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Land resources assessment

Santos GLNG Gas Field Development Project

AUGUST 2014

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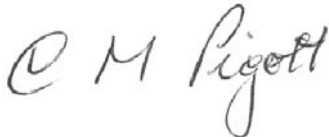
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Appendix A – Geological cross-sections

Appendix B – Interpretation of soil data

Appendix C – Revised universal soil loss equation

Abbreviations

Abbreviation	Description
AHD	Australian Height Datum
ALC	Agricultural land class
APLNG	Australia Pacific LNG
ARI	Average rainfall intensity
ASC	Australian Soil Classification
ATP	Authority to prospect
BTEX	Benzene, toluene, ethylbenzene and xylenes
CEC	Cation exchange capacity
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWMP	Coal Seam Water Management Plan
DAMP	Decommissioning and Abandonment Management Plan
DEM	Digital Elevation Model
DNRM	Department of Natural Resources and Mines, Queensland Government
Draft EM Plan	Draft Environmental Management Plan
EIS	Environmental Impact Statement
EHP	Department of Environment and Heritage Protection, Queensland Government
EHS	Environment Hazard Standards
EHSMS	Environment, Health and Safety Management System
ESCMP	Erosion and Sediment Control Management Plan
ESP	Exchangeable sodium percentage
GFD	Gas Field Development
GLNG	Gladstone Liquefied Natural Gas
GQAL	Good Quality Agricultural Land
ha	Hectares
km	Kilometre
LSU	Landscape unit
m	Metre
ma	Million years ago
PAA	Priority Agricultural Area
PALU	Priority Agricultural Land Use
PAWC	Plant available water capacity
RUSLE	Revised Universal Soil Loss Equation
SCL	Strategic Cropping Land
SMU	Soil mapping unit
SPP	State Planning Policy

Executive summary

URS Australia Pty Ltd (URS) was engaged by Santos GLNG to complete an assessment of the potential impacts on the land resources, specifically geology, topography and soils, which could result from the proposed Gas Field Development Project (the GFD Project) in central and southern Queensland. The subsequent land resources assessment was designed to inform the environmental impact statement (EIS) process. The assessment methodology was aligned with the requirements outlined in the Terms of Reference for the GFD Project EIS dated March 2013.

In completing the assessment, URS reviewed information from primary and secondary sources including soil and land resource studies commissioned or undertaken by Santos GLNG, CSIRO and other government agencies.

Based on recognised protocols, eight broad soil groups and associated soil types have been identified and used as a basis for mapping of soils (13 soil mapping units) and/or soil associations within the GFD Project area.

Potential problem soils (saline, sodic and reactive soils) were identified and described the GFD Project area, which are to be considered during development, operations and decommissioning phases of the GFD Project. An assessment of the suitability and availability of topsoil resources, Good Quality Agricultural Land (GQAL) and Strategic Cropping Areas (SCA) was included. Also an estimate was made of the current erosion and potential rates of soil loss from each of the mapped units. This information provides a means for planning development, and establishing land rehabilitation targets. Indicative stripping depths should be used only as a guide and more detailed, location specific soil investigations may need to be conducted at an appropriate scale and sampling intensity to inform soil management requirements. This may include detailed soil information on the soil properties and soil chemistry.

The primary coal seams of interest to the GFD Project area are the Jurassic age Walloon Coal Measures (Surat Basin) and the late Permian Bandanna Formation (Bowen Basin). The environmental values and potential impacts of the GFD Project operations on the geology were assessed. The potential impacts of hydraulic stimulation, subsidence, and land stability were evaluated in terms of likelihood and consequence. Monitoring and management controls, based on proven methodologies adopted by Santos GLNG, have been compiled.

The potential impacts to the land resources were assessed on the basis of soil, erosion and sediment control and geology, using a significance assessment method. This involved a qualitative assessment of both the sensitivity of identified environmental values to impacts, and the magnitude of consequences that may arise in the event that impacts occur. Consequently, mitigation measures to reduce the risk associated with potential impacts were identified on the basis of management frameworks within Santos GLNG's existing operations, and additional measures specific to the GFD Project. A monitoring program for both baseline and operations assessment was also incorporated to monitor changes in environmental values throughout each development phase of the GFD Project.

Introduction

1.1 Project overview

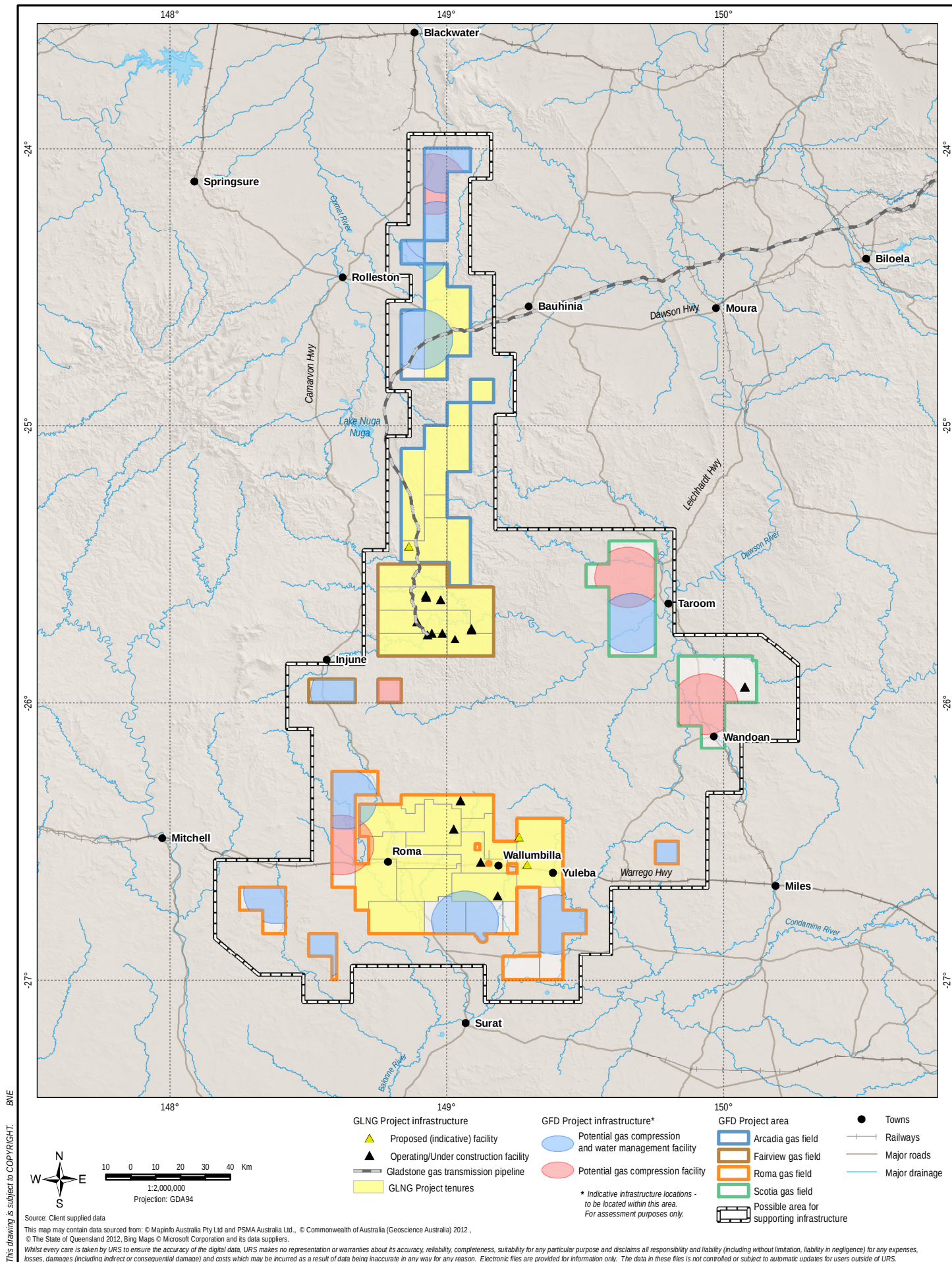
Santos GLNG intends to further develop its Queensland gas resources to augment supply of natural gas to its existing and previously approved Gladstone Liquefied Natural Gas (GLNG) Project.

