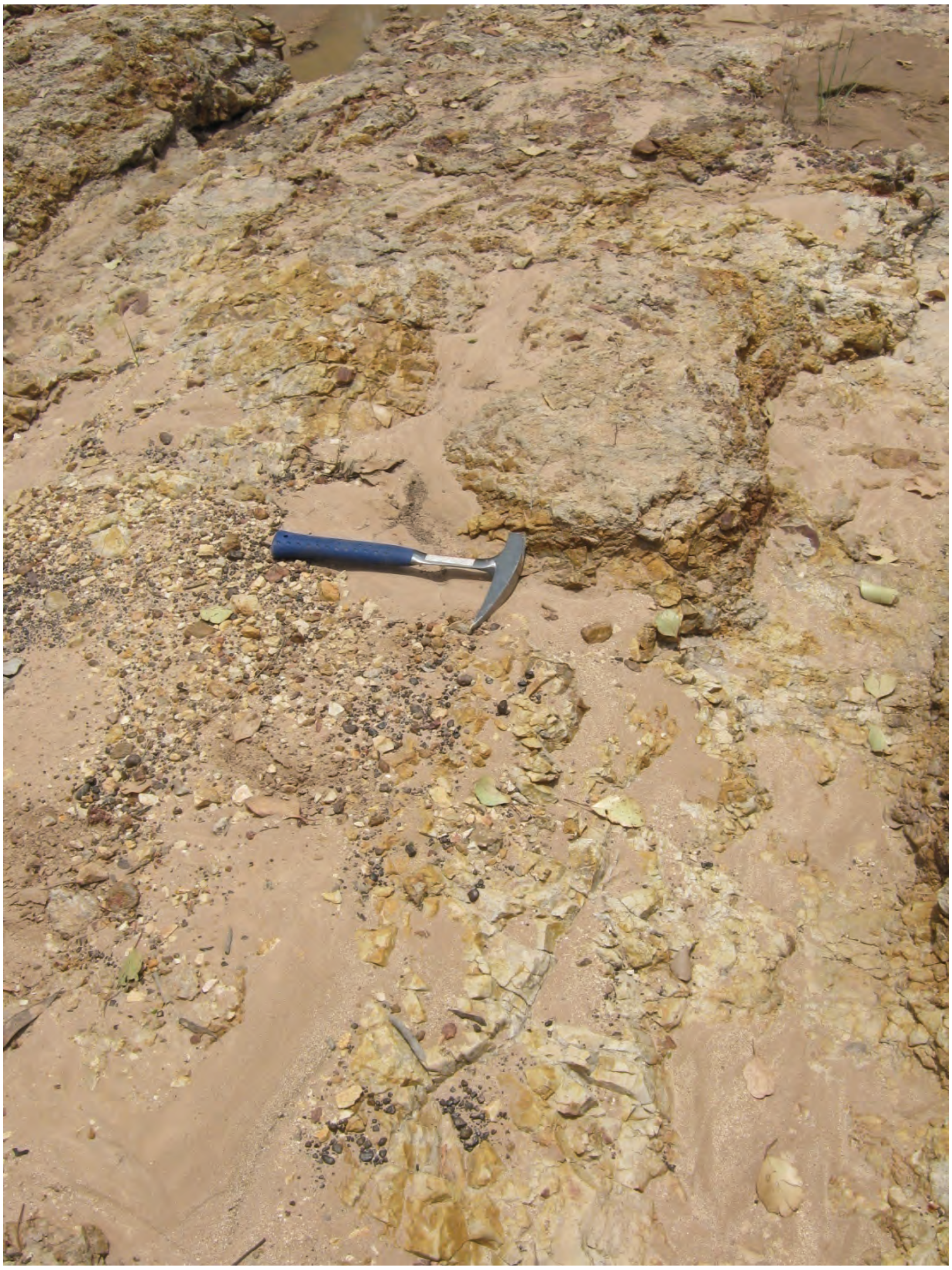


Figure 44: Road drain, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
42	Creek	56	0262115	7041286

Description
No rock observed

Figure 45: Creek, view to North - Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
43	Chinchilla Weir	56	0258962	7033220

Description
River embankment – 10m high (Possible sandstone)

Figure 46: River embankment, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
44	Landscape	56	0259521	7029410

Description
Landscape

Figure 47: Landscape view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
45	Landscape	56	0259250	7026849

Description
Landscape

Figure 48: Landscape, view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
46	Landscape	56	0263907	7016008

Description
No rock observed – soil profile

Figure 49: Landscape, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
47	Landscape	56	0271590	7010330

Description
Surface run off after storm

Figure 50: Storm water run-off, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
48	Borrow Pit	56	0275741	7008569

Description
SANDSTONE, fine to coarse grained, pale grey with some red ironstaining, assessed moderately weathered to fresh and medium to high strength, at least 3 joint sets Some interbedded SILTSTONE and CONGLOMERATE: SILTSTONE, pale grey to grey, assessed slightly weathered to fresh and medium strength CONGLOMERATE, fine to coarse gravel and some cobbles in fine to coarse grained sand matrix, pale grey – white – and some red, with some ironstaining

Figure 51: Borrow pit, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
49	Landscape	56	0275889	7008766

Description
Cutting above Location 48 SANDSTONE, fine to coarse grained, pale grey with some red ironstaining, assessed moderately weathered to fresh and medium to high strength, at least 3 joint sets Some interbedded SILTSTONE and CONGLOMERATE: SILTSTONE, pale grey to grey, assessed slightly weathered to fresh and medium strength CONGLOMERATE, fine to coarse gravel and some cobbles in fine to coarse grained sand matrix, pale grey – white – and some red, with some ironstaining

Figure 52: Landscape view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
50	Landscape/Escarpment	56	0276613	7007970

Description
Escarpment

Figure 53: Landscape and escarpment, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
51	Road Cutting	56	0280495	7009229

Description
SANDSTONE, fine to medium grained, pale brown – pale grey – pale orange, assessed moderately to slightly weathered and medium to high strength, massive

Figure 54: Road cutting, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
52	Landscape	56	02881148	7011736

Description
Landscape

Figure 55: Landscape view, to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
53	Road Cutting and Borrow Pit	56	0283201	7012557

Description
SANDSTONE, fine to coarse grained, pale grey with some red ironstaining, assessed moderately weathered to fresh and medium to high strength, at least 3 joint sets

Figure 56: Road cutting and borrow pit, view to North – Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
54	Landscape	56	0286442	7014743

Description
Landscape

Figure 57: Landscape, view to North - Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
55	Landscape	56	0292109	7019199

Description
Landscape

Figure 58: Landscape, view to West - Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
56	Road Drain	56	0286298	7014104

Description
SANDSTONE, fine to medium grained, white – pale grey with some ironstaining, assessed highly weathered and low strength Some interbedded SILTSTONE (possible CLAYSTONE), pale brown – pale grey, assessed highly weathered and very low to low strength

Figure 59: Road drain, view to West - Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
57	Road Cutting	56	0286086	7012128

Description
SANDSTONE, fine to medium grained, pale brown – pale grey – pale orange, assessed moderately to slightly weathered and medium to high strength, massive

Figure 60: Road cutting view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
58	Road	56	0286165	7010037

Description
SANDSTONE, fine to medium grained, pale brown – pale grey – pale orange, assessed moderately to slightly weathered and medium to high strength, massive

Figure 61: Road, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
59	Borrow Pit	56	0285738	7006185

Description
SANDSTONE, fine to medium grained, pale brown – pale grey – pale orange, assessed moderately to slightly weathered and medium to high strength, massive With some CONGLOMERATE, fine to coarse gravel and some cobbles in fine to coarse grained sand matrix, pale grey – white – and some red, with some ironstaining

Figure 62: Borrow pit, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
60	Creek	56	0288215	7003989

Description
SANDSTONE, medium to coarse grained, pale brown – orange – red, assessed highly to slightly weathered and low to high strength, cross bedding, some honeycomb weathering, SANDSTONE only present on east side of creek

Figure 63: Creek embankment, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
61	Road	56	0290434	7003475

Description
SANDSTONE, medium to coarse grained, pale brown – orange – red, assessed highly to slightly weathered and low to high strength, cross bedding, some honeycomb weathering

Figure 64: Road cutting, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
62	Landscape	56	0299159	7001342

Description
Landscape

Figure 65: Landscape, view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
63	Landscape	56	0304518	7000104

Description
Landscape

Figure 66: Landscape view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
64	Landscape	56	0311886	6991578

Description
Landscape

Figure 67: Landscape view to East - Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
65	Road	56	0301335	6971029

Description
No rock observed

Figure 68: Road, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
66	Landscape	56	0311662	6976313

Description
Landscape

Figure 69: Landscape, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
67	Landscape	56	0329280	6981074

Description
Landscape

Figure 70: Landscape, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
68	Landscape	56	0328345	6965570

Description
Landscape

Figure 71: Landscape, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
69	Landscape	56	0316433	6962163

Description
No rock outcrop observed

Figure 72: Landscape, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
70	Borrow Pit and Landscape	56	0317041	6959174

Description
Borrow pit could not be accessed and therefore no material assessment

Figure 73: Borrow pit, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
71	Borrow Pit	56	0316803	6957245

Description
SANDSTONE, fine to medium grained, pale brown – pale grey, some ironstaining, bedding mm scale, assessed moderately to slightly weathered, high strength, at least 3 joint sets Some SILTSTONE, coarse grained, pale grey and brown

Figure 74: Borrow pit, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
72	Creek	56	0322741	6953200

Description
SANDSTONE, fine to medium grained, pale brown – pale grey, some ironstaining, bedding mm scale, assessed moderately to slightly weathered and high strength, at least 3 joint sets

Figure 75: Road cutting, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
73	Landscape	56	0328132	6948454

Description
Landscape

Figure 76: Landscape, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
74	Landscape	56	0337260	6935156

Description
Landscape

Figure 77: Landscape, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
75	Landscape	56	0326080	6908282

Description
Landscape

Figure 78: Landscape, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
76	Landscape	56	0322923	6894199

Description
Landscape

Figure 79: Landscape, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
77	Dam Excavation	56	0323008	6898837

Description
Apparent soil profile

Figure 80: Dam excavation, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
78	Landscape	56	0319393	6898837

Description
Landscape

Figure 81: Landscape, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
79	Road Cutting	56	0313067	6903850

Description
SANDSTONE, medium to coarse grained, pale grey – pale brown with some ironstaining, assessed highly weathered and low strength

Figure 82: Road cutting, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
80 a	Road Cutting	56	0309560	6903955

Description
North – South trending ridgelines approximately 50m wide (East – West) SANDSTONE, medium to coarse grained, orange – pale brown – pale grey, some red, some ironstaining, assessed highly to slightly weathered and low to high strength, bedding apparent at >200mm spacing

Figure 83: Road cutting, view to North - Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
80 b	Road Cutting	56	0309505	6903982

Description
SANDSTONE, medium to coarse grained, orange – pale brown – pale grey, some red, some ironstaining, assessed highly to slightly weathered and low to high strength, bedding apparent at >200mm spacing

Figure 84: Road cutting, view to North

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
80 c	Borrow Pit	56	0309505	6903982

Description
SANDSTONE, medium to coarse grained, orange – pale brown – pale grey, some red, some ironstaining, assessed highly to slightly weathered and low to high strength, bedding apparent at >200mm spacing CONGLOMERATE, fine to coarse gravel, cobble and some boulder sized clasts in a fine to coarse sand sized matrix, pale orange – orange – red - pale brown, assessed highly to slightly weathered and low to high strength

Figure 85: Borrow pit, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
80 c	Borrow Pit	56	0309505	6903982

Description
BRECCIA, fine to coarse gravel, cobble and boulder sized, sub angular to angular clasts in fine to coarse sand sized matrix, dark grey – grey – some red – some pale grey, assessed moderately to slightly weathered and high strength

Figure 86: Breccia, view to South East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
81	Road Cutting	56	0305627	6904479

Description
SANDSTONE, coarse grained, red – orange – pale grey with orange and red ironstaining, assessed highly to moderately weathered and low to medium strength, some honeycomb weathering, cross bedding observed – cm scale Some interbedded SANDSTONE and SILTSTONE SILTSTONE, red – brown – orange with orange and red ironstaining, assessed highly to moderately weathered, very low to low strength, bedding planar and < cm scale

Figure 87: Road cutting, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
82	Landscape – Cliff Face	56	0285952	6897077

Description
Cliff face

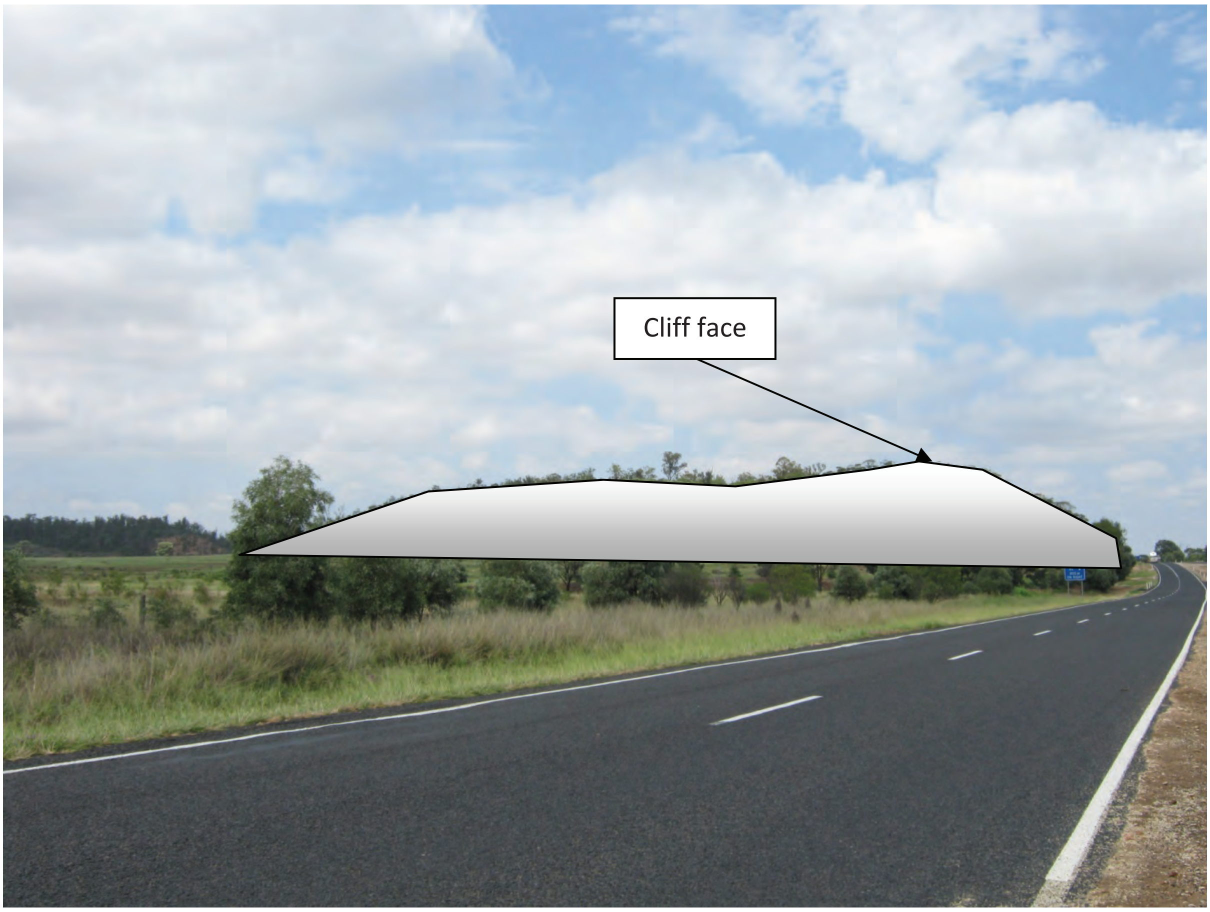


Figure 88: Cliff face, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
83	Road Cutting	56	0205456	6896910

Description
SANDSTONE, fine to medium grained, some coarse grained, pale grey – pale brown – white, some orange ironstaining, assessed highly weathered and low strength, bedding apparent and generally <200mm Extremely weathered material overlying weathered rock, apparent as Clayey SAND, fine to coarse grained, pale grey to orange – brown, low plasticity clay, some fine grained gravel Some Colluvium, apparent as Sandy GRAVEL, fine to coarse grained, pale grey – brown – orange, fine to coarse grained sand, some low plasticity clay, some cobbles, trace boulders

Figure 89: Road cutting, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
84	Landscape	56	0271955	68863432

Description
Landscape

Figure 90: Landscape, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
85	Landscape	56	0251376	6880244

Description
Landscape

Figure 91: Landscape, view to East - Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
86	Creek	56	0269630	6881971

Description
Possible SANDSTONE outcrop

Figure 92: Creek, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
87	Road Cutting	56	0270082	6879543

Description
SANDSTONE, fine to coarse grained, pale grey – pale brown – orange – red, with orange and red ironstaining, assessed highly to moderately weathered and low to high strength, at least 3 joint sets, 300mm – 500mm spacing Some CONGLOMERATE, fine to coarse gravel, some cobbles in fine to coarse sand matrix, pale grey – white – orange – red, with orange and red ironstaining, assessed highly to slightly weathered and low to medium strength

Figure 93: Road cutting, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
88	Borrow Pit	56	0270137	6879588

Description
SANDSTONE, fine to coarse grained, pale grey – pale brown – orange – red, with orange and red ironstaining, assessed highly to moderately weathered and low to high strength, at least 3 joint sets, 300mm – 500mm spacing Some CONGLOMERATE, fine to coarse gravel, some cobbles in fine to coarse sand matrix, pale grey – white – orange – red, with orange and red ironstaining, assessed highly to slightly weathered and low to medium strength

Figure 94: Borrow pit, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
89	Borrow Pit	56	0270634	6875152

Description
SANDSTONE, fine to medium grained, pale grey, with orange and red ironstaining, assessed highly to moderately weathered and low to high strength, at least 3 joint sets, 300mm – 500mm spacing Some CONGLOMERATE, fine to coarse gravel, some cobbles in fine to coarse sand matrix, pale grey – white – orange – red, with orange and red ironstaining, assessed highly to slightly weathered and low to medium strength

Figure 95: Borrow pit, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
90	Borrow Pit	56	0270557	6873682

Description
SANDSTONE, fine to medium grained, pale grey, with orange and red ironstaining, assessed highly to moderately weathered and low to high strength, at least 3 joint sets, 300mm – 500mm spacing Some CONGLOMERATE, fine to coarse gravel, some cobbles in fine to coarse sand matrix, pale grey – white – orange – red, with orange and red ironstaining, assessed highly to slightly weathered and low to medium strength

Figure 96: Borrow pit, view to East - Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
91	Landscape	56	0266205	6863434

Description
Landscape

Figure 97: Landscape view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
92	Landscape	56	0267386	6867465

Description
Landscape

Figure 98: Landscape, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
93	Landscape	56	0276022	6880075

Description
Landscape

Figure 99: Landscape, view to Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
94	Road Drain	56	0278743	6883665

Description
CONGLOMERATE, fine to medium sized gravel, sub rounded to rounded, in fine grained sand sized matrix, some medium to coarse sand sized clasts, pale grey with some orange ironstaining, assessed highly to moderately weathered and very low to medium strength SANDSTONE, fine to medium grained, pale grey – white, assessed highly to moderately weathered and low to medium strength SANDSTONE is dominant lithology, some interbedding, contains some fine grained gravel

Figure 100: Road drain view to North – Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
94	Borrow Pit and Road Drain	56	0278743	6883665