The Santos GLNG GFD Project is an extension of the existing approved gas field development and will involve the construction, operation, decommissioning and rehabilitation of production wells and the associated supporting infrastructure needed to provide additional gas over a project life exceeding 30 years.

Specifically, the GFD Project seeks approval to expand the GLNG Project's gas fields tenure from 6,887 km² to 10,676 km² to develop up to 6,100 production wells beyond the currently authorised 2,650 wells; resulting in a maximum of up to 8,750 production wells. The GFD Project will continue to progressively develop the Arcadia, Fairview, Roma and Scotia gas fields across 35 Santos GLNG petroleum tenures in the Surat and Bowen basins, and associated supporting infrastructure in these tenures and adjacent areas. The location of the GFD Project area and primary infrastructure is shown on Figure 1-1.

This GFD Project will include the following components:

- Production wells
- Fluid injection wells, monitoring bores and potentially underground gas storage wells
- Gas and water gathering lines
- Gas and water transmission pipelines
- Gas compression and treatment facilities
- Water storage and management facilities
- Access roads and tracks
- Accommodation facilities and associated services (e.g. sewage treatment)
- Maintenance facilities, workshops, construction support, warehousing and administration buildings
- Utilities such as water and power generation and supply (overhead and/or underground)
- Laydown, stockpile and storage areas
- Borrow pits and quarries
- Communications.



1 Introduction

The final number, size and location of the components will be determined progressively over the GFD Project life and will be influenced by the location, size and quality of the gas resources identified through ongoing field development planning processes, which include consideration of land access agreements negotiated with landholders, and environmental and cultural heritage values.

Where practicable, the GFD Project will utilise existing or already approved infrastructure (e.g. accommodation camps, gas compression and water management facilities) from the GLNG Project or other separately approved developments. The GFD Project may also involve sourcing gas from third-party suppliers, as well as the sharing or co-location of gas field and associated facilities with third parties.

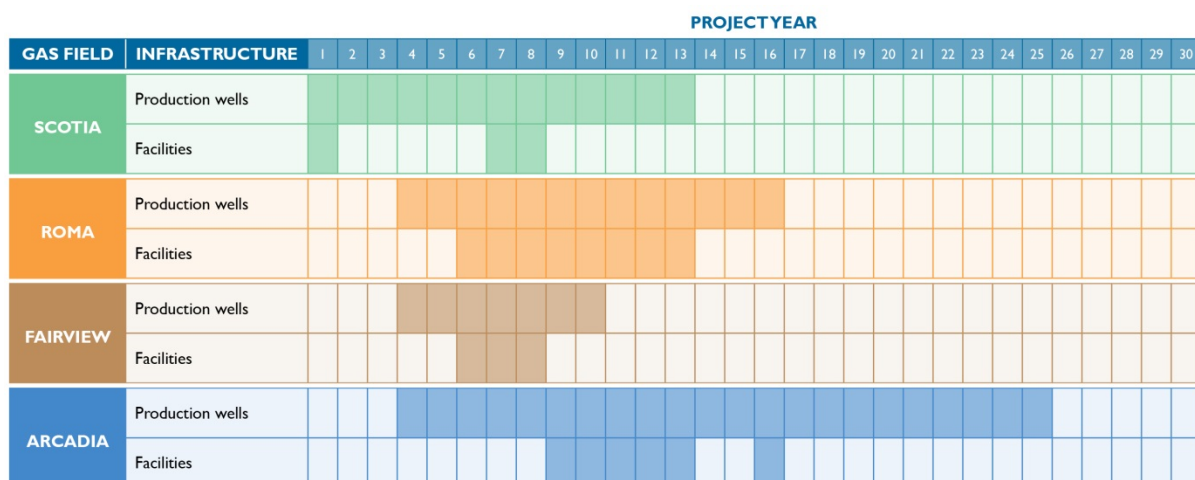
For the purposes of transparency this EIS shows an area off-tenure that may be used for infrastructure such as pipelines and temporary camps (supporting infrastructure area). While not assessed specifically in this EIS, any infrastructure that may be located within this area would be subject to further approval processes separate to this EIS.

Approved exploration and appraisal activities are currently underway across the GFD Project's petroleum tenures to improve understanding of the available gas resources. As the understanding of gas resources increases, investment decisions will be made about the scale, location and timing of the next stages of field development.

For the purposes of this EIS, a scenario based on the maximum development case was developed at the approval of the Terms of Reference. This scenario assumed that production from the wells and upgrading of the gas compression facilities in the Scotia gas field would commence in 2016, followed by the GFD Project wells in the Roma, Arcadia and Fairview gas fields in mid-2019. This schedule is indicative only and was used for the purpose of the impact assessment in this EIS.

The proposed GFD Project schedule is outlined in Figure 1-2. This schedule provides an overall field development scenario for the purposes of assessment in this EIS.

Figure 1-2 Proposed GFD Project development schedule



Decommissioning and rehabilitation will occur progressively throughout the life of the GFD Project as construction activities cease and exhausted gas wells are decommissioned. Final decommissioning and rehabilitation will occur at the end of gas production in accordance with relevant approvals and regulatory requirements.

1 Introduction

1.2 GFD Project infrastructure

A list of the GFD Project infrastructure components and footprint during the operations phase is given in Table 1-1. The area of the operations footprints will be less than those required during construction. The location, size and timing of each of the GFD Project's operations elements will be confirmed as part of the ongoing field development process and presented in plans of operations.

Table 1-1 Estimated footprints for key GFD Project infrastructure components

GFD Project component	Construction footprint	Operational footprint
Well lease	Single well: 1.5 ha	Single well: 0.3 ha
	Multi-well: 2.5 ha	Multi-well: 0.5 ha
Access tracks and roads	1.5 to 3 ha per km	0.8 to 1.5 ha per km
Gas and water gathering lines	1 to 2.5 ha per km	None (right of way maintained)
Gas and water transmission pipelines	2.5 to 5.0 ha per km	None (right of way maintained)
Hub gas compression facility	20 to 40 ha	10 to 15 ha
Nodal gas compression facility	2 to 8 ha	1 to 4 ha
Laydown and storage yards ¹	5 to 40 ha	None
Borrow pits	5 to 50 ha	None
Camps ²	1 to 20 ha per camp	0.5 to 10 ha per camp
Water storage	Up to 1 ha for large tank	Up to 0.5 ha for large tank
	5 to 16 ha for large dam	3 to 8 ha for large dam
Water management facility	5 to 10 ha per facility	2 to 5 ha per facility

¹Laydown and storage yards include fuel storage, workshops and maintenance areas.

²Camps include accommodation facilities, water and sewage treatment facilities, recreational, storage and laydown areas.

ha: hectare. km: kilometre.

Facilities for energy supply, water supply and telecommunications will also be incorporated within GFD Project infrastructure. Most of the supporting infrastructure will be constructed within the GFD Project's tenure, although some may also be located off-tenure in the supporting infrastructure area.

1.3 Scope of work

The Terms of Reference for this assessment requires that a terrain analysis of the GFD Project area be carried out as a basis for the description of the physical environment in terms of geological regimes, landform and associated soil types, and also as a means of identifying potential engineering and environmental impacts that may result. Measures to mitigate such impacts were also to be identified.

The scope of works required for the land resources assessment were as follows:

- Provide maps and descriptions of the GFD Project area in State, regional and local contexts
- Describe the topography and general geomorphology within the GFD Project area, including significant features of the landscape and topography
- Provide maps, including a series of cross-sections and a general description of the geology of the GFD Project area
- Describe geological properties that may influence ground stability, occupational health and safety or the quality of storm water leaving the area disturbed by the GFD Project

1 Introduction

- Address the potential for significant fossil specimen finds in areas of suitable geological type and age that may potentially be uncovered during construction and operations
- Describe the soils of the GFD Project area, with reference to the likely physical and chemical properties of the materials that may influence erosion potential, stormwater run-off quality, rehabilitation and agricultural productivity of the land
- Provide information on soil stability and suitability for construction and operation activities
- Map soil types at a suitable scale and describe the soils according to the *Australian Soil and Land Survey field Handbook* (National Committee on Soil and Terrain, 2009) and *The Australian Soil Classification* (Isbell, 2002)
- Develop procedural management plans for soil surveys at an appropriate scale to the proposed GFD Project activity, including ground surveys and laboratory analyses in order to provide physical and chemical analyses of the soil types
- Provide details of potential impacts to the topography and geomorphology associated with the GFD Project and proposed mitigation measures in relation to:
 - Land disturbance
 - Erosion and stability.

Regulatory context

2.1 Regulatory context

This section discusses legislation relevant to topography, geology, land resources and contamination in Queensland. Relevant standards, State policies and guidelines are also discussed.

2.1.1 Queensland legislation

An overview of the State's legislation guiding the management and potential impact on land resources is provided in Table 2-1.

Table 2-1 State legislation relevant to land resources

Legislation	Applicability
<i>Environmental Protection Act 1994</i> (Qld)	The Environmental Protection Act introduced the principle of General Environmental Duty or duty not to carry out an activity that causes, or is likely to cause, environmental harm unless all reasonable and practical measures are taken to prevent or minimise the harm.
<i>Regional Planning Interests Act 2014</i> (Qld) (RPI Act)	The RPI Act identifies areas of Queensland that are of 'regional interest'. Under the Act, Priority Agricultural Areas (PAAs), Priority Living Areas (PLAs), Strategic Environmental Areas (SEAs) and Strategic Cropping Areas (SCAs) are defined as areas of regional interest. The Act provides for a process for the impact of proposed resource activities and regulated activities on areas of regional interest to be assessed and managed.

2.1.2 State policies, regional plans and guidelines

2.1.2.1 State planning policy

The State planning policy (SPP) issued by Queensland Department of State Development, Infrastructure and Planning in December 2013 is relevant to land resources.

2.1.2.2 Regional plans

Regional Plans relevant to land resources are:

- Darling Downs Regional Plan 2013
- Central Queensland Regional Plan 2013.

State guidelines relevant to land resources and presented in Table 2-2.

Table 2-2 State guidelines relevant to land resources

Guideline	Applicability
<i>Planning guidelines: The identification of good quality agricultural land</i> (Department of Primary Industry and Department of Housing, Local Government and Planning, 1993)	These guidelines support SPP 1/92 and provide definitions of agricultural land classes, and definitions of which agricultural land classes constitute GQAL in various regions of the State. The guidelines are largely focused on the local government agency implementation of GQAL through planning schemes and the development application process, including the publishing of GQAL mapping in planning schemes.

2 Regulatory context

Guideline	Applicability
<i>Technical guidelines for the environmental management of exploration and mining in Queensland</i> (Department of Minerals and Energy, 1995)	The land suitability assessment techniques, within this guideline were originally created to assess the impact of mining projects, but are now commonly used to assess the impact of other resource and infrastructure projects. Land suitability assessment techniques establish the baseline for assessing pre-project and post-project land suitability, including those relating to sampling and data requirements. The assessment techniques include standard assessment criteria in relation to cattle grazing and dryland cropping.

2.2 Santos GLNG policy framework

This section introduces the high level policies and standards applicable to the management of land resources employed by Santos GLNG in their general operations. This framework informs corporate responsibility and key principles across Santos GLNG operations at the corporate level. As such, they will also apply to the proposed GFD Project. Key documents comprising this framework are outlined in Table 2-3.

Table 2-3 Santos GLNG's corporate policies and standards relating to land resources management

Document	Overview
<i>EHSMS11.11: Decommissioning and abandonment</i>	Details the requirements for the decommissioning and abandonment of plant, equipment and facilities, including effective management of environmental, health and safety risks. Requires a scope of work for decommissioning or abandonment activities to be developed with relevant stakeholders prior to the commencement of the activities. Numerous issues must be considered in developing the scope of work, including health and safety, remediation requirements, existing and future land use, legislative requirements, costs and monitoring requirements. On the completion of decommissioning and remediation, an assessment of environmental and safety performance, including residual risk, must be carried out.
<i>EHS01: Biodiversity and land disturbance</i>	Details the requirements for planning and conducting operations in a way which avoids or minimises disturbance to land and allows affected areas to be restored within reasonable timeframes. Requires land disturbance to be carried out in a manner that minimises environmental impact, and in accordance with relevant environmental procedures. The standard also includes provisions for the recording and internal reporting of all disturbances, and for the rehabilitation and fencing of disturbance.
<i>EHS03: Produced (coal seam) water</i>	Details the requirements for minimising environmental impacts associated with produced water generated during the extraction, production or processing of oil and gas. Details the internal assessment and approvals required during the design phase of new or modified produced water management or disposal facility, including review by the Santos GLNG Chief Environmental and Cultural Heritage Advisor. The standard also details the requirement for monitoring and maintenance of produced water disposal facilities and activities.

2 Regulatory context

2.2.1 Constraints planning and field development protocol

The *GFD Project Environmental Protocol for Constraints Planning and Field Development* (the Constraints protocol) (Santos GLNG, 2014) details the process that Santos GLNG will use to identify, assess and manage potential impacts to the environment during field planning and development. The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to:

- Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation
- Support Santos GLNG's environmental policies and the General Environmental Duty (GED) as outlined in the *Environmental Protection Act 1994* (Qld)
- Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances
- Minimise cumulative impacts on environmental values.

The Constraints protocol provides a framework to guide placement of infrastructure and adopts the following management principles:

- Avoidance — avoiding direct and indirect impacts
- Minimisation — minimise potential impacts
- Mitigation — implement mitigation and management measures
- Remediation and rehabilitation — actively remediate and rehabilitate impacted areas
- Offset — offset residual adverse impacts in accordance with regulatory requirements.

The Constraints protocol enables the systematic identification and assessment of environmental values and the application of development constraints to effectively avoid and/or manage environmental impacts.

Consistent with Santos GLNG's environmental management hierarchy, the Constraints protocol prioritises avoidance of environmental impact during field planning by identifying those areas that are not amenable to development. This includes areas of high environmental value as identified in regulatory frameworks and Santos GLNG's baseline surveys. For areas that are considered appropriate to develop, Santos GLNG will identify impacts to environmental values that could potentially occur due to the construction, operations and decommissioning activities of the GFD Project, and determine pre-mitigated impacts (i.e. those that would occur without mitigation).