Description
CONGLOMERATE, fine to medium sized gravel, sub rounded to rounded, in fine grained sand sized matrix, some medium to coarse sand sized clasts, pale grey with some orange ironstaining, assessed highly to moderately weathered and very low to medium strength SANDSTONE, fine to medium grained, pale grey – white, assessed highly to moderately weathered and low to medium strength SANDSTONE is dominant lithology, some interbedding, contains some fine grained gravel

Figure 101: Borrow pit, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
95	Creek Crossing	56	0279064	6883094

Description
Heavy rain made road impassable

Figure 102: Creek, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
96	Rock Outcrop	56	0300412	6899443

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey –some red, some orange ironstaining, assessed moderately weathered and medium to high strength Some interbedded CONGLOMERATE horizons <200mm thick CONGLOMERATE, fine to coarse grained gravel, sub rounded to rounded, clasts in fine to coarse sand sized matrix, pale brown – pale grey – white, some red and orange ironstaining, assessed moderately weathered and medium strength

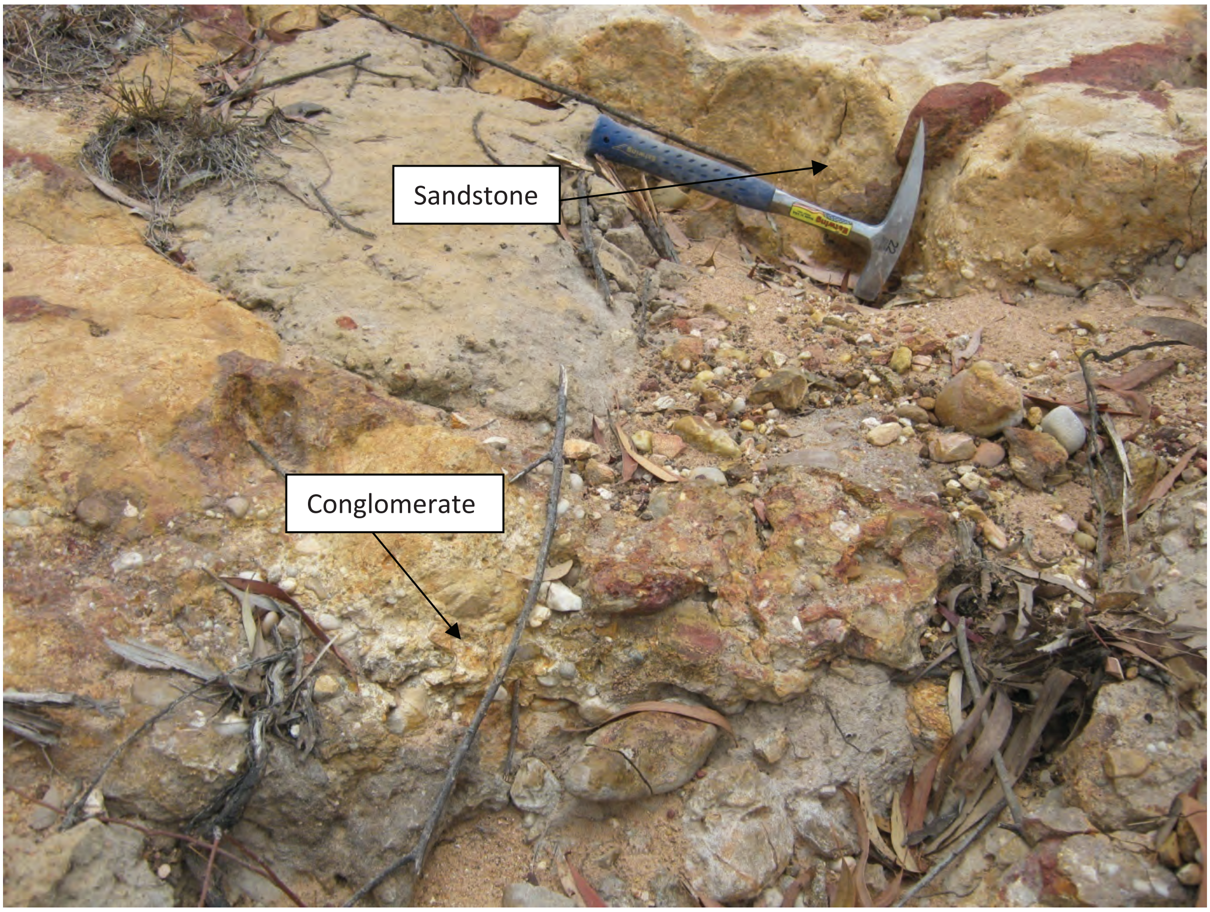


Figure 103: Rock outcrop, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
97	Rock Outcrop	56	0299964	6897948

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey –some red, some orange ironstaining, assessed moderately weathered and medium to high strength

Figure 104: Rock outcrop, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
98	Rock Outcrop	56	0301394	6902650

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey –some red, some orange ironstaining, assessed moderately weathered and medium to high strength, includes some fine clasts

Figure 105: Rock outcrop, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
99	Landscape	56	0301756	6902379

Description
Landscape

Figure 106: Landscape, view to South

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
100	Borrow Pit	56	0302596	6901732

Description
SANDSTONE, medium to coarse grained, pale brown – pale grey –some red, some orange ironstaining, assessed highly to moderately weathered and low to medium strength Some interbedded CONGLOMERATE, fine to coarse gravel, some cobble, some boulder sized clasts, all sub rounded to rounded, in fine to coarse sand sized matrix, pale grey – white – pale brown, some orange and red ironstaining, assessed moderately to slightly weathered and medium to high strength

Figure 107: Borrow pit, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
101	River Crossing	56	0312501	69080174

Description
No rock observed

Figure 108: River crossing, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
102	Landscape	56	0312747	6910464

Description
Landscape

Figure 109: Landscape, view to Northwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
103	Captains Mountain - Basaltic Hill	56	0315070	6909981

Description
Basaltic Hill?

Figure 110: Hill, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
104	Creek Crossing	56	0315267	6909797

Description
SANDSTONE, medium to coarse grained, pale brown, assessed moderately to slightly weathered and medium to high strength, bedding 10mm – 200mm, no joints observed

Figure 111: Creek, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
105	Captains Mountain - Basaltic Hill	56	0319485	6909519

Description
Basaltic Hill?

Figure 112: Hill, view to West

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
106	Captains Mountain - Basaltic Hill	56	0319637	6910905

Description
Basaltic Hill?

Figure 113: Hill, view to Southwest

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
107	Captains Mountain - Basaltic Hill	56	0319728	6910535

Description
Basaltic Hill?

Figure 114: Hill, view to South – Southeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
108	Captains Mountain - ic Hill	56	0322081	6907789

Description
Cliff face

Figure 115: Cliff face, view to Northeast

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
109	Road Cutting	56	0323168	6907430

Description
Basalt cobbles and boulders in soil matrix

Figure 116: Road cutting, view to East

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
PSV1 004	Cuesta			

Description
Cuesta (background) with a plateau-like appearance due to the shallow dip of the strata

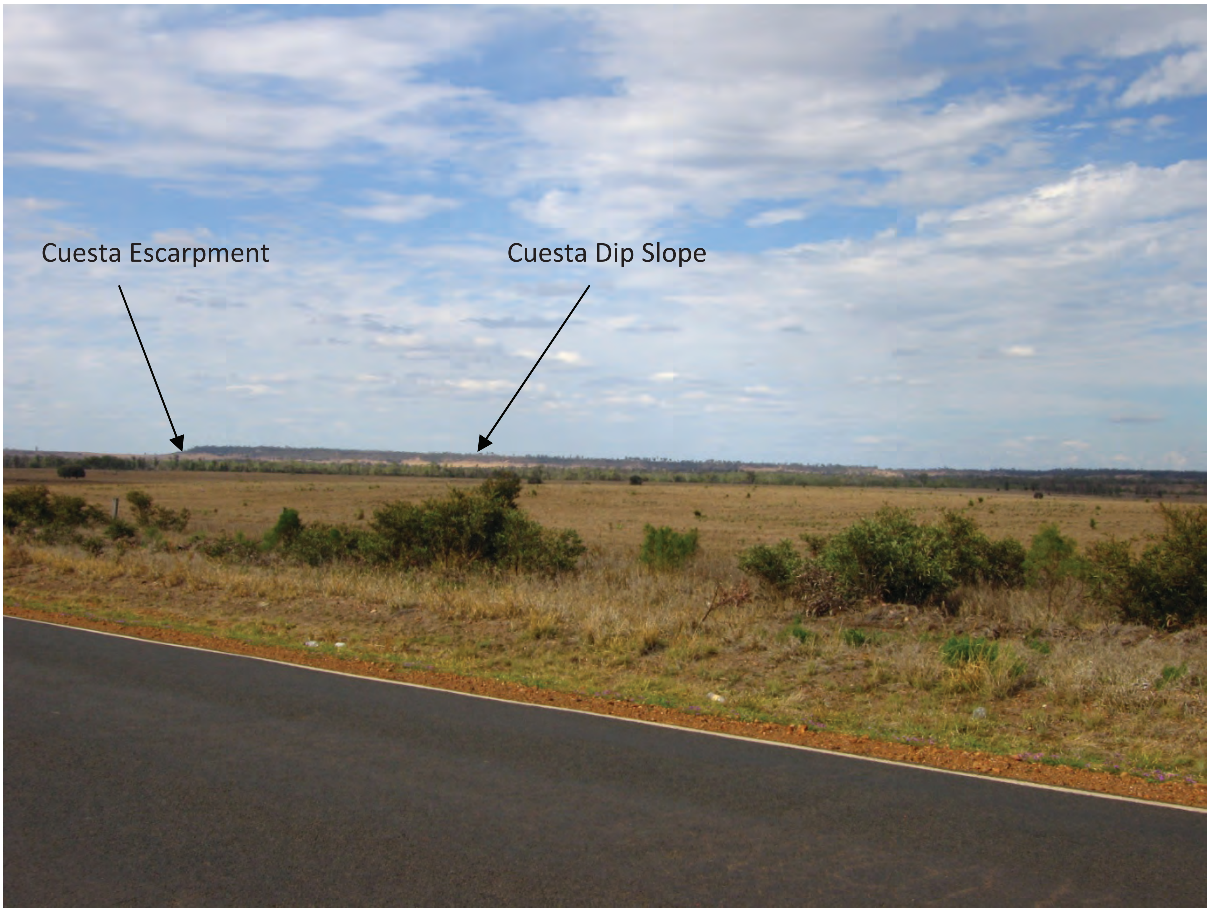


Figure 117

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
PSV1 017	Melonhole gilgai		0234303	7050399

Description
Melonhole gilgai

Figure 218

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
PSV2 005	Creek cut		0316230	6961518

Description
Creek incision exposing dispersive Vertosol profiles.

Figure 319

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
PSV2 005	River channel		0288555	7017083

Description
Incised Condamine River with sandy alluvium base

Figure 420

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP1	Brown Dermosol Profile		0201401	7096770

Description
Test pit excavation exposing Brown Dermosol soil profile (TU IIId; Cheshire LRA soil type)

Figure 521

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP2	Brown Dermosol Profile		0199068	7096534

Description
Test pit excavation exposing Brown Dermosol soil profile (TU Va; Kinnoul LRA soil type)

Figure 622

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP3	Brown Sodosol Profile		0205401	7099375

Description
Test pit excavation exposing Brown Sodosol soil profile (TU IIa; Taurus LRA soil type)

Figure 723

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP4	Grey Vertosol Profile		0234212	7050645

Description
Test pit excavation exposing Grey Vertosol soil profile (TU IIIb; Tara LRA soil type)

Figure 824

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP6	Grey Vertosol Profile		0284766	7023097

Description
Test pit excavation exposing Grey Vertosol soil profile (TU Ia; Condamine LRA soil type)

Figure 925

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP7	Grey Vertosol Profile		0284766	7023097

Description
Test pit excavation exposing Grey Vertosol soil profile (TU IVb; Kupunn LRA soil type)

Figure 1026

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP8	Brown Chromosol Profile		0334207	6973292

Description
Test pit excavation exposing Brown Chromosol soil profile (TU Id; Hazlemere LRA soil type)

Figure 1127

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP9	Brown Sodosol Profile		0334207	6961089

Description
Test pit excavation exposing Brown Sodosol soil profile (TU IVd; Braemar (shallow) LRA soil type)

Figure 1228

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP10	Black Vertosol Profile		0341487	6954231

Description
Test pit excavation exposing Black Vertosol soil profile (TU Ib; Mywybilla LRA soil type)

Figure 1329

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP11	Yellow Chromosol Profile		0314607	6963753

Description
Test pit excavation exposing Yellow Chromosol soil profile (TU IVa; Cutthroat LRA soil type)

Figure 1430

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP12	Red Chromosol Profile		0320595	6935155

Description
Test pit excavation exposing Red Chromosol soil profile (TU IIb; Leyburn LRA soil type)

Figure 1531

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP13	Black Vertosol Profile		0324439	6935557

Description
Test pit excavation exposing Black Vertosol soil profile (TU Ia; Condamine LRA soil type)

Figure 1632

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP15	Yellow Tenosol Profile		0270731	6858413

Description
Test pit excavation exposing Yellow Tenosol soil profile (TU IIb; Marella LRA soil type)

Figure 1733

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP16	Grey Vertosol Profile		0275688	6857279

Description
Test pit excavation exposing Grey Vertosol soil profile (TU IIIb; Calingunee LRA soil type)

Figure 1834

Location ID	Feature/Exposure Type	Location Co-ordinates		
		Zone	Easting	Northing
CTP17	Grey Vertosol Profile		0266038	6861232

Description
Test pit excavation exposing Red Sodosol soil profile (TU Ila; Murra Cul Cul LRA soil type)

Figure 1935

Appendix C

Test Pit Logs and Field/Laboratory Testing Results

Environmental Field Log - Test Pit

Excavation No.	TP1	Sheet	1 of 1				
Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	30/11/2009		
Site Address:	*Burunga Lane*			Date completed:	30/11/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	2 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 7096786	Easting	201401	GPS datum	UTM 56	Orientation:	
Landform	Gently undulating rises	Site disturbance	extensively disturbed; cleared for agriculture; soil tilled				
Soil surface condition	friable	Vegetation	exotic pasture				

Profile Morphology

A	0-0.31 m	Dark Brown (Moist); medium clay; Strong angular blocky structure; Some roots; cracks present <5 mm; Gradual change to:
B2-1	0.31-0.85 m	Brown; medium clay; strong subangular blocky structure; some coarse sand; sand content increasing with depth; Gradual change to
B2-2	0.85-2.0 m	Yellow; sandy clay; sub angular blocky structure;

end of excavation 2.0 m

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Environmental Field Log - Test Pit

Excavation No. TP2

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	30/11/2009		
Site Address:	*Burunga Lane*			Date completed:	30/11/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	2 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 7096045	Easting	799210	GPS datum	UTM 55	Orientation:	

Landform	open depression	Site disturbance	extensively disturbed; cleared for agriculture; soil tilled
Soil surface condition	thin surface crust	Vegetation	exotic pasture

Profile Morphology

A	0-0.08 m	Dark Brown (Moist); fine sandy clay loam; sub angular blocky structure; Some roots; cracks present <5 mm; Clear change to:
B2-1	0.08-0.3 m	Dark brown; light clay; strong sub angular blocky structure; many cracks; highly plastic;clear change to:
B2-2	0.3-1.4 m	Red Brown; sandy clay; sub angular blocky structure; some soft carbonate nodules; strong red mottles increases with depth. Gradual change to:
	1.4-2.5 m	Pale brown; clay loam; sub angular blocky structure; red and orange mottles.

end of excavation 2.5 m

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Environmental Field Log - Test Pit

Excavation No. TP3

Sheet 1 of 1

Client:	Arrow Energy				Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*				Date started:	30/11/2009		
Site Address:	*Burunga Lane*				Date completed:	30/11/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	2 m long	0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 205401		Easting	7099375	GPS datum	UTM 56	Orientation:	
Landform	crest		Site disturbance	extensively disturbed; cleared for agriculture; soil tilled				
Soil surface condition	thin surface crust		Vegetation	exotic pasture				

Profile Morphology

A	0-0.08 m	Pale brown; fine sandy clay loam; moderate sub anfular blocky structure; surface crust of ~ 5mm; high root content; clear change to:
B2-1	0.08-0.6 m	Dark Brown; medium clay; strong angular blocky structure; some soft carbonate nodules present; some cracks <5mm; gradual change to:
B2-2	0.6-1.05 m	Brown; medium clay; moderate columnar structure; gradual change to:
	1.05-2.2m	Pale brown; sandy clay; sub angular blocky structure; some coarse sand content

end of excavation 2.2 m

Environmental Field Log - Test Pit

Excavation No.	TP4	Sheet	1	of	1

Client:	Arrow Energy	Project No.	ENAUBRIS07040AC
Project:	*Surat Gas Field Project*	Date started:	30/11/2009
Site Address:	*Burunga Lane*	Date completed:	30/11/2009

Equipment Type:	*12 T excavator*	Pit Dimensions	*3* m long	0.5 m wide		Logged by:	CM	Checked by:	
GPS Co-ord:	Northing:	234212	Easting	70550645	GPS datum	UTM 56		Orientation:	

Landform	melonhole gilgai	Site disturbance	extensively disturbed; cleared for agriculture;
Soil surface condition	weak self mulching	Vegetation	exotic pasture

Profile Morphology

A	0-0.65 m	Black; heavy clay; sub angular blocky structure; many cracks >5mm; weak self mulching soil surface gradual change to:
B2-1	0.65-2.2 m	Grey; heavy clay; coarse angular blocky structure; many cracks >5mm; slickensides present; moist at depth;

end of excavation 2.2 m

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Environmental Field Log - Test Pit

Excavation No. TP6

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	01/12/2009		
Site Address:	*Burunga Lane*			Date completed:	01/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 276537	Easting	7023693	GPS datum	UTM 56	Orientation:	

Landform	flat	Site disturbance	extensively disturbed; cleared for agriculture;
Soil surface condition	self mulching	Vegetation	cropping

Profile Morphology

A	0-0.05 m	Greyish brown; medium clay; crumb structure; self mulching soil surface; clear change to:
B2-1	0.05-0.25 m	Greyish brown; medium clay; angular blocky structure; many cracks >5mm; clear change to:
	0.25-1.7 m	Brown; heavy clay; lenticular structure; slickensides; clear roots channels with iron staining present; many cracks; clear change to;
	1.7-2.1 m	Dark brown; heavy clay; well structured; some soft carbonate segregations.

end of excavation 2.1m

Environmental Field Log - Test Pit

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Excavation No.	TP7	Sheet	1 of 1				
Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	01/12/2009		
Site Address:	*Burunga Lane*			Date completed:	01/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 204522	Easting	7024960	GPS datum	UTM 56	Orientation:	
Landform	flat	Site disturbance	extensively disturbed; cleared for agriculture;				
Soil surface condition	self mulching	Vegetation	cropping				

Profile Morphology

A	0-0.08 m	Brown; light clay; weak sub angular blocky structure; weakly self-mulching; some gravel on soil surface; abrupt change to:
B2-1	0.09-0.55 m	Greyish brown; medium clay; strong angular blocky structure; some coarse sand content; some soft carbonate segregations; many roots and root channels; cracks >5mm; clear change to:
	0.55-0.9 m	Brown; medium clay; lenticular structure; some gravel content; some soft carbonate segregations; feruginous coatings in cracks; gradual change to:
	0.9-2.3 m	Dark brown; medium heavy clay; lenticular structure; some soft carbonate segregations.