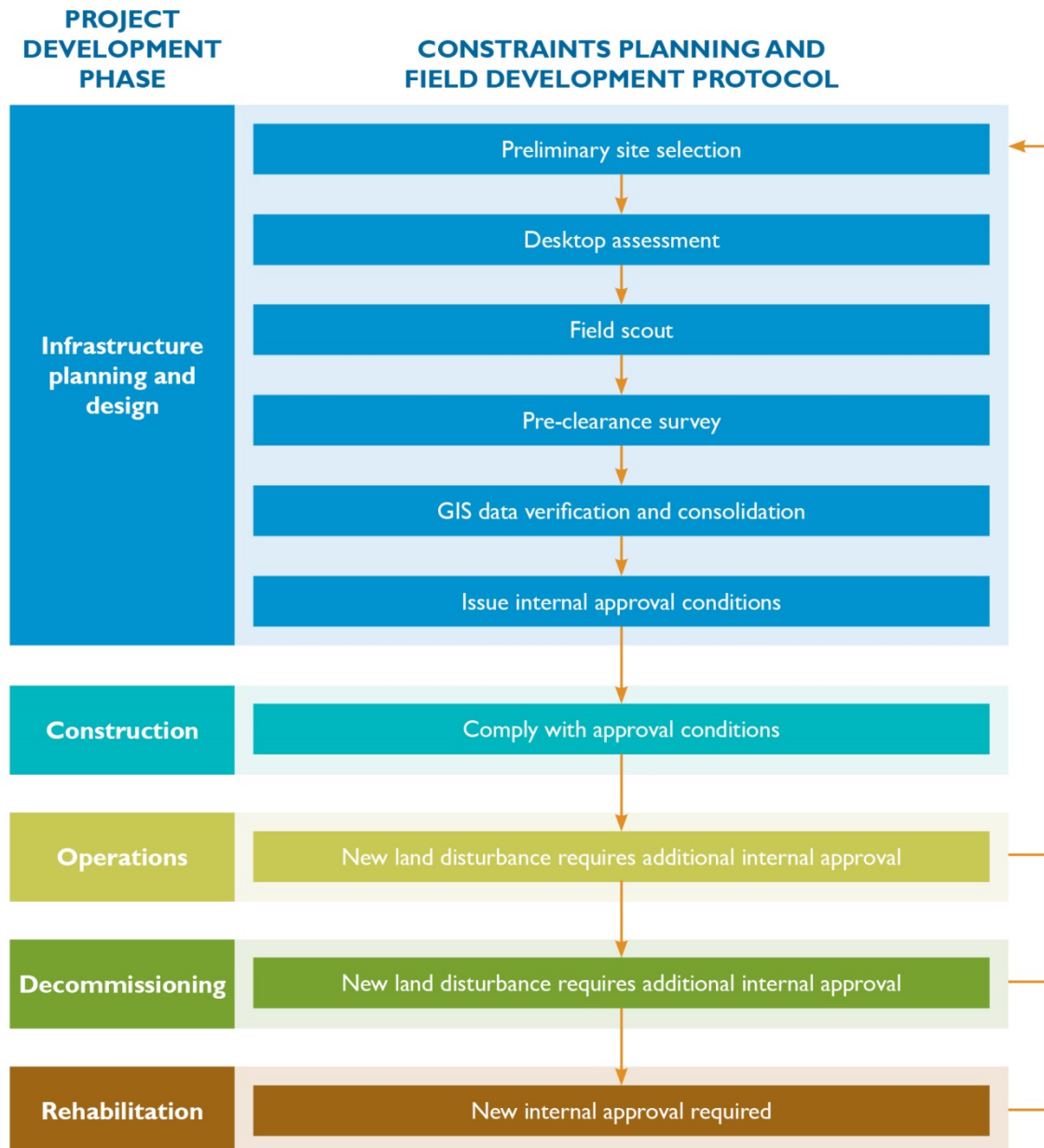
Relevant mitigation and management measures based on the approved environmental management framework already implemented for the GLNG Project are then applied to the pre-mitigated impacts to identify the mitigated (residual) impacts. This process increases certainty about potential impacts by identifying those areas that are not amenable to development, and for those areas where development could occur, how development should proceed.

The post-EIS field development process is a continuation of the field planning process and will be ongoing throughout the life of the GFD Project. The field development process will inform the GFD Project's design, together with a range of other factors including technical feasibility, cost and risk as required by standards applicable to the design, construction, operations, decommissioning and rehabilitation of gas developments. This information will be used to support the subsequent approvals process such as environmental approval application and the plan of operations.

The tasks involved in the field development process are summarised in Figure 2-1.

2 Regulatory context

Figure 2-1 Field development process



Assessment methodology

3.1 Desktop assessment

The land resources occurring within the GFD Project area have been assessed in terms of the regional topography, geology, landforms and the associated soil types. Terrain mapping has been carried out with reference to existing geological, topographic and soil information.

Landscape units occurring within the GLNG Project area (refer to Figure 1-1) were mapped in 2009. This assessment has been expanded as part of this study to incorporate the additional tenure of the GFD Project. Landscape units are comprised of a single or re-occurring area of land that is considered to have a predictable combination of physical attributes in terms of geology, slope, and landform and soil type. Sufficient similarity exists within units that engineering and environmental factors occurring within a unit can be extrapolated to other occurrences of the same terrain unit.

The topography is presented and described at a broad level of detail across the entire GFD Project area, while the remaining land resource features are presented and described in a higher level of detail over each of the four gas field areas of Arcadia, Fairview, Roma and Scotia.

The assessment of impacts on soils has been undertaken in accordance with the significance-based impact assessment methodology outlined in Section 5.

3.2 Data sources

The following data sources were used for the mapping, description and assessment of the land resources within the GFD Project area:

- Previously published documents for the GLNG Project EIS (2009 EIS).
 - Coal Seam Gas Field - Terrain, Soils and Land Capability (2009)
 - Gas Transmission Pipeline - Terrain, Soils and Land Capability (2009).
- Geological mapping derived from the regional geological map sheets of the Surat and Bowen basins, included in the Geoscience Data Set compiled by the Geological Survey of Queensland (2004 and 2008)
- Geological descriptive information from Onshore Australia web pages, Geoscience Australia
- CSIRO Land Resource digital data sets:
 - *Land Research Series No 19 (1967) – Lands of the Isaac-Comet Area Queensland*
 - *Land Research Series No. 21 (1968) – Lands of the Dawson Fitzroy Area Queensland*
 - *Land Research Series No 34 (1974) – Lands of the Balonne-Maranoa Area Queensland.*
- Regional compilation of mapping (1:250,000) Central West Region – Good Quality Agricultural Land (NWR, 2004).

3 Assessment methodology

3.3 Assessment methodology

A description of the land resources of the GFD Project area has involved an assessment of the terrain conditions across the GFD Project area as a means of identifying sensitive areas with reference to erosion potential, engineering constraints, rehabilitation and the agricultural productivity of the land.

The desktop study alone allowed for the compilation of the geology and soil sections, which includes:

- A description of the topography and soils of the GFD Project area
- A description of the geology of the GFD Project area
- A geological map and a series of cross-sections
- A description of geological structures and ground stability
- Comments on the potential for fossil specimens
- Geological values
- Impact assessment and mitigation (described in Section 5).

Environmental values

4.1 Topography and geomorphology

4.1.1 Regional physiography

The GFD Project area is located predominantly within and in proximity to the following physiographic regions from north to south (Figure 4-1):

Mackenzie – Dawson Lowlands. Consists predominantly of alluvial valleys and lowland plains, interrupted occasionally by residual rises and low hills. Parts of the GFD Project area are located within the western arm of this region which is drained towards the north by the Brown and Comet rivers and their associated tributaries.

Expedition Scarplands. This region is similar to the Taroom Hills physiographic region described below, with an exception in that the remnant plateaus areas are smaller in extent, resulting in a greater proportion of the region consisting of very steep escarpments and ravines. The Expedition Range is part of the Expedition Scarplands physiographic region.

Taroom Hills. Consists of gently sloping to strongly undulating dissected broad upland plateau remnants, predominantly on sandstone, with steep ravines and sandstone escarpments. Some areas consist of broad low interfluvies similar to those occurring within the Charleville Tablelands. The region is generally elevated and includes the Carnarvon Range, which in turn forms part of the Great Dividing Range watershed.

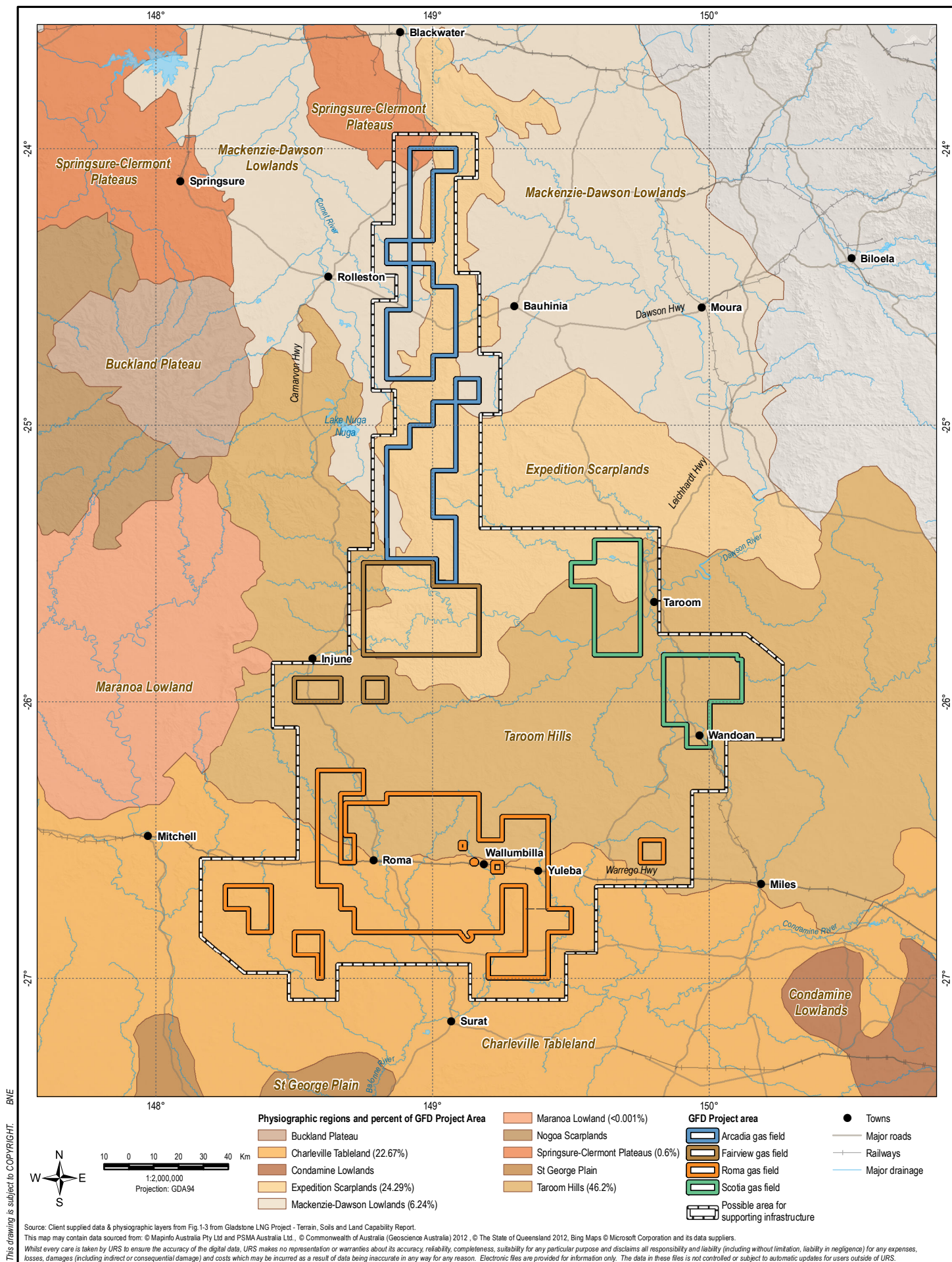
Charleville Tablelands. Consists of elevated, gently sloping to gently undulating terrain, with broad low interfluvies formed predominantly on mudrock (siltstone, claystone and mudstone). Lines of low sandstone hills occur sporadically across the gentle terrain. The upper reaches of the Balonne River and its tributaries form narrow to fairly broad alluvial plains within the tablelands. This region contains part of the intensively cultivated Western Downs agricultural area.

Springsure – Clermont Plateaus. Consists of a complex array of topographic features, including a large number of flat topped and rounded hills, with steep to moderately sloping sides, piedmont slopes and fans, colluvial slopes and alluvial plains.

Descriptions of the physiographic regions occurring adjacent to the units described above fringe the GFD Project area and are described below.

Buckland Plateau. Consists of elevated plateau remnants with deep, steep sided ravines, with the maximum elevations exceeding 1,200 metres Australian height datum (m AHD). The Great Dividing Range continues into this plateau region from the Taroom Hills physiographic region.

Maranoa Lowlands. Consists of moderately sloping piedmont slopes and low hills with narrow alluvial plains of the Merrivale River and its' tributaries including Sandy Creek. In the west, away from the GFD Project area the slopes and low hills of this region tend to give way to broader plains.



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4.1.2 Topography

The extent of the GFD Project area is approximately 375 km in a north-south direction and approximately 210 km from east to west. Overall the topography has a north-south topographical high of the Expedition and Shotover Ranges and an east-west topographical high of the Great Dividing Range. Three major river systems are separated by these topographical highs; the Comet River in the north, draining to the northwest, the Dawson River in the east, draining to the northeast and the south draining Balonne River in the south. The surface elevations within the GFD Project area vary between approximately 164 m to 770 m Australian Height Datum (AHD), as shown in Figure 4-2.

The GFD Project area can be broadly divided into the following terrain units:

- **Undulating.** Comprising broad areas of low-relief, gently undulating low hills with broad ridges and wide, flat bottomed valleys, with occasional isolated low hills and narrow alluvial plains of tributary creeks. Long slopes with less than 5% gradient are typical. While this terrain unit occurs throughout the GFD Project area, it dominates the eastern and southern project areas.
- **Mesa.** Comprising flat to undulating plateau surface remnants with very steep slopes and escarpments. This landscape occurs around the edge of the tenure in the most eastern, most northern and most south-western extent of the GFD Project area.
- **Alluvial plains.** Comprises flat and near flat plains along valleys and other subdued topographic areas. The most extensive alluvial plains occur along the three main streams draining the GFD Project area however, some of the tributary streams, such as the Juandah Creek have also developed alluvial plains, locally up to a few kilometres wide.