end of excavation 2.3 m

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Environmental Field Log - Test Pit

Excavation No.	TP8
Sheet	1 of 1

Client:	Arrow Energy	Project No.	ENAUBRIS07040AC
Project:	*Surat Gas Field Project*	Date started:	01/12/2009
Site Address:	*Burunga Lane*	Date completed:	01/12/2009

Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 332003	Easting	6973546	GPS datum	UTM 56	Orientation:	

Landform	flat	Site disturbance	extensively disturbed; cleared for agriculture;
Soil surface condition	hardsetting	Vegetation	mixed pasture

Profile Morphology

A	0-0.05 m	Brown; sandy clay loam; massive; hardsetting; abrupt change to:
B2-1	0.05-0.16 m	Dark brown; medium clay; strong coarse blocky structure; some coarse sand; clear change to:
	0.16-2 m	Reddish brown; medium clay; dinstinct orange mottling; moderate angular blocky structure; some soft calcareous nodules; some manganese nodules.

end of excavation 2.0 m

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Environmental Field Log - Test Pit

Excavation No. **TP9**

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	01/12/2009		
Site Address:	*Burunga Lane*			Date completed:	01/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 324363	Easting	6960043	GPS datum	UTM 56	Orientation:	
Landform	flat	Site disturbance	extensively disturbed; cleared for agriculture;				
Soil surface condition	loose gravel with ferrugionous coating on surface	Vegetation	mixed pasture				

Profile Morphology

A	0.0-0.5	Greyish brown; sandy loam; massive; contains ravel with ferriginous surface coating; clear change to:
B2-1	0.05-0.2 m	Reddish Brown; fine sandy loam; massive structure; conspiciously bleached; contains gravel with ferriginous surface coating; sharp change to:
	0.2-1.3 m	Yellow; sandy clay; some grey mottling; columar structure; clay content increasing with depth; gradual change to:
	1.3-1.8 m	whiteish yellow; sandy clay; massive; some fragments of weathered sandstone

end of excavation 1.8 m

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Environmental Field Log - Test Pit

Excavation No. TP10

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	01/12/2009		
Site Address:	*Burunga Lane*			Date completed:	01/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 340889	Easting	6955180	GPS datum	UTM 56	Orientation:	
Landform	flat	Site disturbance	extensively disturbed; lazer levelled, irrigated				
Soil surface condition	self mulching	Vegetation	cropping				

Profile Morphology

A	0-0.6 m	brownish black; medium clay; granular structure; self mulching; abrupt change to:
B2-1	0.6-1.7 m	black; heavy clay; lenticular structure; some medium soft carbonate nodules, slickensides present; cracks >5mm, gradual change to:
	1.7-2.1 m	Grey; some brown mottling; medium heavy clay; strong lenticular structure; cracks throughout; many soft carbonate nodules.

end of excavation 2.1 m

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Environmental Field Log - Test Pit

Excavation No.	TP11	Sheet 1 of 1	
Client:	Arrow Energy	Project No.	ENAUBRIS07040AC
Project:	*Surat Gas Field Project*	Date started:	02/12/2009
Site Address:	*Burunga Lane*	Date completed:	02/12/2009

Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long	0.5 m wide	Logged by: CM	Checked by:	
GPS Co-ord:	Northing: 314158	Easting	6962252	GPS datum	UTM 56	Orientation:	

Landform	midslope	Site disturbance	vegetation cleared; site deep ripped
Soil surface condition	hard setting surface	Vegetation	native vegetation regrowth

Profile Morphology

A	0-0.18 m	Brown; fine sandy loam; massive; some gravel with ferrugionous coatings; hard setting; clear change to:
B2-1	0.18-0.55 m	Pale brownish yellow; fine sandy clay loam; conpicuously bleached; weak sub angular blocky structure; some gravel; abrupt change to:
	0.55-0.7 m	Pale grey; loose; very fine gravelly; some ferriginous coatings on gravel; subrounded gravel; clear change to:
	0.7-1.12 m	Brown; red and yellow mottling; sandy clay; weaky blocky structure; some gravel; gradual change to:
	1.12-1.30 m	Weathered sandstone.

end of excavation 1.3 m

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Environmental Field Log - Test Pit

Excavation No. **TP12**

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	02/12/2009		
Site Address:	*Burunga Lane*			Date completed:	02/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	*3* m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 320444	Easting	6935335	GPS datum	UTM 56	Orientation:	

Landform	midslope	Site disturbance	vegetation cleared; site deep ripped
Soil surface condition	hard setting surface	Vegetation	mixed pasture

Profile Morphology

A	0.15-0.44 m	Yellowish brown; fine sandy loam; weak subangular blocky structure; harsetting surface; clear change to:
B2-1	0.44-0.92 m	Pale yellowish brown; fine sandy loam; weak subangular blocky structure; conspicouously bleached; clear change to:
	0.92-1.65 m	Brown; sandy clay; moderate angular blocky structure; gradual change to:
	1.65-1.8 m	Brown; medium clay; some weather sandstone fragments.

end of excavation 1.8 m

Environmental Field Log - Test Pit

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Excavation No. TP13

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC
Project:	*Surat Gas Field Project*			Date started:	02/12/2009
Site Address:	*Burunga Lane*			Date completed:	02/12/2009
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by: CM	Checked by:
GPS Co-ord:	Northing: 323712	Easting	6936775	GPS datum UTM 56	Orientation:
Landform	open depression; near condamine river banks	Site disturbance	cultivation, irrigated, lazer levelled		
Soil surface condition	self mulching	Vegetation	cropping		

Profile Morphology

A	0-0.35 m	Black; medium clay; strong angular blocky structure; some coarse sand wash on surface; many cracks; contains some ferriginous coated gravel; clear change to:
B2-1	0.35-1.28 m	Brown; light clay; strong angular bolocky structure; many cracks >5mm; contains soft carbonate nodules; many cracks .5mm; some manganese nodules; some compaction evident; clear change to:
	1.28-1.55 m	Yellow; coarse sand; very coarse appears to be depositional; clear change to:
	1.55-2.0 m	Grey; medium clay; strong angular blocky structure; slickensides present; some yellow mottling; damp at depth;

end of excavation 2.0 m

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Environmental Field Log - Test Pit

Excavation No. TP14

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	02/12/2009		
Site Address:	*Burunga Lane*			Date completed:	02/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 323712	Easting	6936775	GPS datum	UTM 56	Orientation:	

Landform	Alluvial plains; flat	Site disturbance	cultivation, irrigated, lazer levelled
Soil surface condition	self mulching	Vegetation	cropping

Profile Morphology

A	0-0.1m	Brownish black; medium clay; self mulching; crumb structure; gradual change to:
B2-1	0.1-1.8 m	Black; medium heavy clay; strong angular blocky structure; many cracks >5mm; slickensides present; gradual change to:
	1.8-2.15 m	Brown; light clay; fine subangular blocky structure; some soft carbonate nodules; some manganese nodules; slickensides; some cracks >5mm.

end of excavation 2.15m

Environmental Field Log - Test Pit

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Excavation No. TP15

Sheet 1 of 1

Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	03/12/2009		
Site Address:	*Burunga Lane*			Date completed:	03/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 271077	Easting	6858577	GPS datum	UTM 56	Orientation:	

Landform	flat; alluvial fan	Site disturbance	cleared; pasture; cutivated at some stage
Soil surface condition	surface crust	Vegetation	native grasses

Profile Morphology

A	0.0-0.44 m	Yellowish brown; loamy sand; apedal; massive, contains many roots; gradual change to:
B2-1	0.44-0.92 m	Pale yellow; sand; bleached; apedal; massive; clear change to:
	0.92-2.1 m	Reddish yellow; clayey sand; apedal; massive; clay content increasing with depth; gradual change to:
	2.1-2.4 m	Grey; sandy clay; many yellow and red mottles; weak subangular blocky structure.

end of excavation 2.4m

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Environmental Field Log - Test Pit

Excavation No.	TP16	Sheet	1	of	1		
Client:	Arrow Energy			Project No.	ENAUBRIS07040AC		
Project:	*Surat Gas Field Project*			Date started:	03/12/2009		
Site Address:	*Burunga Lane*			Date completed:	03/12/2009		
Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 275581	Easting	6857628	GPS datum	UTM 56	Orientation:	
Landform	flat; alluvial plain	Site disturbance	cultivation; rainfed				
Soil surface condition	surface crust	Vegetation	cropping				

Profile Morphology

A	0-0.05 m	Brown; medium clay; massive; some coarse sand content on surface; weak surface crust; clear change to:
B2-1	0.05-0.89 m	Brownish black; medium clay; well structured subangular blocky; many cracks > 5mm, some soft carbonate nodules; slickensides; clear change to:
	0.89-1.43 m	Brown; many grey mottles; medium clay; strong angular blocky structure, many cracks > 5mm, many soft carbonate nodules; clickensides; gradual change to:
	1.43-2.1 m	Grey; sandy clay; many yellow and red mottles; weak subangular blocky structure.

end of excavation 2.1m

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Environmental Field Log - Test Pit

Excavation No.	TP17
Sheet	1 of 1

Client:	Arrow Energy	Project No.	ENAUBRIS07040AC
Project:	*Surat Gas Field Project*	Date started:	03/12/2009
Site Address:	*Burunga Lane*	Date completed:	03/12/2009

Equipment Type:	*12 T excavator*	Pit Dimensions	3 m long 0.5 m wide	Logged by:	CM	Checked by:	
GPS Co-ord:	Northing: 266038	Easting	6861232	GPS datum	UTM 56	Orientation:	

Landform	undulating	Site disturbance	cleared; pasture; cutivated at some stage
Soil surface condition	surface crust	Vegetation	pasture

Profile Morphology

A	0.0.08 m	Pale red; fine sandy loam; massive; thick surface crust; clear change to:
B2-1	0.08-1.23 m	reddish brown; medium clay; stong sub angular blocky structure; many red mottles; many cracks and old root channels evident; some mangaese nodules; clear change to:
	1.23-1.960 m	Brown; sandy clay; strong subangular blocky structure; many grey and red mottles; some soft calcium carbonate nodules; some manganese nodules.

end of excavation 1.96m

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47 Doggett Street Newstead QLD 4006
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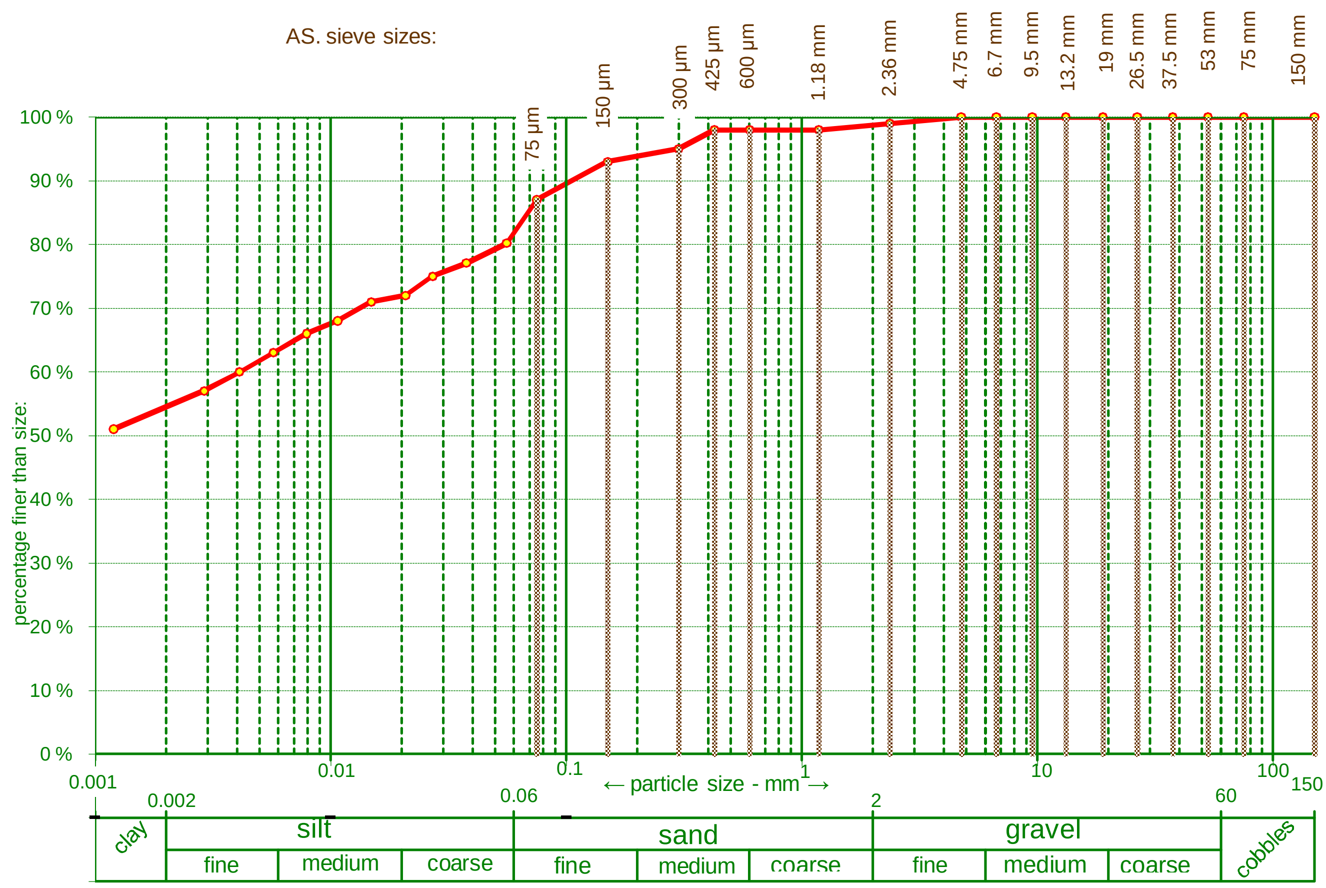
ABN: 92 114 364 046

PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	*NATURAL SYSTEMS (NSYSBRIS0704AA)*	Job No:	*INFONEWS00178AA*
Principal:	*ARROW ENERGY PTY LTD*	Laboratory:	*NEWSTEAD*
Project:	*SURAT BASIN*	Report Date	*21-Jan-10*
Location:	*DALBY, QLD*	Test report No:	*NEWS09W00827*
Test procedure:	*AS1289.3.6.1, 3.62*	Depth:	*@ 1 m*
Sample No:	*NEWS09S- 3136*		
Sample Identification:	*CTP1 _1.0*		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	**% Passing**	**Particle Size µm**	**% Passing**
75	*100*	*55.9*	*80*
53	*100*	*37.7*	*77*
37.5	*100*	*27.1*	*75*
26.5	*100*	*20.8*	*72*
19	*100*	*14.9*	*71*
13.2	*100*	*10.7*	*68*
9.5	*100*	*7.9*	*66*
6.7	*100*	*5.7*	*63*
4.75	*100*	*4.1*	*60*
2.36	*99*	*2.9*	*57*
1.18	*98*	*1.2*	*51*
600 µm	*98*		
425 µm	*98*		
300 µm	*95*		
150 µm	*93*		
75 µm	*87*		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03136 (WAT).xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory: *Chris Park*

Date: *21 January 10*

Newstead, Brisbane Laboratory

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: CBR:NEWS09S-03136
Issue No: 1

California Bearing Ratio Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

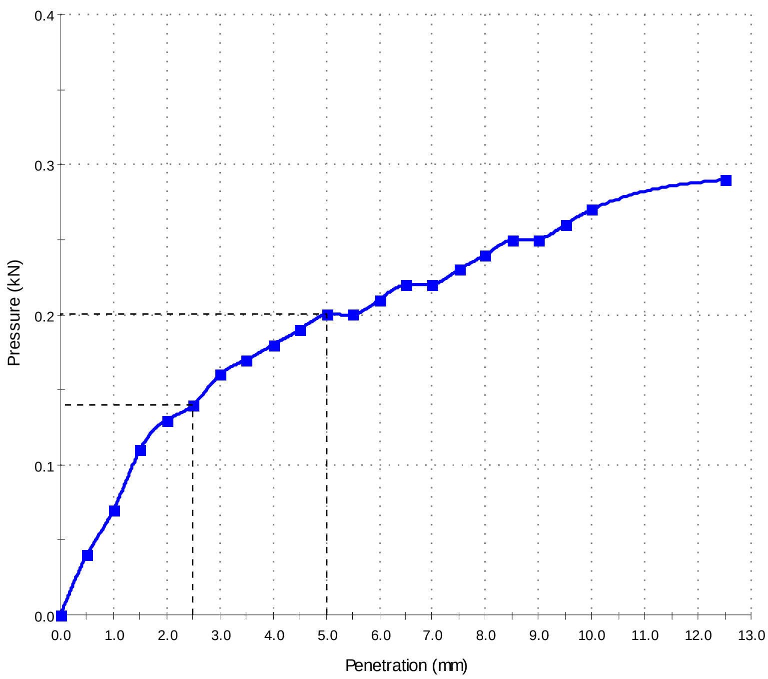
Sample Details

Product:	In situ	**Date Sampled:**	30/11/2009
Source:	On site	**Sampling Method:**	Submitted by client
Location:	Dalby, QLD	**Sample ID:**	NEWS09S-03136
Client Ref:	CTP1_1.0		

Test Results

Description	Result
Test Method	AS 1289.6.1.1
Maximum Dry Density (t/m³)	1.630
Optimum Moisture Content (%)	20.9
CBR 2.5mm (%)	**1.1**
CBR 5.0mm (%)	1.0
Preparation	Soaked
Initial Moisture Content (%)	21.2
Achieved Dry Density (t/m³)	1.580
Achieved Moisture Content (%)	21.2
Swell (%)	5.5
Period of Soaking (days)	4
Moisture Content of Top 30mm (%)	36.4
Moisture of Penetrated End (%)	36.4
Compaction Type	Standard
Surcharge Mass (kg)	4.50
Laboratory Moisture Ratio After Compaction (%)	102
Laboratory Density Ratio After Compaction (%)	97
Oversize Material	Excluded
Oversize Material (%)	0.0
Rate of Penetration	1.0

Chart



CBR (%): 1.1

Comments

N/A

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03136
Issue No: 1

Material Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03136
Field Sample:	CTP1_1.0
Date Sampled:	30/11/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #1 @1.0m

Other Test Results

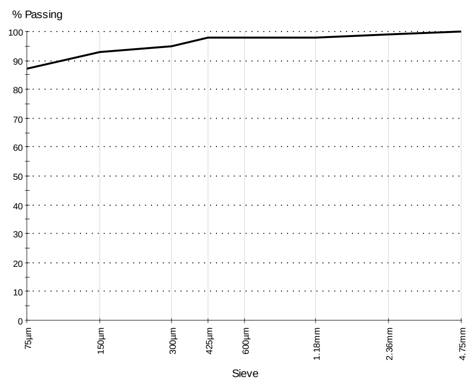
Description	Method	Result	Limits
CBR At 2.5 (%)	AS 1289.6.1.1	**1.0**	
Maximum Dry Density (t/m³)		1.63	
Optimum Moisture Content (%)		20.9	
Dry Density before Soaking (t/m³)		1.58	
Density Ratio before Soaking (%)		97	
Moisture Content before Soaking (%)		21.2	
Moisture Ratio before Soaking (%)		102	
Dry Density after Soaking (t/m³)		1.50	
Density Ratio after Soaking (%)		92	
Swell (%)		5.5	
Moisture Content of Top 30mm (%)		36.4	
Moisture Content of Remaining Depth (%)		36.4	
Compactive Effort		Standard	
Surcharge Mass (kg)		4.50	
Period of Soaking (Days)		4	
Oversize Material		Excluded	
Oversize Material (%)		0.0	
Standard Maximum Dry Density (t/m³)	AS 1289.5.1.1	1.63	
Standard Optimum Moisture Content (%)		21.0	
Retained Sieve 19mm (%)		0	
Sample History	AS 1289.1.1	Air-dried	
Preparation	AS 1289.1.1	Dry Sieved	
Linear Shrinkage (%)	AS 1289.3.4.1	18.0	
Mould Length (mm)		249.5	
Crumbling		No	
Curling		No	
Liquid Limit (%)	AS 1289.3.1.1	59	
Method		Four Point	
Plastic Limit (%)	AS 1289.3.2.1	20	
Plasticity Index (%)	AS 1289.3.3.1	39	