Notable topographic features within the GFD Project area include:

- Broad areas of low-level-relief undulating terrain and alluvial plains, interrupted by occasional low hills, across the southern eastern part of the GFD Project area including the Roma and Scotia gas fields.
- Near-level to strongly undulating plateau surface remnants cut by very steep-sided ravines and terminating in precipitous sandstone escarpments, occurring in the central part of the GFD Project area including the Fairview and Arcadia gas fields.
- The broad alluvial plains and foot slopes of the Arcadia-Comet valley feature extending northward from the northern margin of the Fairview gas field to the northern limit of the GFD Project area.

Surface slopes within the GFD Project area vary from near level (<1%) in parts of the alluvial plains to very steep, and in places vertical, sandstone escarpments and ravine slopes in the Expedition Range.

In the north, the tenure is located on the western mid and lower slopes of the Expedition and Shotover Ranges. The highest elevations occur within the Expedition and Shotover Ranges, along the eastern edge of the tenure and are approximately 770 m AHD. The elevation on the alluvial plains of most creeks varies between about 260 m and 280 m AHD.

In the east, the tenure is located in gently undulating terrain, and includes the alluvial plains of the Dawson River west of Taroom and Juandah Creek alluvial plains between Taroom and Wandoan. The elevation in this tenure varies between approximately 186 m to 375 m AHD.

In the south, the tenure is located on the northern and southern lower slopes of the Great Dividing Range. The southern lower slopes form a gradual transition to the gently undulating terrain further south to the southern alluvial plains. The undulating terrain is well defined by a north facing escarpment. The higher elevations in the southern area are between 241 and 635 m AHD. The tenure

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is generally located on the southern lower slopes of the Great Dividing Range and alluvial plains of the Balonne River and its tributaries. North of the Great Dividing Range, the transition between the Great Dividing Range and the undulating terrain is well defined by a north facing escarpment, generally with steep slopes. The higher elevations in the south are between about 380 m and 420 m AHD between Injune and the southwestern extent of the GFD Project area, while the high topography is about 360 m AHD south of the Warrego Highway.

Figure 4-3 to Figure 4-6 show the elevation occurring across the GFD Project area, by gas field and similarly Figure 4-7 to Figure 4-10 show the surface slopes occurring throughout the GFD Project area.

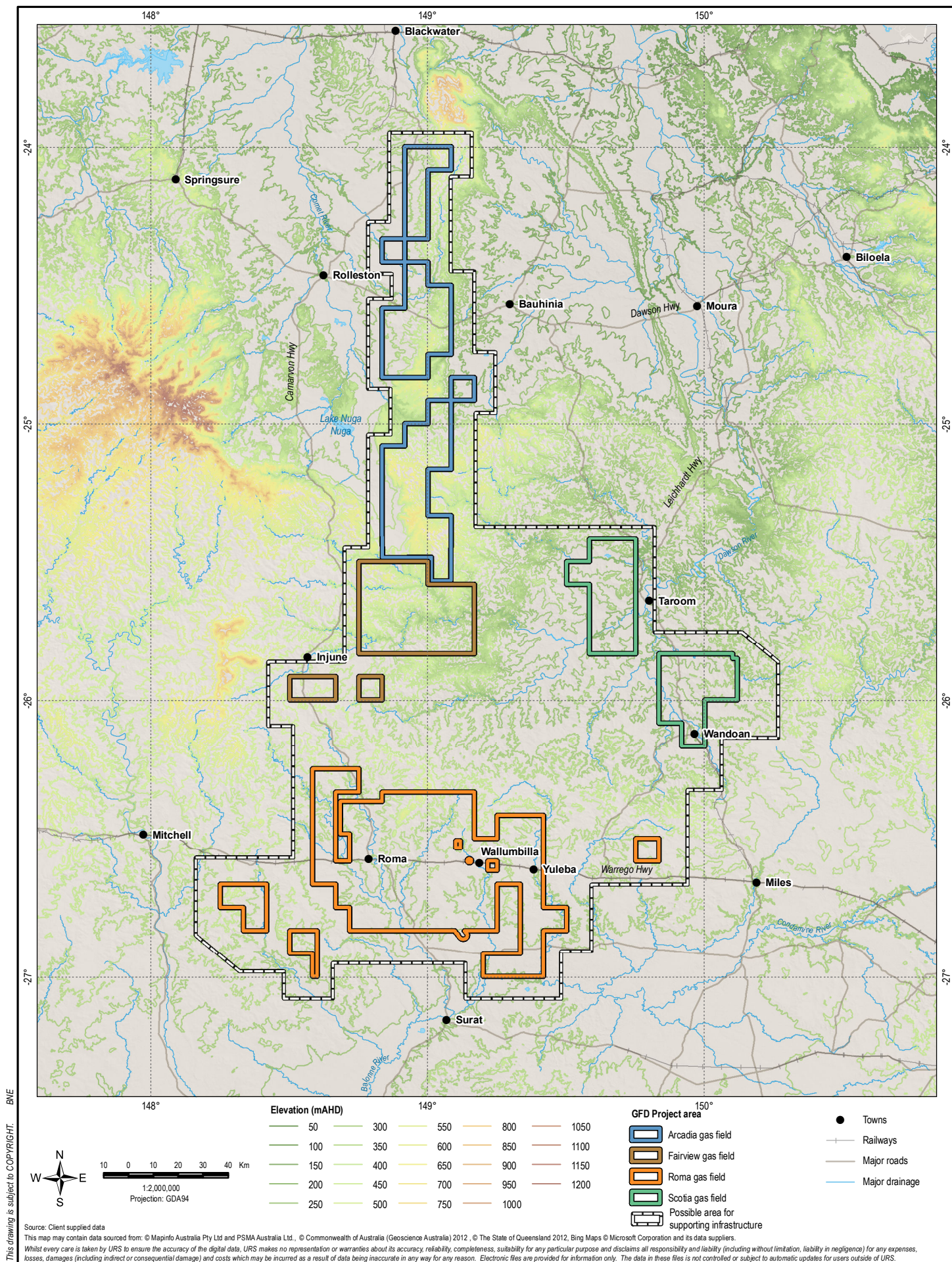
The digital elevation model (DEM) for the GFD Project area was sourced from the 1 second SRTM DEM-S (smoothed) v1.0 (coverage of Queensland, supplied by Geoscience Australia). The DEM-S is supplied in generic GRID format, so no further conversion was necessary. The DEM-S was also used to create the Hillshade Terrain used as a background detail.