Particle Size Distribution

Method:	AS 1289.3.6.1
Drying by:	Oven
Note:	Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	99	
1.18mm	98	
600µm	98	
425µm	98	
300µm	95	
150µm	93	
75µm	87	

Chart



Comments

N/A

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03136
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03136
Field Sample: CTP1_1.0
Date Sampled: 30/11/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #1
@1.0m

Other Test Results

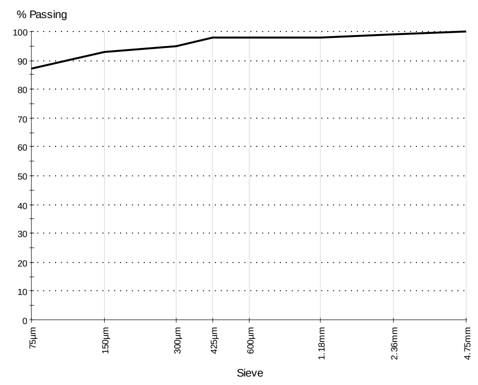
Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	
Moisture Content (%)	AS 1289.2.1.1	9.5	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	99	
1.18mm	98	
600µm	98	
425µm	98	
300µm	95	
150µm	93	
75µm	87	

Chart



Comments

N/A

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Report No: MAT:NEWS09S-03137
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03137
Field Sample: CTP3_0.5
Date Sampled: 30/11/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #3 @0.5m

Other Test Results

Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	

Particle Size Distribution

Method:

Drying by:
Date Tested:

Sieve Size	% Passing	Limits

Chart

Comments

N/A

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Report No: MAT:NEWS09S-03138
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03138
Field Sample: CTP3_1.5
Date Sampled: 30/11/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #3
@1.5m

Other Test Results

Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 1	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	

Particle Size Distribution

Method:
Drying by:
Date Tested:

Sieve Size	% Passing	Limits

Chart

Comments

N/A

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03139
Issue No: 1

Material Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

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Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03139
Field Sample:	CTP7_0.5
Date Sampled:	01/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #7 @0.5m

Other Test Results

Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 3	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	

Particle Size Distribution

Method:

Drying by:
Date Tested:

Sieve Size	% Passing	Limits

Chart

Comments

N/A

Newstead, Brisbane Laboratory

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: CBR:NEWS09S-03140
Issue No: 1

California Bearing Ratio Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

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NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

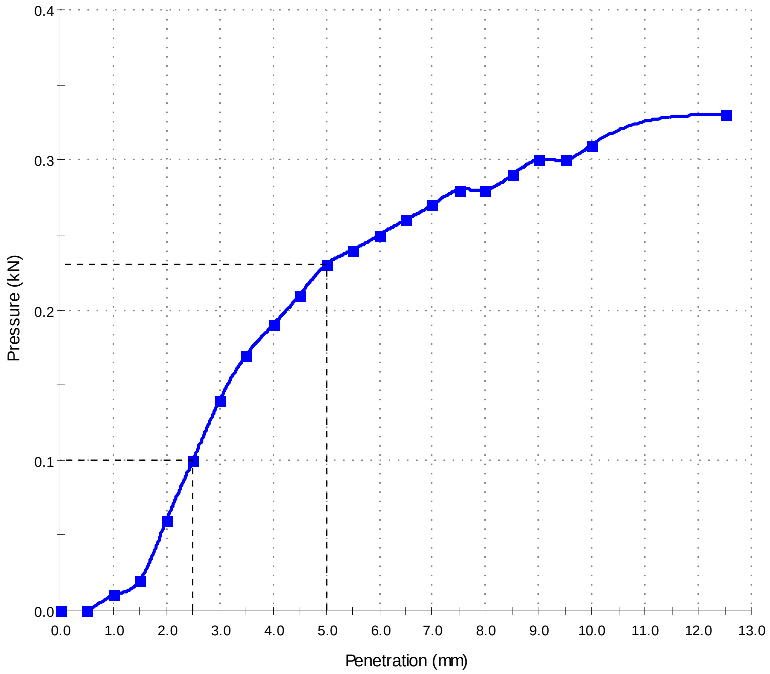
Sample Details

Product:	In situ	**Date Sampled:**	1/12/2009
Source:	On site	**Sampling Method:**	Submitted by client
Location:	Dalby, QLD	**Sample ID:**	NEWS09S-03140
Client Ref:	CTP10_1.0		

Test Results

Description	Result
Test Method	AS 1289.6.1.1
Maximum Dry Density (t/m³)	1.340
Optimum Moisture Content (%)	30.8
CBR 2.5mm (%)	0.8
CBR 5.0mm (%)	**1.2**
Preparation	Soaked
Initial Moisture Content (%)	31.4
Achieved Dry Density (t/m³)	1.288
Achieved Moisture Content (%)	31.4
Swell (%)	9.9
Period of Soaking (days)	4
Moisture Content of Top 30mm (%)	54.8
Moisture of Penetrated End (%)	54.8
Compaction Type	Standard
Surcharge Mass (kg)	4.50
Laboratory Moisture Ratio After Compaction (%)	102
Laboratory Density Ratio After Compaction (%)	96
Oversize Material	Excluded
Oversize Material (%)	0.0
Rate of Penetration	1.0

Chart



CBR (%): 1.2

Comments

N/A

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coffey information
SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03140
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

NATA WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03140
Field Sample: CTP10_1.0
Date Sampled: 01/12/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #10
0.6m - 2.1m

Other Test Results

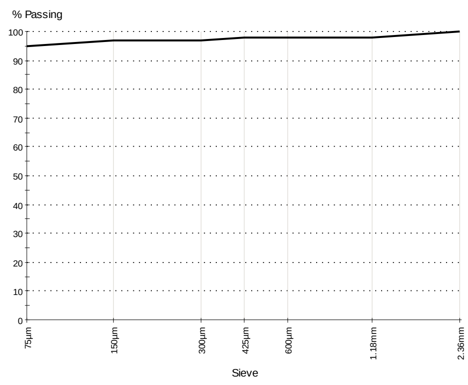
Description	Method	Result	Limits
CBR At 5.0 (%)	AS 1289.6.1.1	**1.0**	
Maximum Dry Density (t/m³)		1.34	
Optimum Moisture Content (%)		30.8	
Dry Density before Soaking (t/m³)		1.29	
Density Ratio before Soaking (%)		96	
Moisture Content before Soaking (%)		31.4	
Moisture Ratio before Soaking (%)		102	
Dry Density after Soaking (t/m³)		1.17	
Density Ratio after Soaking (%)		87	
Swell (%)		10.0	
Moisture Content of Top 30mm (%)		54.8	
Moisture Content of Remaining Depth (%)		54.8	
Compactive Effort		Standard	
Surcharge Mass (kg)		4.50	
Period of Soaking (Days)		4	
Oversize Material		Excluded	
Oversize Material (%)		0.0	
Sample History	AS 1289.1.1	Air-dried	
Preparation	AS 1289.1.1	Dry Sieved	
Linear Shrinkage (%)	AS 1289.3.4.1	25.0	
Mould Length (mm)		250	
Crumbling		No	
Curling		No	
Liquid Limit (%)	AS 1289.3.1.1	104	
Method		Four Point	
Plastic Limit (%)	AS 1289.3.2.1	39	
Plasticity Index (%)	AS 1289.3.3.1	65	
Standard Maximum Dry Density (t/m³)	AS 1289.5.1.1	1.34	
Standard Optimum Moisture Content (%)		31.0	
Retained Sieve 19mm (%)		0	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
2.36mm	100	
1.18mm	98	
600µm	98	
425µm	98	
300µm	97	
150µm	97	
75µm	95	

Chart



Comments

N/A

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Material Test Report

Report No: MAT:NEWS09S-03140
Issue No: 1

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

NATA WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03140
Field Sample: CTP10_1.0
Date Sampled: 01/12/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #10
0.6m - 2.1m

Other Test Results

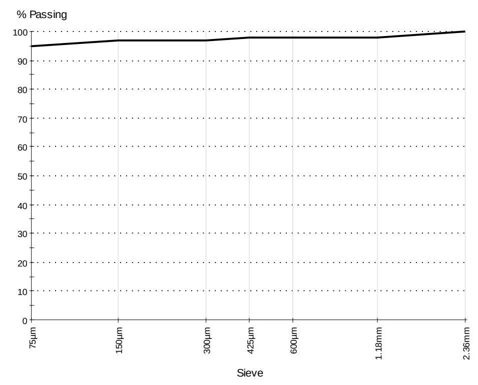
Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	
Moisture Content (%)	AS 1289.2.1.1	22.4	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
2.36mm	100	
1.18mm	98	
600µm	98	
425µm	98	
300µm	97	
150µm	97	
75µm	95	

Chart



Comments

N/A

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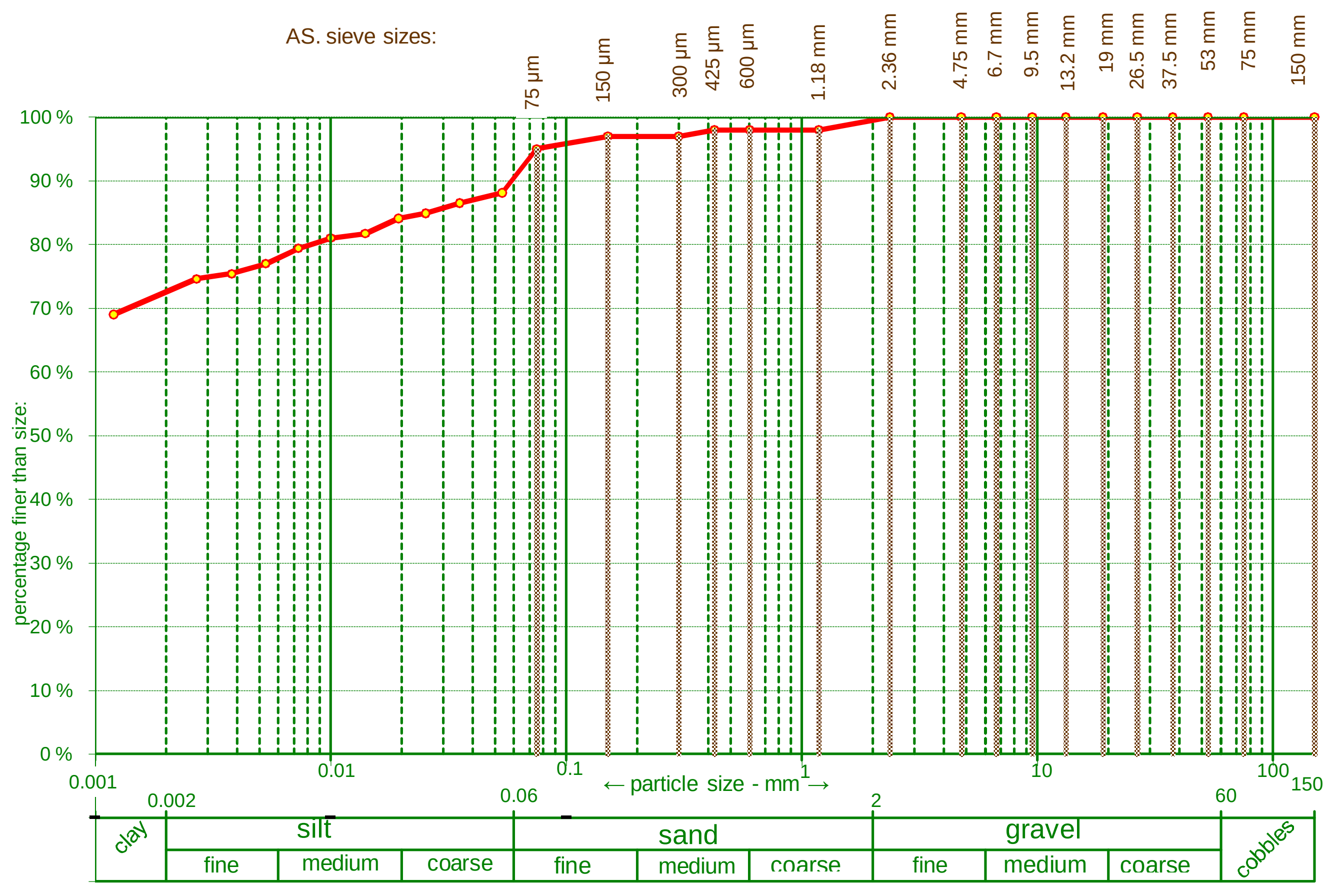
ABN: 92 114 364 046

PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	NATURAL SYSTEMS (NSYSBRIS0704AA)	Job No:	INFONEWS00178AA
Principal:	ARROW ENERGY PTY LTD	Laboratory:	NEWSTEAD
Project:	SURAT BASIN	Report Date	21-Jan-10
Location:	DALBY, QLD	Test report No:	NEWS09W00827
Test procedure:	AS1289.3.6.1, 3.62	Depth:	0.6 - 1.7 m
Sample No:	NEWS09S- 3140		
Sample Identification:	CTP10 _1.0		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	% Passing	Particle Size µm	% Passing
75	100	53.5	88
53	100	35.3	87
37.5	100	25.3	85
26.5	100	19.4	84
19	100	14.0	82
13.2	100	10.0	81
9.5	100	7.3	79
6.7	100	5.3	77
4.75	100	3.8	75
2.36	100	2.7	75
1.18	98	1.2	69
600 µm	98		
425 µm	98		
300 µm	97		
150 µm	97		
75 µm	95		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03140 (WAT).xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory: Chris Park
Date: 21 January 10

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: CBR:NEWS09S-03141
Issue No: 1

California Bearing Ratio Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

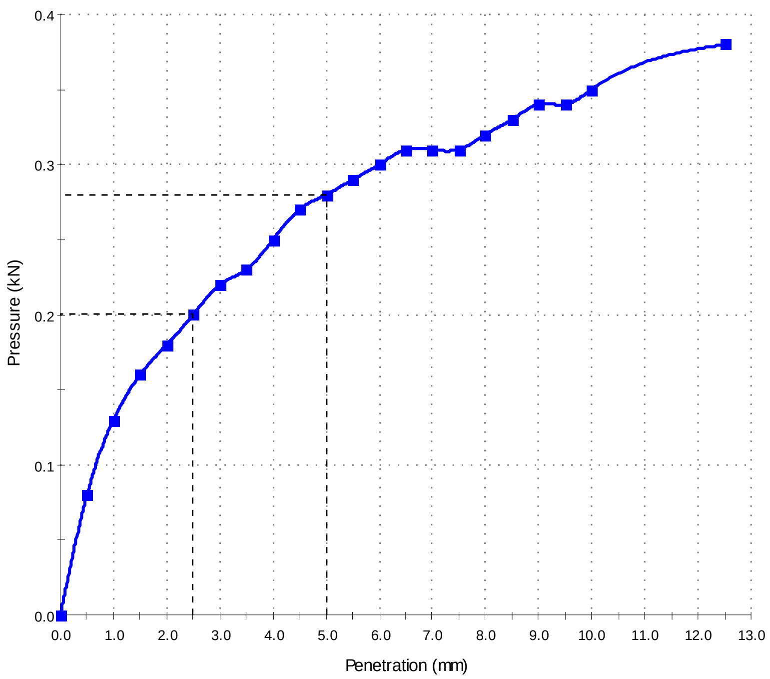
Sample Details

Product:	In situ	**Date Sampled:**	2/12/2009
Source:	On site	**Sampling Method:**	Submitted by client
Location:	Dalby, QLD	**Sample ID:**	NEWS09S-03141
Client Ref:	CTP11_1.0		

Test Results

Description	**Result**
Test Method	AS 1289.6.1.1
Maximum Dry Density (t/m³)	1.860
Optimum Moisture Content (%)	13.7
CBR 2.5mm (%)	**1.5**
CBR 5.0mm (%)	1.4
Preparation	Soaked
Initial Moisture Content (%)	12.1
Achieved Dry Density (t/m³)	1.863
Achieved Moisture Content (%)	12.1
Swell (%)	1.8
Period of Soaking (days)	4
Moisture Content of Top 30mm (%)	18.5
Moisture of Penetrated End (%)	18.5
Compaction Type	Standard
Surcharge Mass (kg)	4.50
Laboratory Moisture Ratio After Compaction (%)	89
Laboratory Density Ratio After Compaction (%)	100
Oversize Material	Excluded
Oversize Material (%)	0.0
Rate of Penetration	1.0

Chart



CBR (%): 1.5

Comments

N/A

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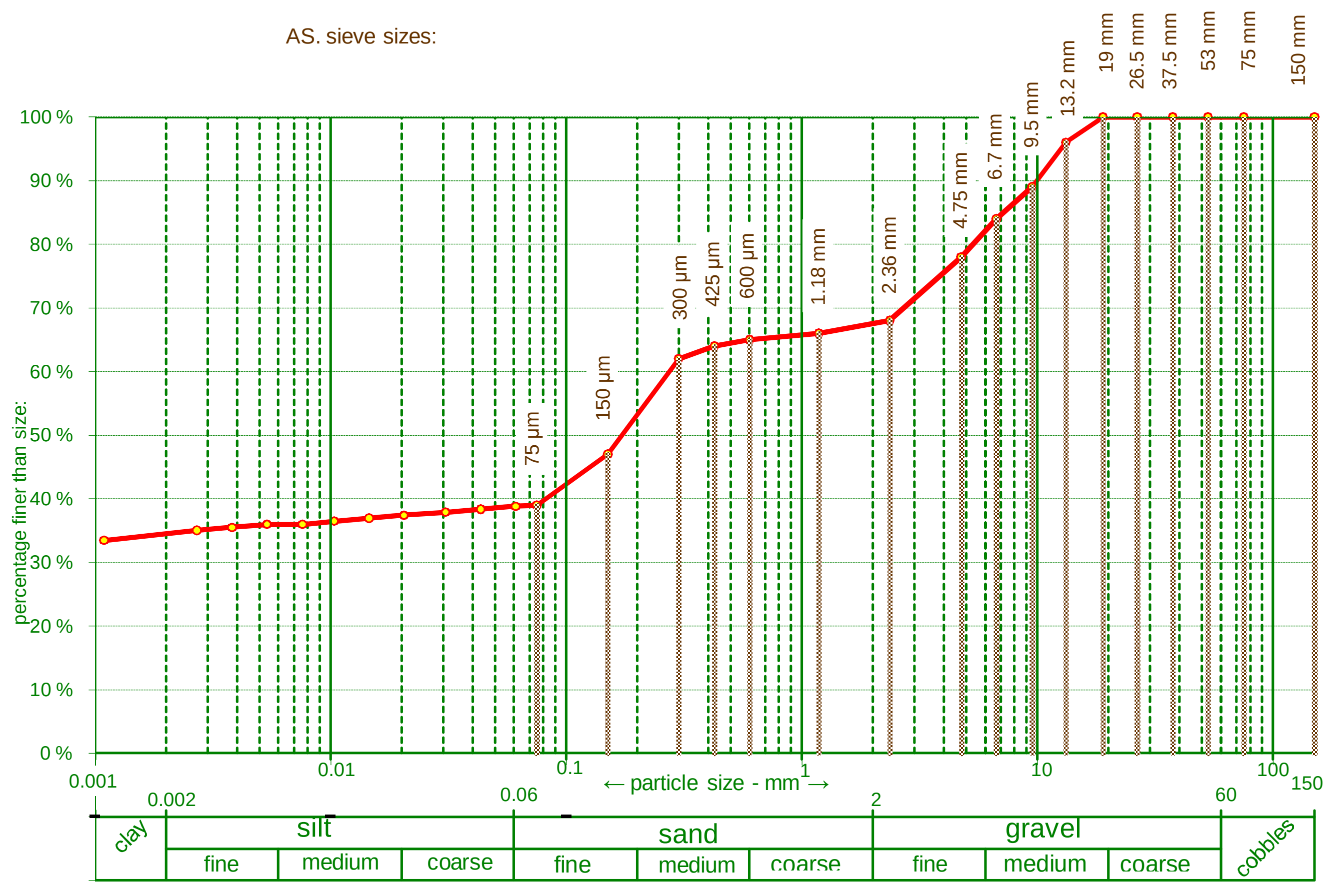
PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	NATURAL SYSTEMS (NSYSBRIS0704AA)	Job No:	INFONEWS00178AA
Principal:	ARROW ENERGY PTY LTD	Laboratory:	NEWSTEAD
Project:	SURAT BASIN	Report Date	21-Jan-10
Location:	DALBY, QLD	Test report No:	NEWS09W00827
Test procedure:	AS1289.3.6.1, 3.62	Depth:	0.7 - 1.1 m
Sample No:	NEWS09S- 3141		
Sample Identification:	CTP11 _1.0		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	% Passing	Particle Size µm	% Passing
75	100	60.9	39
53	100	43.3	38
37.5	100	30.7	38
26.5	100	20.5	37
19	100	14.6	37
13.2	96	10.3	36
9.5	89	7.6	36
6.7	84	5.4	36
4.75	78	3.8	36
2.36	68	2.7	35
1.18	66	1.1	33
600 µm	65		
425 µm	64		
300 µm	62		
150 µm	47		
75 µm	39		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03141.xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory: Chris Park
Date: 21 January 10

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03141
Issue No: 1

Material Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

NATA WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03141
Field Sample:	CTP11_1.0
Date Sampled:	02/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #11 0.7 - 1.1m

Other Test Results

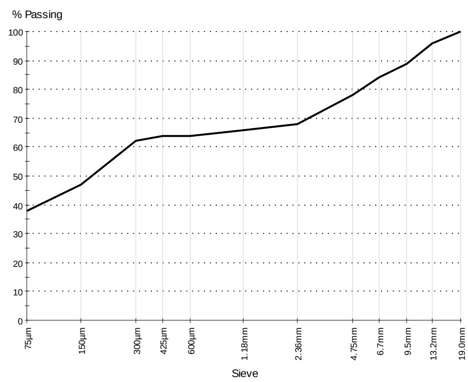
Description	Method	Result	Limits
CBR At 2.5 (%)	AS 1289.6.1.1	**1.5**	
Maximum Dry Density (t/m³)		1.86	
Optimum Moisture Content (%)		13.7	
Dry Density before Soaking (t/m³)		1.86	
Density Ratio before Soaking (%)		100	
Moisture Content before Soaking (%)		12.1	
Moisture Ratio before Soaking (%)		89	
Dry Density after Soaking (t/m³)		1.83	
Density Ratio after Soaking (%)		98	
Swell (%)		2.0	
Moisture Content of Top 30mm (%)		18.5	
Moisture Content of Remaining Depth (%)		18.5	
Compactive Effort		Standard	
Surcharge Mass (kg)		4.50	
Period of Soaking (Days)		4	
Oversize Material		Excluded	
Oversize Material (%)		0.0	
Sample History	AS 1289.1.1	Air-dried	
Preparation	AS 1289.1.1	Dry Sieved	
Linear Shrinkage (%)	AS 1289.3.4.1	12.0	
Mould Length (mm)		249.8	
Crumbling		No	
Curling		No	
Liquid Limit (%)	AS 1289.3.1.1	40	
Method		Four Point	
Plastic Limit (%)	AS 1289.3.2.1	13	
Plasticity Index (%)	AS 1289.3.3.1	27	
Standard Maximum Dry Density (t/m³)	AS 1289.5.1.1	1.86	
Standard Optimum Moisture Content (%)		13.5	
Retained Sieve 19mm (%)		0	

Particle Size Distribution

Method:	AS 1289.3.6.1
Drying by:	Oven
Note:	Sample Washed

Sieve Size	% Passing	Limits
19.0mm	100	
13.2mm	96	
9.5mm	89	
6.7mm	84	
4.75mm	78	
2.36mm	68	
1.18mm	66	
600µm	64	
425µm	64	
300µm	62	
150µm	47	
75µm	38	

Chart



Comments

N/A

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03141
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03141
Field Sample:	CTP11_1.0
Date Sampled:	02/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #11 0.7 - 1.1m

Other Test Results

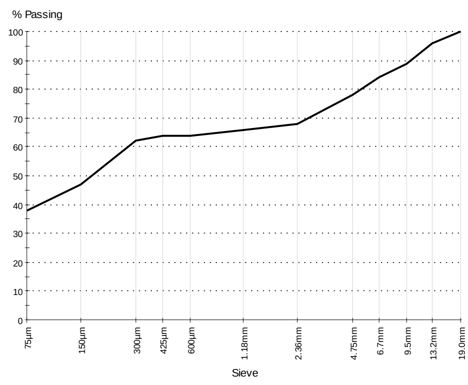
Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	
Moisture Content (%)	AS 1289.2.1.1	5.8	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
19.0mm	100	
13.2mm	96	
9.5mm	89	
6.7mm	84	
4.75mm	78	
2.36mm	68	
1.18mm	66	
600µm	64	
425µm	64	
300µm	62	
150µm	47	
75µm	38	

Chart



Comments

N/A

Newstead, Brisbane Laboratory

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03142
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03142
Field Sample: CTP12_0.5
Date Sampled: 02/12/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP12_0.5

Other Test Results

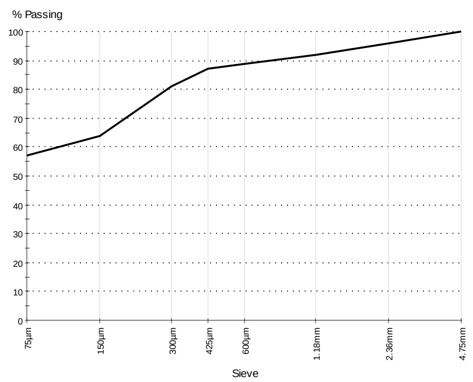
Description	Method	Result	Limits
CBR At 2.5 (%)	AS 1289.6.1.1	**3.5**	
Maximum Dry Density (t/m³)		1.86	
Optimum Moisture Content (%)		13.2	
Dry Density before Soaking (t/m³)		1.83	
Density Ratio before Soaking (%)		98	
Moisture Content before Soaking (%)		12.8	
Moisture Ratio before Soaking (%)		97	
Dry Density after Soaking (t/m³)		1.76	
Density Ratio after Soaking (%)		95	
Swell (%)		4.0	
Moisture Content of Top 30mm (%)		27.4	
Moisture Content of Remaining Depth (%)		27.4	
Compactive Effort		Standard	
Surcharge Mass (kg)		4.50	
Period of Soaking (Days)		4	
Oversize Material		Excluded	
Oversize Material (%)		0.0	
Sample History	AS 1289.1.1	Air-dried	
Preparation	AS 1289.1.1	Dry Sieved	
Linear Shrinkage (%)	AS 1289.3.4.1	12.5	
Mould Length (mm)		249.9	
Crumbling		No	
Curling		No	
Liquid Limit (%)	AS 1289.3.1.1	39	
Method		Four Point	
Plastic Limit (%)	AS 1289.3.2.1	13	
Plasticity Index (%)	AS 1289.3.3.1	26	
Standard Maximum Dry Density (t/m³)	AS 1289.5.1.1	1.86	
Standard Optimum Moisture Content (%)		13.0	
Retained Sieve 19mm (%)		0	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by:
Note: Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	96	
1.18mm	92	
600µm	89	
425µm	87	
300µm	81	
150µm	64	
75µm	57	

Chart



Comments

N/A

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Report No: MAT:NEWS09S-03142
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03142
Field Sample:	CTP12_0.5
Date Sampled:	02/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP12_0.5

Other Test Results

Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	
Moisture Content (%)	AS 1289.2.1.1	4.7	

Particle Size Distribution

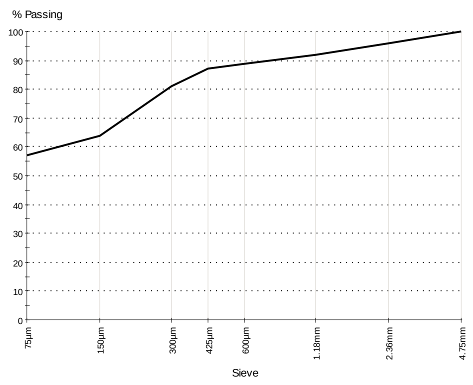
Method: AS 1289.3.6.1

Drying by:

Note: Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	96	
1.18mm	92	
600µm	89	
425µm	87	
300µm	81	
150µm	64	
75µm	57	

Chart



Comments

N/A

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

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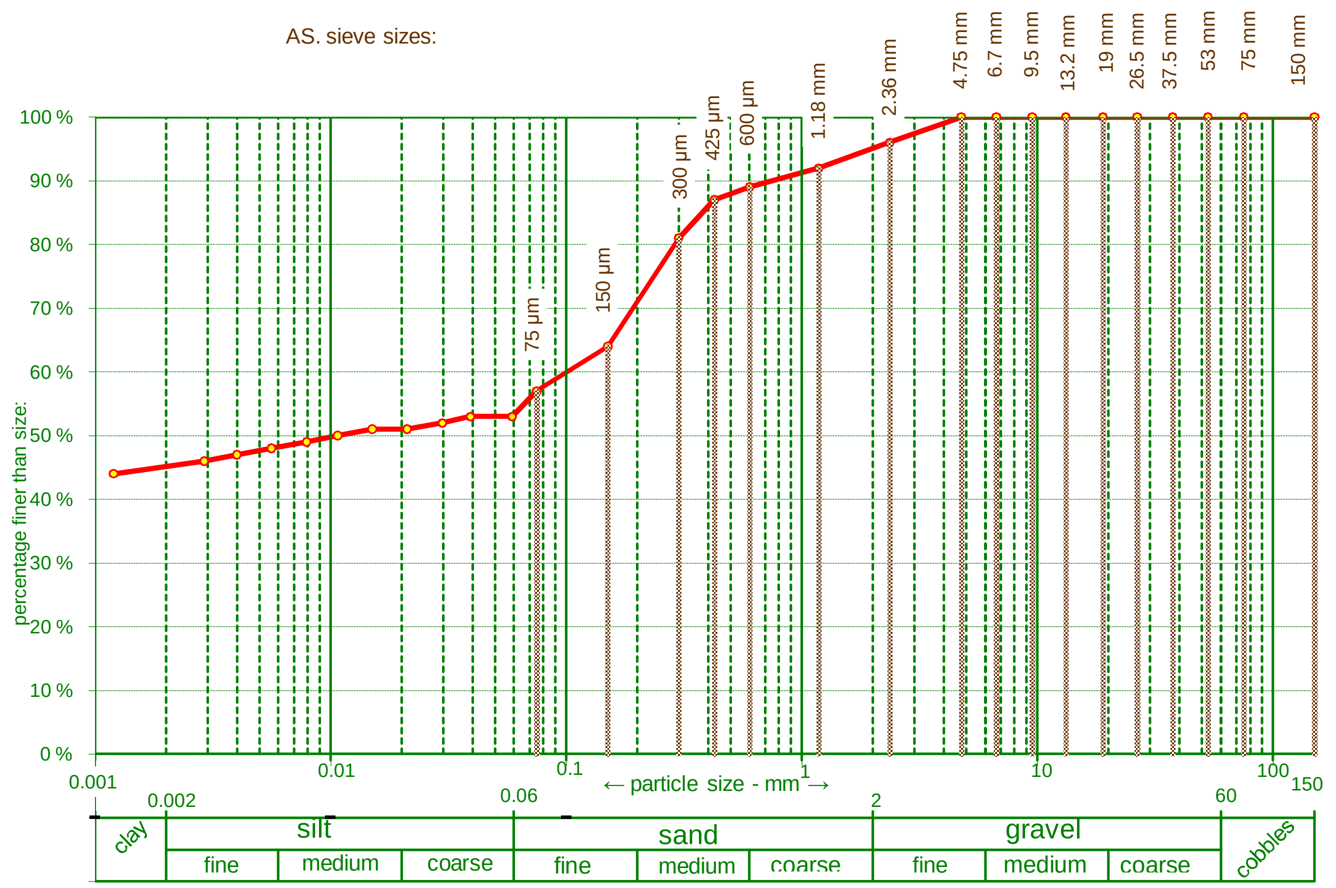
ABN: 92 114 364 046

PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	NATURAL SYSTEMS (NSYSBRIS0704AA)	Job No:	INFONEWS00178AA
Principal:	ARROW ENERGY PTY LTD	Laboratory:	NEWSTEAD
Project:	SURAT BASIN	Report Date	21-Jan-10
Location:	DALBY, QLD	Test report No:	NEWS09W00827
Test procedure:	AS1289.3.6.1, 3.62	Depth:	
Sample No:	NEWS09S- 3142		
Sample Identification:	CTP12 _0.5		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	% Passing	Particle Size µm	% Passing
75	100	59.0	53
53	100	39.2	53
37.5	100	29.8	52
26.5	100	21.1	51
19	100	15.0	51
13.2	100	10.7	50
9.5	100	7.9	49
6.7	100	5.6	48
4.75	100	4.0	47
2.36	96	2.9	46
1.18	92	1.2	44
600 µm	89		
425 µm	87		
300 µm	81		
150 µm	64		
75 µm	57		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03142.xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory:
Chris Park

Date:
21 January 10

Newstead, Brisbane Laboratory

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coffey information
SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: CBR:NEWS09S-03142
Issue No: 1

California Bearing Ratio Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

NATA
WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

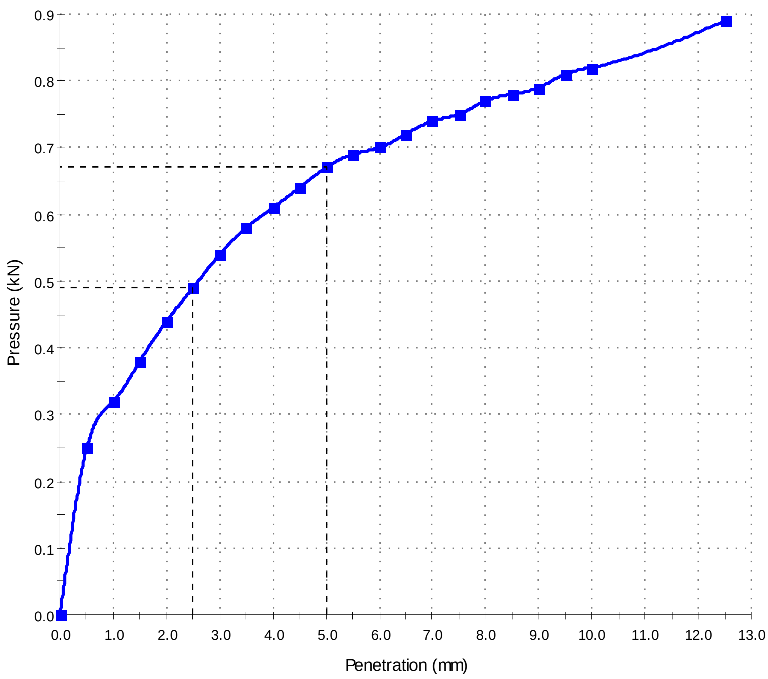
Sample Details

Product:	In situ	**Date Sampled:**	2/12/2009
Source:	On site	**Sampling Method:**	Submitted by client
Location:	Dalby, QLD	**Sample ID:**	NEWS09S-03142
Client Ref:	CTP12_0.5		

Test Results

Description	Result
Test Method	AS 1289.6.1.1
Maximum Dry Density (t/m³)	1.860
Optimum Moisture Content (%)	13.2
CBR 2.5mm (%)	**3.7**
CBR 5.0mm (%)	3.4
Preparation	Soaked
Initial Moisture Content (%)	12.8
Achieved Dry Density (t/m³)	1.830
Achieved Moisture Content (%)	12.8
Swell (%)	4.1
Period of Soaking (days)	4
Moisture Content of Top 30mm (%)	27.4
Moisture of Penetrated End (%)	27.4
Compaction Type	Standard
Surcharge Mass (kg)	4.50
Laboratory Moisture Ratio After Compaction (%)	97
Laboratory Density Ratio After Compaction (%)	98
Oversize Material	Excluded
Oversize Material (%)	0.0
Rate of Penetration	1.0

Chart



CBR (%): 3.7

Comments

N/A

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coffey information
SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03143
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03143
Field Sample: CTP14_0.5
Date Sampled: 02/12/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #14
0.0m - 1.8m

Other Test Results

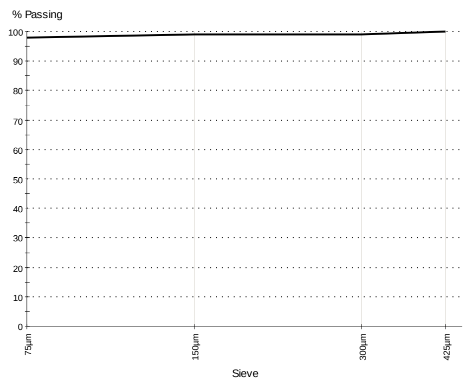
Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 3	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
425µm	100	
300µm	99	
150µm	99	
75µm	98	