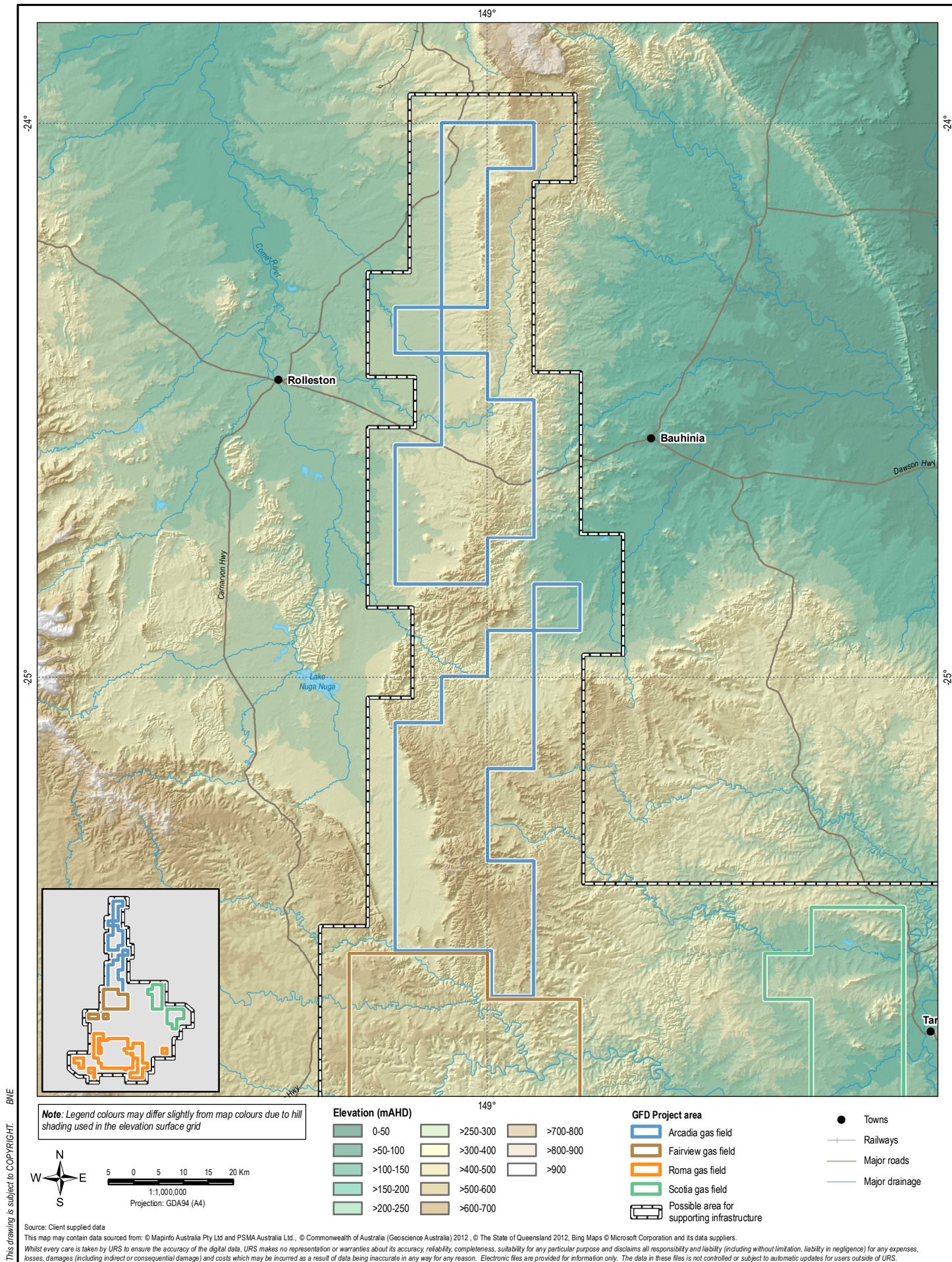
The Slope DEM was created from the DEM-S GRID and the Slope calculation tool from the Spatial Analysis toolset, available in ArcGIS. Output measurement was set to PERCENT_RISE, also referred to as percent slope.

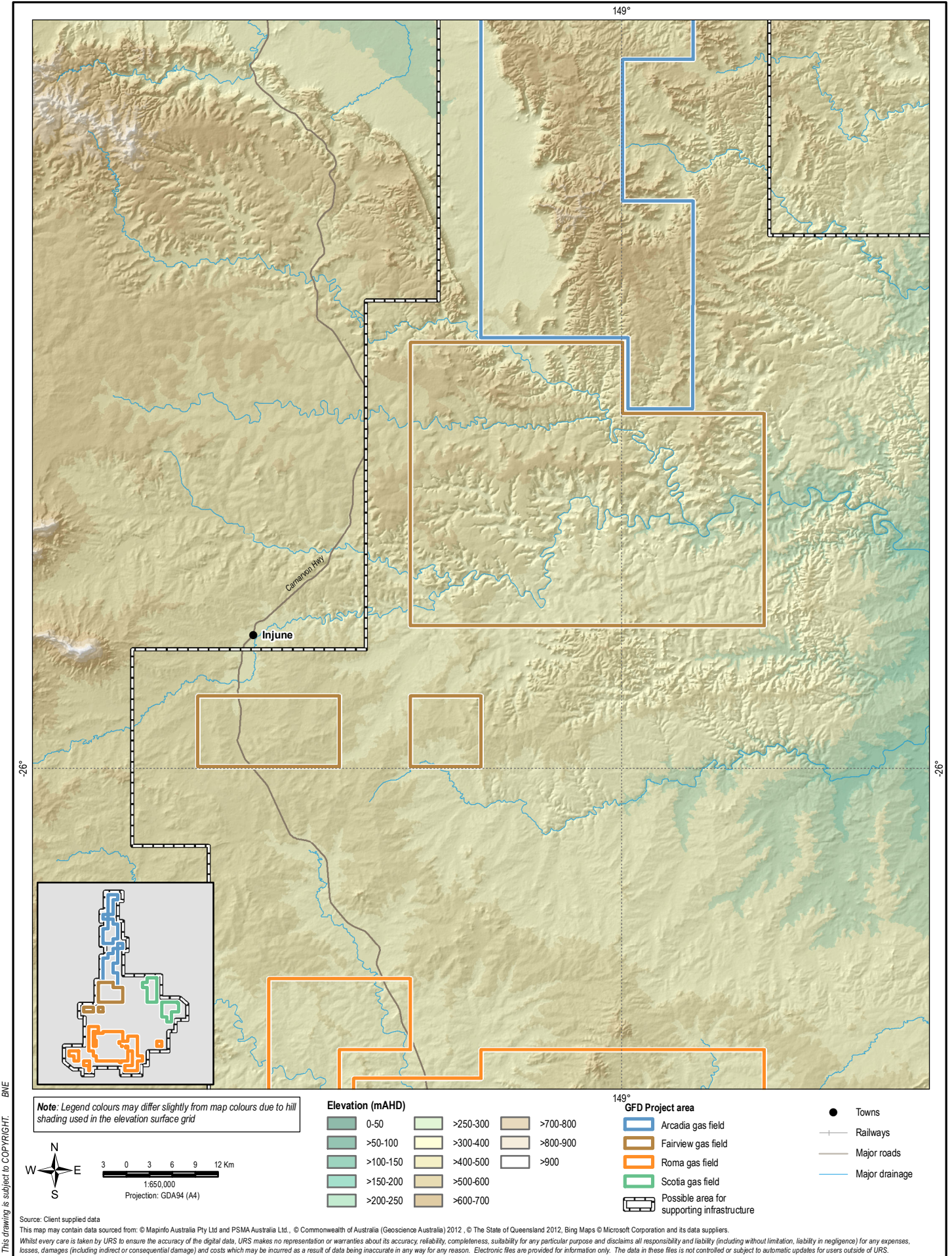
Across all four gas fields the slopes range from near level (<1%) to near vertical (>50%), and the elevation ranges for the four gas fields are presented in Table 4-1.