Chart



Comments

N/A

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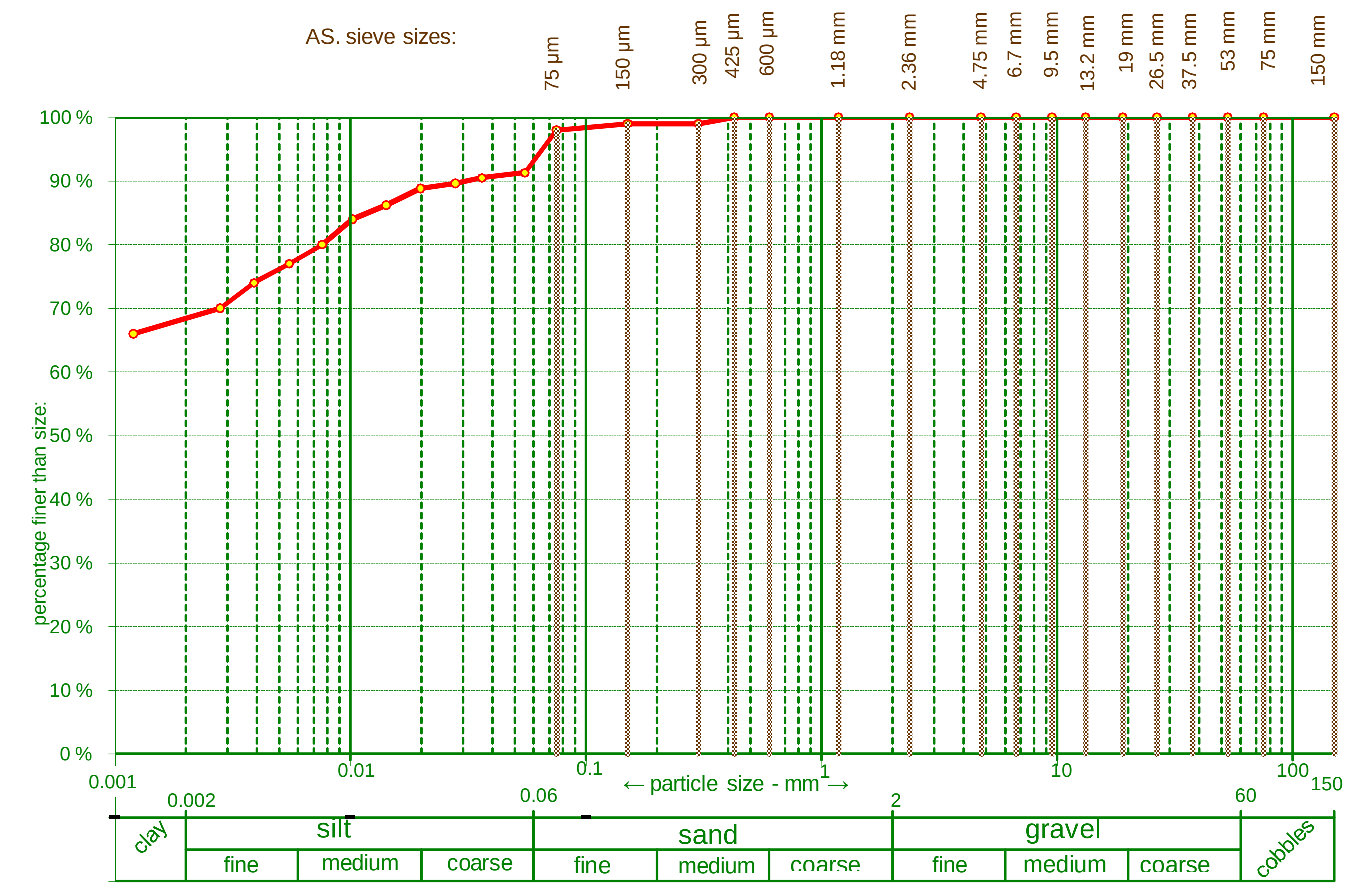
ABN: 92 114 364 046

PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	NATURAL SYSTEMS (NSYSBRIS0704AA)	Job No:	INFONEWS00178AA
Principal:	ARROW ENERGY PTY LTD	Laboratory:	NEWSTEAD
Project:	SURAT BASIN	Report Date	21-Jan-10
Location:	DALBY, QLD	Test report No:	NEWS09W00827
Test procedure:	AS1289.3.6.1, 3.62	Depth:	1.5 - 1.8 m
Sample No:	NEWS09S- 3143		
Sample Identification:	CTP14 _0.5		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	% Passing	Particle Size µm	% Passing
75	100	55.0	91
53	100	36.2	91
37.5	100	27.9	90
26.5	100	19.8	89
19	100	14.2	86
13.2	100	10.2	84
9.5	100	7.6	80
6.7	100	5.5	77
4.75	100	3.9	74
2.36	100	2.8	70
1.18	100	1.2	66
600 µm	100		
425 µm	100		
300 µm	99		
150 µm	99		
75 µm	98		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03143 (WAT).xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory: Chris Park
Date: 21 January 10

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03144
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID: NEWS09S-03144
Field Sample: CTP14_2.0
Date Sampled: 02/12/2009
Source: On site
Material: In situ
Specification: AS Grading
Sampling Method: Submitted by client
Project Location: Dalby, QLD
Sample Location: CTP #14
1.8m - 2.2m

Other Test Results

Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 3	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	

Particle Size Distribution

Method:
Drying by:
Date Tested:

Sieve Size	% Passing	Limits

Chart

Comments

N/A

Newstead, Brisbane Laboratory

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: CBR:NEWS09S-03145
Issue No: 1

California Bearing Ratio Test Report

Client:	Coffey Naturals Systems Pty Ltd Level 21, 12 Creek Street brisbane QLD 4000
Principal:	Arrow Energy Pty Ltd
Project No.:	INFONEWS00178AA
Project Name:	NSYSBRIS07040AA - Surat Basin
Lot No.:	**TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

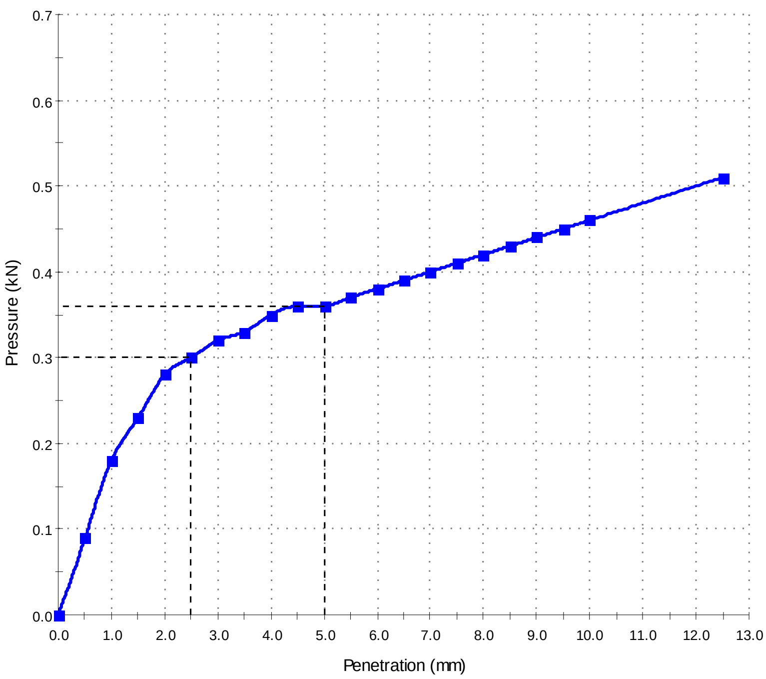
Sample Details

Product:	In situ	**Date Sampled:**	3/12/2009
Source:	On site	**Sampling Method:**	Submitted by client
Location:	Dalby, QLD	**Sample ID:**	NEWS09S-03145
Client Ref:	CTP 16_1.0		

Test Results

Description	Result
Test Method	AS 1289.6.1.1
Maximum Dry Density (t/m³)	1.760
Optimum Moisture Content (%)	15.1
CBR 2.5mm (%)	**2.3**
CBR 5.0mm (%)	1.8
Preparation	Soaked
Initial Moisture Content (%)	14.8
Achieved Dry Density (t/m³)	1.765
Achieved Moisture Content (%)	14.8
Swell (%)	4.4
Period of Soaking (days)	4
Moisture Content of Top 30mm (%)	25.8
Moisture of Penetrated End (%)	25.8
Compaction Type	Standard
Surcharge Mass (kg)	4.50
Laboratory Moisture Ratio After Compaction (%)	98
Laboratory Density Ratio After Compaction (%)	100
Oversize Material	Excluded
Oversize Material (%)	0.0
Rate of Penetration	1.0

Chart



CBR (%): 2.3

Comments

N/A

coffey information
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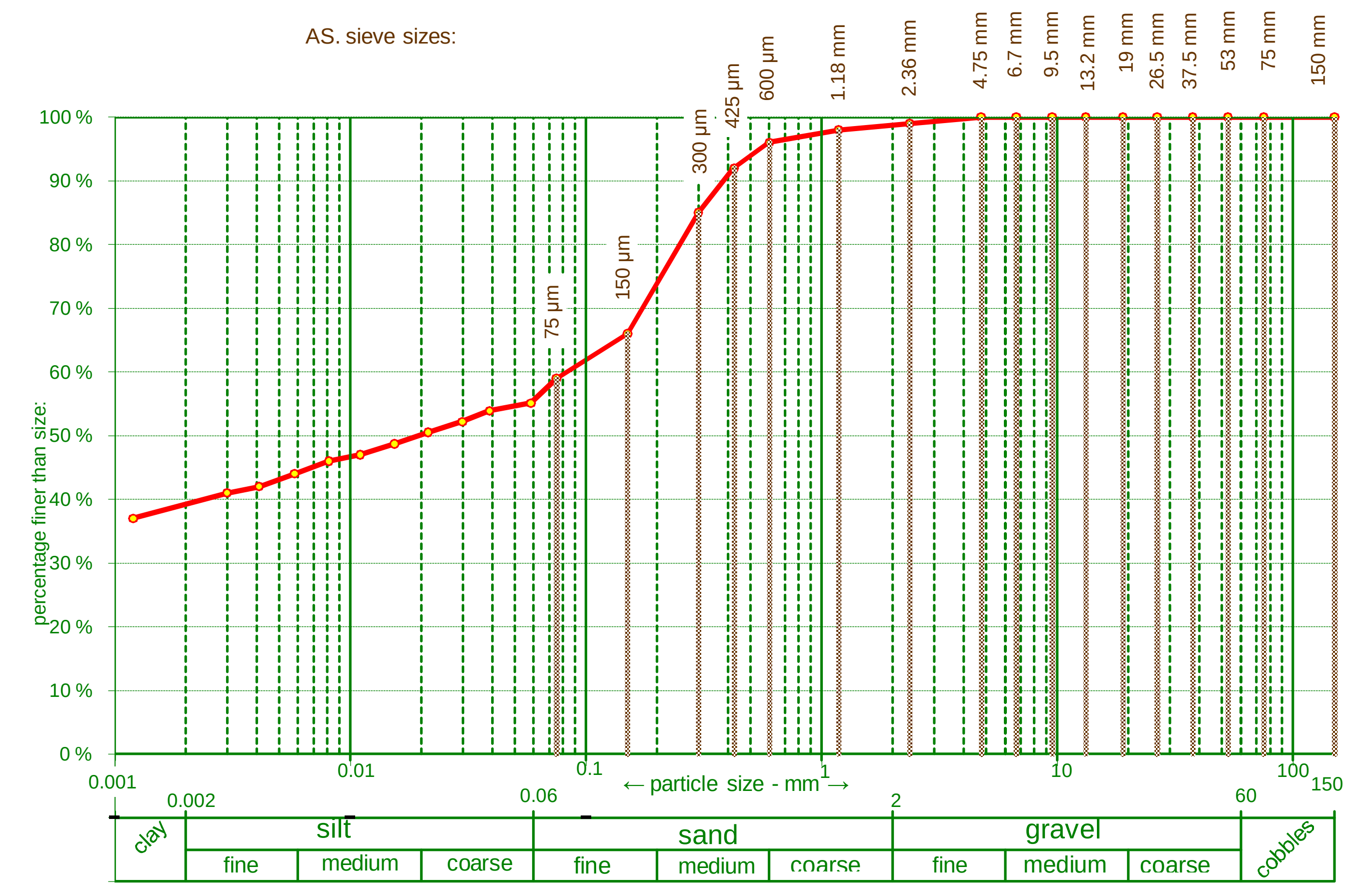
ABN: 92 114 364 046

PARTICLE SIZE DISTRIBUTION & HYDROMETER

Client:	NATURAL SYSTEMS (NSYSBRIS0704AA)	Job No:	INFONEWS00178AA
Principal:	ARROW ENERGY PTY LTD	Laboratory:	NEWSTEAD
Project:	SURAT BASIN	Report Date	21-Jan-10
Location:	DALBY, QLD	Test report No:	NEWS09W00827
Test procedure:	AS1289.3.6.1, 3.62	Depth:	0.8 - 1.4 m
Sample No:	NEWS09S- 3145		
Sample Identification:	CTP16 _1.0		



Sieve Analysis		Hydrometer Analysis	
Sieve Size mm	% Passing	Particle Size µm	% Passing
75	100	58.4	55
53	100	39.0	54
37.5	100	29.9	52
26.5	100	21.4	51
19	100	15.4	49
13.2	100	11.0	47
9.5	100	8.1	46
6.7	100	5.8	44
4.75	100	4.1	42
2.36	99	3.0	41
1.18	98	1.2	37
600 µm	96		
425 µm	92		
300 µm	85		
150 µm	66		
75 µm	59		

Comments

NOTES:

Loss of mass in pretreatment:	No pretreatment.
Dispersion method:	Sodium hexametaphosphate and Sodium carbonate
Type of hydrometer:	Carlton
Soil Particle density:	2.65 g/cm3
Moisture Content (as received)	N.D
N.D. = not determined	N.O.= not obtainable

F:\INFO\JOBS\INFONEWS00178AA\[Arrow Energy Report - 03145.xlsx]Report

NATA Accredited Laboratory No. 431
Approved Signatory: Chris Park
Date: 21 January 10

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03145
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

WORLD RECOGNISED ACCREDITATION

Sample Details

Sample ID:	NEWS09S-03145
Field Sample:	CTP 16_1.0
Date Sampled:	03/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #16 0.8m - 2.1m

Other Test Results

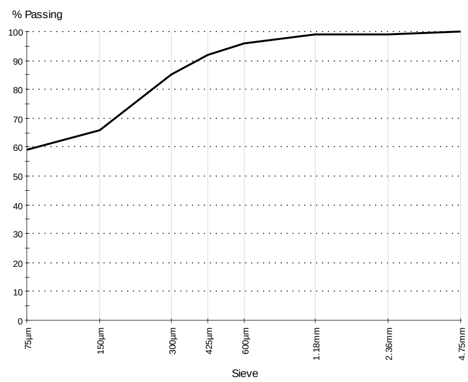
Description	Method	Result	Limits
CBR At 2.5 (%)	AS 1289.6.1.1	**2.5**	
Maximum Dry Density (t/m³)		1.76	
Optimum Moisture Content (%)		15.1	
Dry Density before Soaking (t/m³)		1.76	
Density Ratio before Soaking (%)		100	
Moisture Content before Soaking (%)		14.8	
Moisture Ratio before Soaking (%)		98	
Dry Density after Soaking (t/m³)		1.69	
Density Ratio after Soaking (%)		96	
Swell (%)		4.5	
Moisture Content of Top 30mm (%)		25.8	
Moisture Content of Remaining Depth (%)		25.8	
Compactive Effort		Standard	
Surcharge Mass (kg)		4.50	
Period of Soaking (Days)		4	
Oversize Material		Excluded	
Oversize Material (%)		0.0	
Sample History	AS 1289.1.1	Air-dried	
Preparation	AS 1289.1.1	Dry Sieved	
Linear Shrinkage (%)	AS 1289.3.4.1	16.5	
Mould Length (mm)		253.1	
Crumbling		No	
Curling		No	
Liquid Limit (%)	AS 1289.3.1.1	44	
Method		Four Point	
Plastic Limit (%)	AS 1289.3.2.1	16	
Plasticity Index (%)	AS 1289.3.3.1	28	
Standard Maximum Dry Density (t/m³)	AS 1289.5.1.1	1.76	
Standard Optimum Moisture Content (%)		15.0	
Retained Sieve 19mm (%)		0	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	99	
1.18mm	99	
600µm	96	
425µm	92	
300µm	85	
150µm	66	
75µm	59	

Chart



Comments

N/A

Newstead, Brisbane Laboratory

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SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

Report No: MAT:NEWS09S-03145
Issue No: 1

Material Test Report

Client: Coffey Naturals Systems Pty Ltd
Level 21, 12 Creek Street
brisbane QLD 4000

Principal: Arrow Energy Pty Ltd
Project No.: INFONEWS00178AA
Project Name: NSYSBRIS07040AA - Surat Basin
Lot No.: **TRN:**

NATA
WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Chris Park
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 21/01/2010

Sample Details

Sample ID:	NEWS09S-03145
Field Sample:	CTP 16_1.0
Date Sampled:	03/12/2009
Source:	On site
Material:	In situ
Specification:	AS Grading
Sampling Method:	Submitted by client
Project Location:	Dalby, QLD
Sample Location:	CTP #16 0.8m - 2.1m

Other Test Results

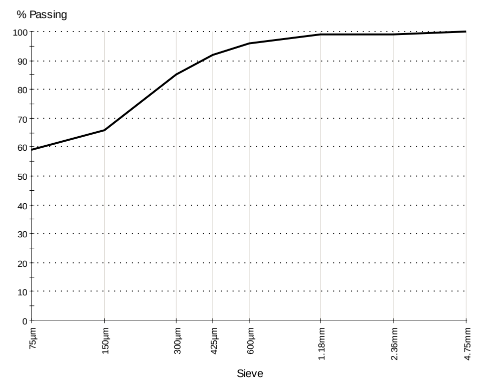
Description	Method	Result	Limits
Emerson Class Number	AS 1289.3.8.1	Class 2	
Soil Description			
Type of Water		Distilled	
Temperature of Water (℃)		22.0	
Moisture Content (%)	AS 1289.2.1.1	7.0	

Particle Size Distribution

Method: AS 1289.3.6.1
Drying by: Oven
Note: Sample Washed

Sieve Size	% Passing	Limits
4.75mm	100	
2.36mm	99	
1.18mm	99	
600µm	96	
425µm	92	
300µm	85	
150µm	66	
75µm	59	

Chart



Comments

N/A

Point Load Strength Index Test Results

Method: AS4133.4.1-1993 inc. Amdt 1 1994

Client: Arrow Energy
Project: Surat Basin Coal Seam Gas
Job No. ENVINEWS08791AA
Office: NEWSTEAD
Location: Surat Basin

Test aparatus:	GSA Bench mounted (E)	
Inst. calibration slope (a):	0.9999	kN/MPa
Inst. calibration intercept (b):	0	kN
Inst. Calibration date	18/07/2008	
Estimated UCS constant (K):	20	x $Is_{(50)}$ = UCS MPa
Date Tested:	Date checked:	
Tested By:	Checked by:	

Strength Classification

$Is_{(50)}$ (MPa)	Class
0 to 0.03	-
0.03 to 0.1	VL
0.1 to 0.3	L
0.3 to 1	M
1 to 3	H
3 to 10	VH
10 or greater	EH

Test Type

A	Axial
D	Diametral
L	Lump/Irregular

Break Type

BB	Bad Break
P	Failure parallel to bedding
D	Failure along defect
S	Failure through substance

Location	Depth	Test Type	platen separation (D) mm	core diameter (dc) mm	sample broken length (L) mm	irregular width (W) mm	instrument failure pressure (Pin) kN	rock type	break type	geometry check L	geometry check W or dc	calibration corrected failure load (P) kN	equivalent diameter (De) mm	raw index (Is)	**Point Load Index $Is_{(50)}$**	Rock Strength Class	Estimated UCS (MPa)
1	N/A	L	29			94	13.35	SANDSTONE		L<D/2	OK	1.64	58.9	0.47	**0.51**	M	10.2
1	N/A	L	40			68	13.35	SANDSTONE		L<D/2	OK	1.23	58.8	0.36	**0.38**	M	7.6
11	N/A	L	41			39	13.35	SANDSTONE		L<D/2	OK	0.68	45.1	0.33	**0.32**	M	6.4
20	N/A	L	36			118	13.35	CONGLOMERATE		L<D/2	OK	15.49	73.5	2.86	**3.41**	VH	68.1
22	N/A	L	52			83	13.35	SILTSTONE		L<D/2	OK	4.96	74.1	0.90	**1.08**	H	21.6
27	N/A	L	40			78	13.35	SANDSTONE		L<D/2	OK	2.94	63.0	0.74	**0.82**	M	16.4
27	N/A	L	65			86	13.35	SANDSTONE		L<D/2	OK	4.41	84.4	0.62	**0.78**	M	15.7
28	N/A	L	26			79	13.35	SANDSTONE		L<D/2	OK	0.30	51.1	0.11	**0.12**	L	2.3
28	N/A	L	47			53	13.35	SANDSTONE		L<D/2	OK	0.94	56.3	0.30	**0.31**	M	6.3
48	N/A	L	42			83	13.35	SANDSTONE		L<D/2	OK	2.52	66.6	0.57	**0.65**	M	12.9
57	N/A	L	42			71	13.35	SANDSTONE		L<D/2	OK	0.30	61.6	0.08	**0.09**	VL	1.7
57	N/A	L	34			75	13.35	SANDSTONE		L<D/2	OK	1.62	57.0	0.50	**0.53**	M	10.6
80	N/A	L	46			105	13.35	SANDSTONE		L<D/2	OK	0.84	78.4	0.14	**0.17**	L	3.3
80	N/A	L	40			75	13.35	SANDSTONE		L<D/2	OK	0.94	61.8	0.25	**0.27**	L	5.4
80	N/A	L	52			122	13.35	SANDSTONE		L<D/2	OK	1.42	89.9	0.18	**0.23**	L	4.6

mgt Environmental

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CERTIFICATE OF ANALYSIS

Coffey Environments Pty Ltd QLD
47 Doggett Street
New Stead
Queensland 4006
Site: ARROW SURAT NSYSBRIS07040AA

Report Number: 257134-A-V1 Page 1 of 17
Order Number:
Date Received: Dec 18, 2009
Date Sampled: Nov 30, 2009
Date Reported: Jan 14, 2010
Contact: Charlotte Moore

Methods

- APHA 5310B Total Organic Carbon
- Method 102 - ANZECC - % Moisture
- APHA 4500 pH by Direct Measurement
- APHA 2510 Conductivity by Direct Measurement
- Acid Sulphate Soils Laboratory Methods Guidelines, Version 2.1

Comments

Notes

Authorised

Report Number: 257134-A-V1

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Senior Principal Chemist
NATA Signatory

Onur Mehmet
Client Manager
NATA Signatory

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Chief Organic Chemist
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Adelaide
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GLOSSARY OF TERMS

UNITS

mg/kg	milligrams per Kilogram	**mg/l**	milligrams per litre
ug/l	micrograms per litre	**ppm**	Parts per million
ppb	Parts per billion	**%**	Percentage
org/100ml	Organisms per 100 millilitres	**NTU**	Units

TERMS

Dry	Where a moisture has been determined on a solid sample the result is expressed on a dry basis.
LOR	Limit of Reporting.
SPIKE	Addition of the analyte to the sample and reported as percentage recovery.
RPD	Relative Percent Difference between two Duplicate pieces of analysis.
LCS	Laboratory Control Sample - reported as percent recovery
CRM	Certified Reference Material - reported as percent recovery
Method Blank	In the case of solid samples these are performed on laboratory certified clean sands. In the case of water samples these are performed on de-ionised water.
Surr - Surrogate	The addition of a like compound to the analyte target and reported as percentage recovery.
Duplicate	A second piece of analysis from the same sample and reported in the same units as the result to show comparison.
Batch Duplicate	A second piece of analysis from a sample outside of the clients batch of samples but run within the laboratory batch of analysis.
Batch SPIKE	Spike recovery reported on a sample from outside of the clients batch of samples but run within the laboratory batch of analysis.
USEPA	United States Environment Protection Authority
APHA	American Public Health Association
ASLP	Australian Standard Leaching Procedure (AS4439.3)
TCLP	Toxicity Characteristic Leaching Procedure
COC	Chain of Custody
SRA	Sample Receipt Advice

QC - ACCEPTANCE CRITERIA

RPD Duplicates	Results <10 times the LOR : No Limit Results between 10-20 times LOR : RPD must lie between 0-50% Results >20 times LOR : RPD must lie between 0-20%
LCS Recoveries	Recoveries must lie between 70-130% - Phenols 30-130%
CRM Recoveries	Recoveries must lie between 70-130% - Phenols 30-130%
Method Blanks	Not to exceed LOR
SPIKE Recoveries	Recoveries must lie between 70-130% - Phenols 30-130%
Surrogate Recoveries	Recoveries must lie between 50-150% - Phenols 20-130%

GENERAL COMMENTS

1. All results in this report supersede any previously corresponded results.
2. All soil results are reported on a dry basis.
3. Samples are analysed on an as received basis.

QC DATA GENERAL COMMENTS

1. Where a result is reported as a less than (<), higher than the nominated LOR this is due to either Matrix Interference, extract dilution required due to interferences or contaminant levels within the sample, high moisture content or insufficient sample provided.
2. Duplicate data shown within this report that states the word "BATCH" is a Batch Duplicate from outside of your sample batch, but within the laboratory sample batch at a 1:10 ratio. The Parent and Duplicate data shown is not data from your samples.
3. Organochlorine Pesticide analysis - where reporting LCS data, Toxaphene & Chlordane are not added to the LCS.
4. Orgaonchlorine Pesticide analysis - where reporting Spike data, Toxaphene is not added to the Spike.
5. Total Recoverable Hydrocarbons - where reporting Spike & LCS data, a single spike of commercial Hydrocarbon products in the range of C12-C30 is added and it's Total Recovery is reported in the C10-C14 cell of the Report.
6. Recovery Data (Spikes & Surrogates) - where chromatographic interference does not allow the determination of Recovery the term "INT" appears against that analyte.
7. Polychlorinated Biphenyls are spiked only using Arochlor 1260 in Matrix Spikes and LCS's.
8. For Matrix Spikes and LCS results a dash "-" in the report means that the specific analyte was not added to the QC sample.
9. Duplicate RPD's are calculated from raw analytical data thus it is possible to have two two sets of data below the LOR with a positive RPD - eg: LOR 0.1, Result A = <0.1 (raw data is 0.02) & Result B = <0.1 (raw data is 0.03) resulting in a RPD of 40% calculated from the raw data.

REPORT SPECIFIC NOTES

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Company Name: Coffey Environments Pty Ltd QLD
Address: 47 Doggett Street, New Stead, Queensland 4006

Order No.:
Report #: 257134
Phone: 07 3608 2500
Fax: 07 3899 9692

Received: Dec 18, 2009 12:00
Due: Dec 25, 2009 04:24
Priority: 5 Day
Contact name: Charlotte Moore

Client Job No.: ARROW SURAT NSYSBRIS07040AA

mgt Client Manager: Onur Mehmet

Sample Detail					% Moisture	Calcium (exchangeable)	Cation Exchange Capacity	Conductivity (1:5 aqueous extract)	Exchangeable Sodium Percentage(ESP)	Magnesium (exchangeable)	pH (1:5 Aqueous extract)	Potassium (exchangeable)	Sodium (exchangeable)	Total Organic Carbon	Chromium Suite
Laboratory where analysis is conducted															
Melbourne Laboratory - NATA Site #1254					X	X	X	X	X	X	X	X	X	X	X
Sydney Laboratory - NATA Site #18217															
Sample ID	**Sample Date**	**Sampling Time**	**Matrix**	**LAB ID**											
CTP1_0.1	Nov 30, 2009		Soil	M09-De06801	X			X			X				
CTP1_0.5	Nov 30, 2009		Soil	M09-De06802	X			X	X		X				
CTP2_0.1	Nov 30, 2009		Soil	M09-De06803	X			X			X				
CTP2_1.0	Nov 30, 2009		Soil	M09-De06804	X	X	X	X	X	X	X	X	X		
CTP3_0.05	Nov 30, 2009		Soil	M09-De06805	X			X			X				
CTP3_0.5	Nov 30, 2009		Soil	M09-De06806	X	X	X	X	X	X	X	X	X	X	X
CTP4_0.5	Nov 30, 2009		Soil	M09-De06807	X			X			X				
CTP4_1.0	Nov 30, 2009		Soil	M09-De06808	X		X	X	X		X				
CTP6_0.1	Dec 01, 2009		Soil	M09-De06809	X			X			X				
CTP6_1.0	Dec 01, 2009		Soil	M09-De06810	X	X	X	X	X	X	X	X	X		

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Laboratory where analysis is conducted															
Melbourne Laboratory - NATA Site #1254					X	X	X	X	X	X	X	X	X	X	X
Sydney Laboratory - NATA Site #18217															
Sample ID	**Sample Date**	**Sampling Time**	**Matrix**	**LAB ID**											
CTP7_0.1	Dec 01, 2009		Soil	M09-De06811	X			X			X				
CTP7_0.6	Dec 01, 2009		Soil	M09-De06812	X	X	X	X	X	X	X	X	X		
CTP8_0.1	Dec 01, 2009		Soil	M09-De06813	X			X			X				
CTP8_1.0	Dec 01, 2009		Soil	M09-De06814	X	X	X	X	X	X	X	X	X		
CTP9_0.1	Dec 01, 2009		Soil	M09-De06815	X			X			X				
CTP9_0.5	Dec 01, 2009		Soil	M09-De06816	X	X	X	X	X	X	X	X	X		
CTP10_0.1	Dec 01, 2009		Soil	M09-De06817	X			X			X				
CTP10_1.0	Dec 01, 2009		Soil	M09-De06818	X			X	X		X			X	
CTP11_0.1	Dec 02, 2009		Soil	M09-De06819	X			X			X				
CTP11_0.3	Dec 02, 2009		Soil	M09-De06820	X	X	X	X	X	X	X	X	X		X

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Sample Detail					% Moisture	Calcium (exchangeable)	Cation Exchange Capacity	Conductivity (1:5 aqueous extract)	Exchangeable Sodium Percentage(ESP)	Magnesium (exchangeable)	pH (1:5 Aqueous extract)	Potassium (exchangeable)	Sodium (exchangeable)	Total Organic Carbon	Chromium Suite
Laboratory where analysis is conducted															
Melbourne Laboratory - NATA Site #1254					X	X	X	X	X	X	X	X	X	X	X
Sydney Laboratory - NATA Site #18217															
Sample ID	**Sample Date**	**Sampling Time**	**Matrix**	**LAB ID**											
CTP12_0.1	Dec 02, 2009		Soil	M09-De06822	X			X			X				
CTP12_0.6	Dec 02, 2009		Soil	M09-De06823	X	X	X	X	X	X	X	X	X		
CTP13_0.1	Dec 02, 2009		Soil	M09-De06824	X			X			X				
CTP13_1.3	Dec 02, 2009		Soil	M09-De06825	X			X	X		X				
CTP14_0.5	Dec 02, 2009		Soil	M09-De06826	X			X			X			X	
CTP14_2.0	Dec 02, 2009		Soil	M09-De06827	X			X	X		X				
CTP15_0.2	Dec 03, 2009		Soil	M09-De06828	X			X			X				
CTP15_1.0	Dec 03, 2009		Soil	M09-De06829	X	X	X	X	X	X	X	X	X		
CTP16_0.2	Dec 03, 2009		Soil	M09-De06830	X			X			X				
CTP16_1.0	Dec 03, 2009		Soil	M09-De06831	X			X	X		X				

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mgt Client Manager: Onur Mehmet

Sample Detail					% Moisture	Calcium (exchangeable)	Cation Exchange Capacity	Conductivity (1:5 aqueous extract)	Exchangeable Sodium Percentage(ESP)	Magnesium (exchangeable)	pH (1:5 Aqueous extract)	Potassium (exchangeable)	Sodium (exchangeable)	Total Organic Carbon	Chromium Suite
Laboratory where analysis is conducted															
Melbourne Laboratory - NATA Site #1254					X	X	X	X	X	X	X	X	X	X	X
Sydney Laboratory - NATA Site #18217															
Sample ID	**Sample Date**	**Sampling Time**	**Matrix**	**LAB ID**											
CTP17_0.5	Dec 03, 2009		Soil	M09-De06832	X			X			X				
CTP17_1.5	Dec 03, 2009		Soil	M09-De06833	X	X	X	X	X	X	X	X	X		X

Coffey Environments Pty Ltd QLD	**Client Sample ID**		**CTP1_0.1**	**CTP1_0.5**	**CTP2_0.1**	**CTP2_1.0**
47 Doggett Street	**Lab Number**		**M09-De06801**	**M09-De06802**	**M09-De06803**	**M09-De06804**
New Stead	**Matrix**		**Soil**	**Soil**	**Soil**	**Soil**
Queensland 4006	**Sample Date**		**Nov 30, 2009**	**Nov 30, 2009**	**Nov 30, 2009**	**Nov 30, 2009**
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	-	-	3500
Cation Exchange Capacity	0.05	meq/100g	-	-	-	37
Exchangeable Sodium Percentage(ESP)	0.1	%	-	4.2	-	3.1
Magnesium (exchangeable)	5	mg/kg	-	-	-	470
Potassium (exchangeable)	5	mg/kg	-	-	-	120
Sodium (exchangeable)	5	mg/kg	-	-	-	730
% Moisture	0.1	%	9.8	10	8.8	8.3
Conductivity (1:5 aqueous extract)	10	uS/cm	100	790	780	120
pH (1:5 Aqueous extract)	0.1	units	8.8	8.9	9.4	9.1

COMMENTS:

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Coffey Environments Pty Ltd QLD	Client Sample ID		CTP3_0.05	CTP3_0.5	CTP4_0.5	CTP4_1.0
47 Doggett Street	Lab Number		M09-De06805	M09-De06806	M09-De06807	M09-De06808
New Stead	Matrix		Soil	Soil	Soil	Soil
Queensland 4006	Sample Date		Nov 30, 2009	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	4100	-	-
Cation Exchange Capacity	0.05	meq/100g	-	27	-	34
Exchangeable Sodium Percentage(ESP)	0.1	%	-	8.6	-	8.9
Magnesium (exchangeable)	5	mg/kg	-	1100	-	-
Potassium (exchangeable)	5	mg/kg	-	220	-	-
Sodium (exchangeable)	5	mg/kg	-	980	-	-
% Moisture	0.1	%	7.0	9.3	9.0	16
Conductivity (1:5 aqueous extract)	10	uS/cm	100	170	230	1700
pH (1:5 Aqueous extract)	0.1	units	8.8	9.3	7.8	4.6
Total Organic Carbon	50	mg/kg	-	16000	-	-
Acid Base Accounting (Chromium Reducible Sulfur)						
ANC Fineness Factor	0.5		-	1.5	-	-
Liming rate	1	kg CaCO3/t	-	< 1	-	-
Net Acidity (acidity units)	10	mol H+/t	-	< 10	-	-
Net Acidity (sulfur units)	0.02	% S	-	< 0.02	-	-
Chromium Suite						
pH-KCL	0.1	units	-	7.5	-	-
Chromium Reducible Sulfur	0.02	% S	-	< 0.02	-	-
Acid trail - Titratable Actual Acidity	2	mol H+/t	-	< 2	-	-
sulfidic - Titratable Actual Acidity	0.02	% pyrite S	-	< 0.02	-	-

COMMENTS:

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Coffey Environments Pty Ltd QLD	**Client Sample ID**		**CTP6_0.1**	**CTP6_1.0**	**CTP7_0.1**	**CTP7_0.6**
47 Doggett Street	**Lab Number**		**M09-De06809**	**M09-De06810**	**M09-De06811**	**M09-De06812**
New Stead	**Matrix**		**Soil**	**Soil**	**Soil**	**Soil**
Queensland 4006	**Sample Date**		**Dec 1, 2009**	**Dec 1, 2009**	**Dec 1, 2009**	**Dec 1, 2009**
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	3000	-	3900
Cation Exchange Capacity	0.05	meq/100g	-	54	-	25
Exchangeable Sodium Percentage(ESP)	0.1	%	-	3.8	-	3.0
Magnesium (exchangeable)	5	mg/kg	-	1300	-	590
Potassium (exchangeable)	5	mg/kg	-	310	-	43
Sodium (exchangeable)	5	mg/kg	-	1300	-	580
% Moisture	0.1	%	10	18	6.7	7.3
Conductivity (1:5 aqueous extract)	10	uS/cm	92	560	120	230
pH (1:5 Aqueous extract)	0.1	units	7.4	7.9	9.2	9.4

COMMENTS:

Coffey Environments Pty Ltd QLD	Client Sample ID		CTP8_0.1	CTP8_1.0	CTP9_0.1	CTP9_0.5
47 Doggett Street	Lab Number		M09-De06813	M09-De06814	M09-De06815	M09-De06816
New Stead	Matrix		Soil	Soil	Soil	Soil
Queensland 4006	Sample Date		Dec 1, 2009	Dec 1, 2009	Dec 1, 2009	Dec 1, 2009
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	2500	-	510
Cation Exchange Capacity	0.05	meq/100g	-	48	-	18
Exchangeable Sodium Percentage(ESP)	0.1	%	-	4.5	-	6.1
Magnesium (exchangeable)	5	mg/kg	-	2000	-	1000
Potassium (exchangeable)	5	mg/kg	-	210	-	57
Sodium (exchangeable)	5	mg/kg	-	1200	-	1100
% Moisture	0.1	%	15	18	1.9	11
Conductivity (1:5 aqueous extract)	10	uS/cm	140	400	14	570
pH (1:5 Aqueous extract)	0.1	units	8.1	8.8	7.0	9.2

COMMENTS:

Coffey Environments Pty Ltd QLD	Client Sample ID		CTP10_0.1	CTP10_1.0	CTP11_0.1	CTP11_0.3
47 Doggett Street	Lab Number		M09-De06817	M09-De06818	M09-De06819	M09-De06820
New Stead	Matrix		Soil	Soil	Soil	Soil
Queensland 4006	Sample Date		Dec 1, 2009	Dec 1, 2009	Dec 2, 2009	Dec 2, 2009
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	-	-	58
Cation Exchange Capacity	0.05	meq/100g	-	-	-	6.0
Exchangeable Sodium Percentage(ESP)	0.1	%	-	2.1	-	3.7
Magnesium (exchangeable)	5	mg/kg	-	-	-	120
Potassium (exchangeable)	5	mg/kg	-	-	-	16
Sodium (exchangeable)	5	mg/kg	-	-	-	120
% Moisture	0.1	%	14	25	1.2	2.6
Conductivity (1:5 aqueous extract)	10	uS/cm	84	120	18	38
pH (1:5 Aqueous extract)	0.1	units	7.8	9.0	6.8	6.7
Total Organic Carbon	50	mg/kg	-	7700	-	-
Acid Base Accounting (Chromium Reducible Sulfur)						
ANC Fineness Factor	0.5		-	-	-	1.5
Liming rate	1	kg CaCO3/t	-	-	-	< 1
Net Acidity (acidity units)	10	mol H+/t	-	-	-	< 10
Net Acidity (sulfur units)	0.02	% S	-	-	-	< 0.02
Chromium Suite						
pH-KCL	0.1	units	-	-	-	7.6
Chromium Reducible Sulfur	0.02	% S	-	-	-	< 0.02
Acid trail - Titratable Actual Acidity	2	mol H+/t	-	-	-	< 2
sulfidic - Titratable Actual Acidity	0.02	% pyrite S	-	-	-	< 0.02

COMMENTS:

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Coffey Environments Pty Ltd QLD	**Client Sample ID**		**CTP12_0.1**	**CTP12_0.6**	**CTP13_0.1**	**CTP13_1.3**
47 Doggett Street	**Lab Number**		**M09-De06822**	**M09-De06823**	**M09-De06824**	**M09-De06825**
New Stead	**Matrix**		**Soil**	**Soil**	**Soil**	**Soil**
Queensland 4006	**Sample Date**		**Dec 2, 2009**	**Dec 2, 2009**	**Dec 2, 2009**	**Dec 2, 2009**
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	83	-	-
Cation Exchange Capacity	0.05	meq/100g	-	20	-	-
Exchangeable Sodium Percentage(ESP)	0.1	%	-	5.6	-	6.9
Magnesium (exchangeable)	5	mg/kg	-	730	-	-
Potassium (exchangeable)	5	mg/kg	-	18	-	-
Sodium (exchangeable)	5	mg/kg	-	470	-	-
% Moisture	0.1	%	1.5	9.3	11	13
Conductivity (1:5 aqueous extract)	10	uS/cm	11	110	140	850
pH (1:5 Aqueous extract)	0.1	units	5.9	6.7	9.0	7.9

COMMENTS:

Coffey Environments Pty Ltd QLD	Client Sample ID		CTP14_0.5	CTP14_2.0	CTP15_0.2	CTP15_1.0
47 Doggett Street	Lab Number		M09-De06826	M09-De06827	M09-De06828	M09-De06829
New Stead	Matrix		Soil	Soil	Soil	Soil
Queensland 4006	Sample Date		Dec 2, 2009	Dec 2, 2009	Dec 3, 2009	Dec 3, 2009
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	-	-	19
Cation Exchange Capacity	0.05	meq/100g	-	-	-	1.6
Exchangeable Sodium Percentage(ESP)	0.1	%	-	3.8	-	9.7
Magnesium (exchangeable)	5	mg/kg	-	-	-	28
Potassium (exchangeable)	5	mg/kg	-	-	-	9.9
Sodium (exchangeable)	5	mg/kg	-	-	-	59
% Moisture	0.1	%	27	22	1.8	2.9
Conductivity (1:5 aqueous extract)	10	uS/cm	200	150	13	15
pH (1:5 Aqueous extract)	0.1	units	7.0	8.5	6.8	7.0
Total Organic Carbon	50	mg/kg	101000	-	-	-

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Coffey Environments Pty Ltd QLD	**Client Sample ID**		**CTP16_0.2**	**CTP16_1.0**	**CTP17_0.5**	**CTP17_1.5**
47 Doggett Street	**Lab Number**		**M09-De06830**	**M09-De06831**	**M09-De06832**	**M09-De06833**
New Stead	**Matrix**		**Soil**	**Soil**	**Soil**	**Soil**
Queensland 4006	**Sample Date**		**Dec 3, 2009**	**Dec 3, 2009**	**Dec 3, 2009**	**Dec 3, 2009**
Analysis Type	**LOR**	**Units**				
Ion Exchange Properties						
Calcium (exchangeable)	5	mg/kg	-	-	-	1300
Cation Exchange Capacity	0.05	meq/100g	-	-	-	21
Exchangeable Sodium Percentage(ESP)	0.1	%	-	3.2	-	9.9
Magnesium (exchangeable)	5	mg/kg	-	-	-	730
Potassium (exchangeable)	5	mg/kg	-	-	-	89
Sodium (exchangeable)	5	mg/kg	-	-	-	1300
% Moisture	0.1	%	6.7	9.0	6.0	8.0
Conductivity (1:5 aqueous extract)	10	uS/cm	60	400	380	550
pH (1:5 Aqueous extract)	0.1	units	7.1	9.3	8.8	9.7
Acid Base Accounting (Chromium Reducible Sulfur)						
ANC Fineness Factor	0.5		-	-	-	1.5
Liming rate	1	kg CaCO3/t	-	-	-	< 1
Net Acidity (acidity units)	10	mol H+/t	-	-	-	< 10
Net Acidity (sulfur units)	0.02	% S	-	-	-	< 0.02
Chromium Suite						
pH-KCL	0.1	units	-	-	-	7.5
Chromium Reducible Sulfur	0.02	% S	-	-	-	< 0.02
Acid trail - Titratable Actual Acidity	2	mol H+/t	-	-	-	< 2
sulfidic - Titratable Actual Acidity	0.02	% pyrite S	-	-	-	< 0.02

COMMENTS:

Coffey Environments Pty Ltd QLD	**Client Sample ID**	**CTP1_0.1**	**CTP1_0.1**	**RPD**	**SPIKE**
47 Doggett Street	**Lab Number**	**09-De06801**	**09-De06801**	**09-De06801**	**09-De06801**
New Stead	**QA Description**		**Duplicate**	**Duplicate % RPD**	**Spike % Recovery**
Queensland 4006	**Matrix**	**Soil**	**Soil**	**Soil**	**Soil**
	Sample Date	**Nov 30, 2009**	**Nov 30, 2009**	**Nov 30, 2009**	**Nov 30, 2009**
Analysis Type	**Units**			% RPD	% Recovery
Conductivity (1:5 aqueous extract)		100	100	1.0	-

COMMENTS:

Coffey Environments Pty Ltd QLD	Client Sample ID	CTP3_0.5	CTP3_0.5	RPD	SPIKE	Method blank
47 Doggett Street	Lab Number	09-De06806	09-De06806	09-De06806	09-De06806	Batch
New Stead	QA Description		Duplicate	Duplicate % RPD	Spike % Recovery	
Queensland 4006	Matrix	Soil	Soil	Soil	Soil	Soil
	Sample Date	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009
Analysis Type	**Units**			% RPD	% Recovery	mg/kg
Total Organic Carbon		-	-	15	-	< 50

COMMENTS:

Coffey Environments Pty Ltd QLD	Client Sample ID	CTP4_1.0	CTP4_1.0	RPD	SPIKE
47 Doggett Street	Lab Number	09-De06808	09-De06808	09-De06808	09-De06808
New Stead	QA Description		Duplicate	Duplicate % RPD	Spike % Recovery
Queensland 4006	Matrix	Soil	Soil	Soil	Soil
	Sample Date	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009	Nov 30, 2009
Analysis Type	**Units**			% RPD	% Recovery
pH (1:5 Aqueous extract)		4.6	4.7	-	-

COMMENTS:

Coffey Environments Pty Ltd QLD	**Client Sample ID**	**CTP7_0.1**	**CTP7_0.1**	**RPD**	**SPIKE**
47 Doggett Street	**Lab Number**	**09-De06811**	**09-De06811**	**09-De06811**	**09-De06811**
New Stead	**QA Description**		**Duplicate**	**Duplicate % RPD**	**Spike % Recovery**
Queensland 4006	**Matrix**	**Soil**	**Soil**	**Soil**	**Soil**
	Sample Date	**Dec 1, 2009**	**Dec 1, 2009**	**Dec 1, 2009**	**Dec 1, 2009**
Analysis Type	**Units**			% RPD	% Recovery
Conductivity (1:5 aqueous extract)		120	120	1.0	-
pH (1:5 Aqueous extract)		9.2	9.2	-	-

COMMENTS:

Melbourne
3-5 Kingston Town Close
Oakleigh Vic 3166
Phone : 03 9564 7055
NATA Site # 1254

Sydney
1a Chilvers Rd
Thornleigh NSW 2120
Phone : 02 9484 3300
NATA Site # 18217

Adelaide
140 Richmond Rd
Marleston SA 5033
Phone : 08 8443 4430

Coffey Environments Pty Ltd QLD	**Client Sample ID**	**CTP12_0.1**	**CTP12_0.1**	**RPD**	**SPIKE**
47 Doggett Street	**Lab Number**	**09-De06822**	**09-De06822**	**09-De06822**	**09-De06822**
New Stead	**QA Description**		**Duplicate**	**Duplicate % RPD**	**Spike % Recovery**
Queensland 4006	**Matrix**	**Soil**	**Soil**	**Soil**	**Soil**
	Sample Date	**Dec 2, 2009**	**Dec 2, 2009**	**Dec 2, 2009**	**Dec 2, 2009**
Analysis Type	**Units**			% RPD	% Recovery
Conductivity (1:5 aqueous extract)		11	12	14	-
pH (1:5 Aqueous extract)		5.9	5.8	-	-

COMMENTS:

Melbourne
3-5 Kingston Town Close
Oakleigh Vic 3166
Phone : 03 9564 7055
NATA Site # 1254

Sydney
1a Chilvers Rd
Thornleigh NSW 2120
Phone : 02 9484 3300
NATA Site # 18217

Adelaide
140 Richmond Rd
Marleston SA 5033
Phone : 08 8443 4430

Coffey Environments Pty Ltd QLD	**Client Sample ID**	**CTP17_0.5**	**CTP17_0.5**	**RPD**	**SPIKE**
47 Doggett Street	**Lab Number**	**09-De06832**	**09-De06832**	**09-De06832**	**09-De06832**
New Stead	**QA Description**		**Duplicate**	**Duplicate % RPD**	**Spike % Recovery**
Queensland 4006	**Matrix**	**Soil**	**Soil**	**Soil**	**Soil**
	Sample Date	**Dec 3, 2009**	**Dec 3, 2009**	**Dec 3, 2009**	**Dec 3, 2009**
Analysis Type	**Units**			% RPD	% Recovery
Conductivity (1:5 aqueous extract)		380	350	9.0	-
pH (1:5 Aqueous extract)		8.8	8.9	-	-

COMMENTS:

Appendix D

Terms of Reference Cross-Reference Table

Cross-reference with the Terms of Reference issued by the Department of Environment and Resource Management for the Arrow Energy Surat Basin Project EIS					
ToR Ref	**Terms of Reference Requirement**	**Technical Specialist**	**Technical Report Section Reference**	**Coffey Environments Comments**	**Technical Specialist Comments**
	Description of environmental values				
4.2.1	This section describes the existing environment 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, describe how nominated quantitative standards and indicators may be achieved, and how the achieving of the objectives will be monitored, audited and managed.	Coffey Geotechnics: Geology, Landform and Soils	Section 5.1: Terrain Unit Mapping and Environmental Values		
4.2.1.1	Topography/Geomorphology: Detail the topography of the project area and any other potentially impacted areas with contours at suitable increments, shown with respect to Australian Height Datum and drafted to the Geocentric Datum of Australia (GDA) 94 datum. Include other significant features of the locality including any locations subsequently referred to in the EIS (including the nearest noise sensitive locations) that are not included on other maps in section 4.2. Provide commentary on the maps highlighting the significant topographical features.		Section 3.2.2: Physiography, Topography and Geomorphology Table 3.1: Summary of Study Area Environmental Characteristics Figure 4.5: Topographic Map		
4.2.1.2	Geology: Provide a description, map and series of cross sections 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, including areas outside the project site that could be influenced by the project's activities Geological properties that may influence ground stability (including seismic activity, if relevant), occupational health and safety, rehabilitation programs, or the quality of wastewater leaving any area disturbed by the project should be described.		Section 3.1: Geology Table 3.1: Summary of Study Area Environmental Characteristics Appendix B: Geological Mapping and Site Photographs Figure 3.1: Environmental Characteristics of the Condamine River Valley Figure 3.2: Stratigraphic Profile of the Study Area Figure 3.3: Surface Geology of the Study Area and Environs		

Cross-reference with the Terms of Reference issued by the Department of Environment and Resource Management for the Arrow Energy Surat Basin Project EIS					
ToR Ref	**Terms of Reference Requirement**	**Technical Specialist**	**Technical Report Section Reference**	**Coffey Environments Comments**	**Technical Specialist Comments**
4.2.1.4	Soils: Provide a soil survey of the site affected by the project, with a particular reference to the physical and chemical properties of the materials that will influence erosion potential, storm water run-off quality, rehabilitation and agricultural productivity of the land. Provide information on soil stability and suitability for the activity. Assess the need for acid sulfate soil investigation. Map and describe soil profiles according to the Australia Soil and Land survey Field Handbook and the ASC. Conduct on-ground surveys and laboratory analysis to provide chemical and physical analysis of soil types. Assess soils information against SPP1/92, and the Draft Strategic Cropping Land Policy.		Section 3.3: Soils Table 3.1: Summary of Study Area Environmental Characteristics Appendix C: Test Pit Logs and Field/Laboratory Testing Results Figure 4.1: Terrain Units of the Study Area and Environs Section 3.4: GQAL in the Study Area Section 3.5: Strategic Cropping Land in the Study Area		
4.2.1.5	Land Use: Describe the land use suitability of the affected area in terms of the physical attributes by setting out soil and landform subclasses assigned to soil mapping units in order to derive land suitability classes. Provide a land suitability map of the proposed and adjacent area. Show GQAL in accordance with SPP 1/92.		Section 3.3: Soils Section 5.1: Terrain Unit Mapping and Environmental Values Figure 3.8: Agricultural Land Classification (GQAL) of the Study Area and Environs		
4.2.1.7	Sensitive Environmental Areas: The proximity of the project to any environmentally sensitive areas should be shown on a map of suitable scale. This section of the EIS should then identify whether any other those environmentally sensitive areas could be affected, directly and indirectly, by the project		4.2: Landscape Sensitivity Assessment 4.3: Sensitivity Ranking Summary and Overall Terrain Unit Sensitivity Figures 4.1 – 4.6: Sensitivity Mapping		

Cross-reference with the Terms of Reference issued by the Department of Environment and Resource Management for the Arrow Energy Surat Basin Project EIS					
ToR Ref	**Terms of Reference Requirement**	**Technical Specialist**	**Technical Report Section Reference**	**Coffey Environments Comments**	**Technical Specialist Comments**
Potential Impacts and mitigation measures					
4.2.2.1	Land Use Suitability: The potential for the project's construction and operation to change existing and potential land uses of the project area should be detailed. Post-operations land-use options should be detailed including suitability of the area to be used for primary production, industry, or nature conservation. The factors favouring or limiting the establishment of those options should be given in the context of land use suitability prior to the project and minimising potential liabilities for long-term management. The potential environmental harm caused by the project on areas currently used for agriculture, urban development, recreation, tourism, other business and the implications of the project for future developments in the project area including constraints on surrounding land uses should be described. Mitigation measures should be proposed for any potentially adverse impacts on stock route operations during the construction and operational phases of the development. If the development adjoins or potentially impacts on good quality agricultural land, then an assessment of the potential for land use conflict is required. Investigations should follow the procedures set out in the planning guideline, The Identification of Good Quality Agricultural Land, which supports State Planning Policy 1/92.		6.4: Specific Potential Impacts on GQAL and Strategic Cropping Land 7.1.3: Protection of GQAL and Strategic Cropping Land Section 7.4.1: Gathering Infrastructure GQAL Management Measures		Partially applicable to Geology, Landform and Soils Study

Cross-reference with the Terms of Reference issued by the Department of Environment and Resource Management for the Arrow Energy Surat Basin Project EIS					
ToR Ref	**Terms of Reference Requirement**	**Technical Specialist**	**Technical Report Section Reference**	**Coffey Environments Comments**	**Technical Specialist Comments**
4.2.2.2	A strategy should be developed that will minimise the amount of land disturbed at any one time. The strategic approach to progressively rehabilitating landforms and final decommissioning should be described with particular regard to the impacts in the short, medium and long timeframes. The methods to be used for the project, including backfilling, covering, re-contouring, topsoil handling and revegetation, should be described. However, a description of erosion and sediment control could be deferred to section 4.2.2.4. Any proposals to disturb land that would impede or divert overland flow or waterways, and any subsequent reinstatement, during construction or operations should be first described in this section. However, the potential impacts of interfering with flow on the quantity and quality of water resources should be assessed in section 4.5. Also, the final drainage and seepage control systems and any long-term monitoring plans should be described. In addition to assessing the operational phase of land disturbance, the EIS should address the ultimate changes following implementation of the decommissioning and rehabilitation plan described in section 3.2.15. The EIS should detail the proposed long-term changes that will occur to the land after petroleum activities cease compared to the situation before activities commenced. Those changes should be illustrated on maps at a suitable scale and with contours at intervals sufficient to assess the likely drainage pattern for ground and surface waters (though the assessment of the impacts on drainage and water quality should be provided in the water resources section of the EIS). The mitigation measures for land disturbance to be used during decommissioning should be assessed in sufficient detail to decide their feasibility. In particular, the EIS should address the long-term stability of disturbed sites, safety of access to sites and the residual risks that will be transferred to the subsequent landholder. Rehabilitation success criteria for land disturbance should be proposed in this section while rehabilitation success criteria for revegetation should be proposed in the section on nature conservation. If geological conditions are conducive, the proponent should consider the possibility that significant fossil specimens (such as of dinosaurs or their tracks) may be uncovered during construction or operations and propose strategies to protect the specimens and alert the Queensland Museum to the find.		Section 7: Management and Mitigation Measures, in particular: Section 7.1.5: Land Degradation Management and Mitigation Measures Section 7.1.9: Backfilling Management Measures Section 7.1.8: Soil Management Section 7.7: Inspection, Monitoring and Maintenance Programme Section 8: Residual Impacts Section 7.1.2: Fossil Disturbance Management Strategies		Partially applicable to Geology, Landform and Soils Study

Cross-reference with the Terms of Reference issued by the Department of Environment and Resource Management for the Arrow Energy Surat Basin Project EIS					
ToR Ref	**Terms of Reference Requirement**	**Technical Specialist**	**Technical Report Section Reference**	**Coffey Environments Comments**	**Technical Specialist Comments**
4.2.2.4	Erosion and Stability: For all permanent and temporary landforms, possible erosion rates and management techniques should be described. For each soil type identified, erosion potential (wind and water) and erosion management techniques should be outlined. 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 report should include an assessment of likely erosion and stability effects for all disturbed areas such as: • areas cleared of vegetation • dams, banks and creek crossings • the plant site, including buildings • access roads or other transport corridors • bores • pipelines for gas or water • electricity transmission corridors. Methods proposed to prevent or control erosion should be specified and should be developed with regard to (a) the long-term stability of disturbed areas; (b) preventing soil loss in order to maintain land capability/suitability, and (c) preventing significant degradation of local waterways by suspended solids. Erosion control measures should be developed into an erosion and sediment control plan for inclusion in the EM plan. Acid sulfate soils are characteristically found in coastal areas at elevations less than 5 m. They can also occur at higher elevations inland, where pyrite conditions are present, and where there are organically rich deposits on the edges of lakes and waterways. It is recognised that such conditions are highly unlikely to occur in the proposed development area. Managing acid sulfate soils should be based on assessment in accordance with the Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998 and management and monitoring plans prepared in consultation with officers of DERM.		Section 4.2.3: Landscape Sensitivity to Erosion (Erodibility) and Erosion Hazard Section 6.2: Generic Environmental Impacts – Land Degradation (and subsequent sub-sections) Section 7.1.5: Land Degradation Management and Mitigation Measures Acid Sulfate Soils not considered to be an issue within the project development area, Section 3.3.4: Acid Sulfate Soils		
4.2.2.5	Landscape Character: Describe the potential impacts of the project upon the landscape character of the development area and the surrounding area. Particular mention should be made of any changes to the broad-scale topography and vegetation character of the area, such as due to broad-scale clearing. Details should be provided of measures to be undertaken to mitigate or avoid the identified impacts.		Section 6.2.9: Topographic Alteration and Landslides Section 7.1.10: Rehabilitation Section 7.7: Inspection, Monitoring and Maintenance Programme		Partially applicable to Geology, Landform and Soils Study

Appendix E

Important Information about your Coffey Report

coffey geotechnics
SPECIALISTS MANAGING THE EARTH

Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

Important information about your **Coffey** Report

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way.

Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment.
Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.