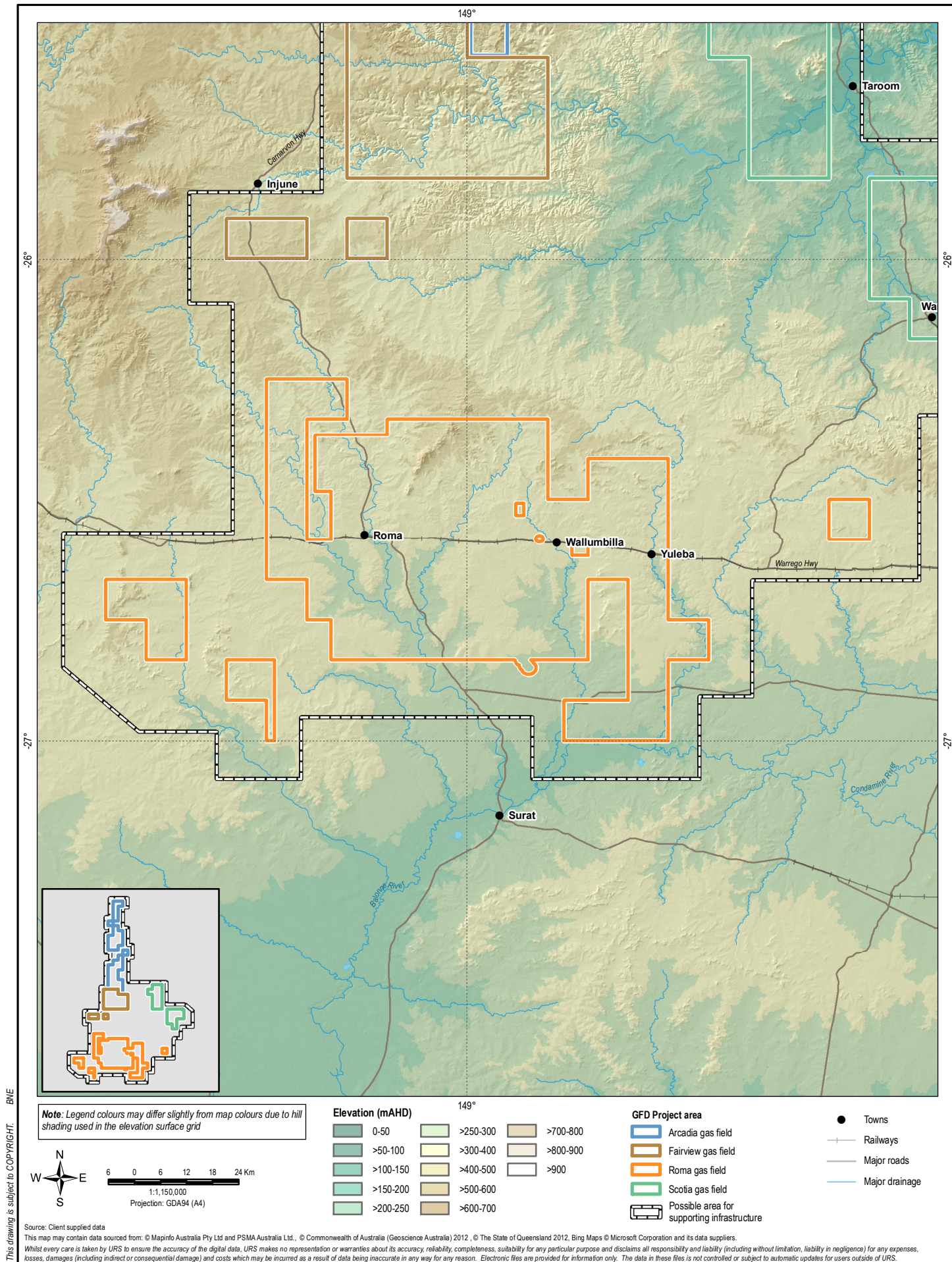
Table 4-1 GFD Project elevation ranges

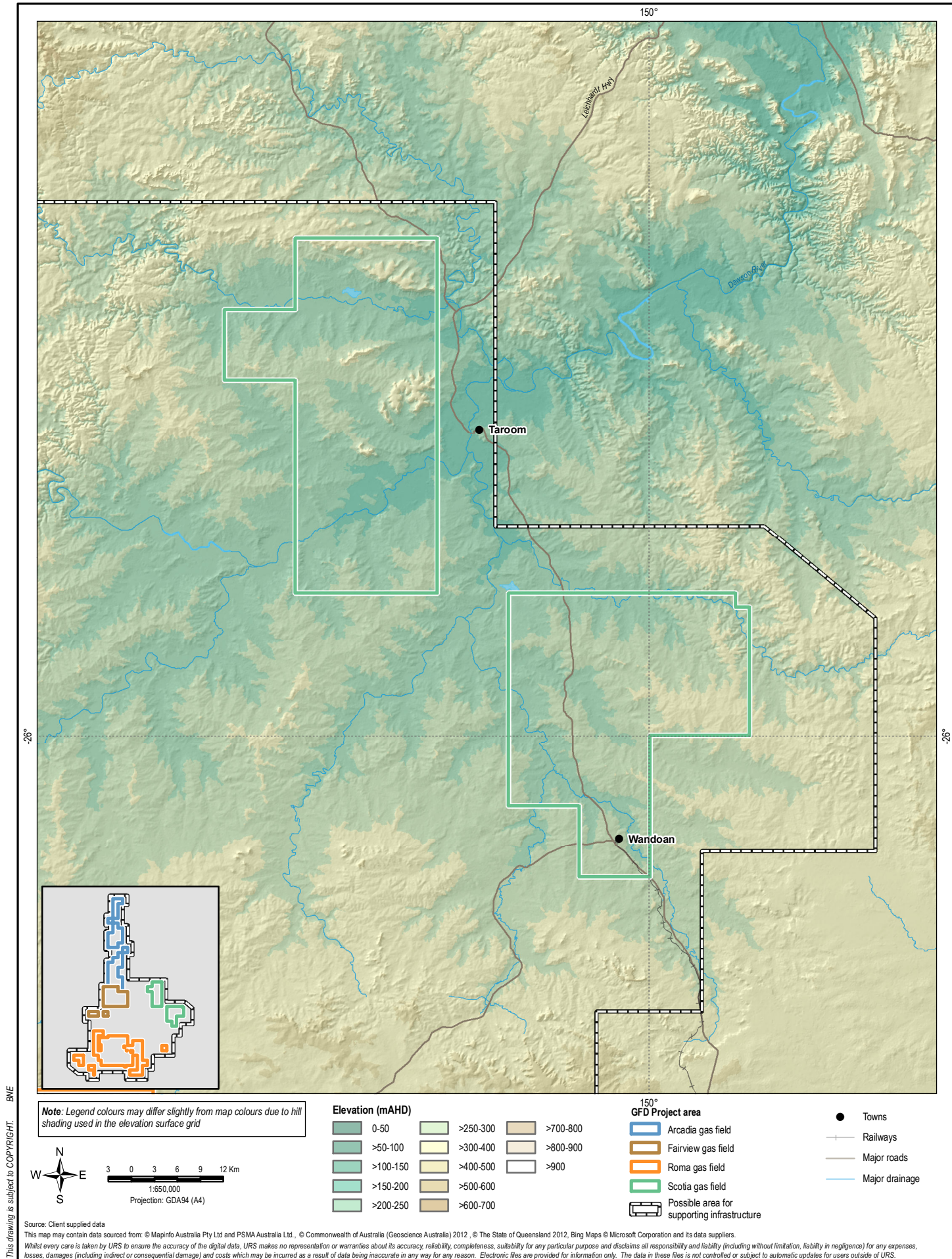
Gas field	Elevation range (~ m AHD)
Arcadia gas field	190 to 770
Fairview gas field	245 to 633
Roma gas field	241 to 635
Scotia gas field	186 to 375

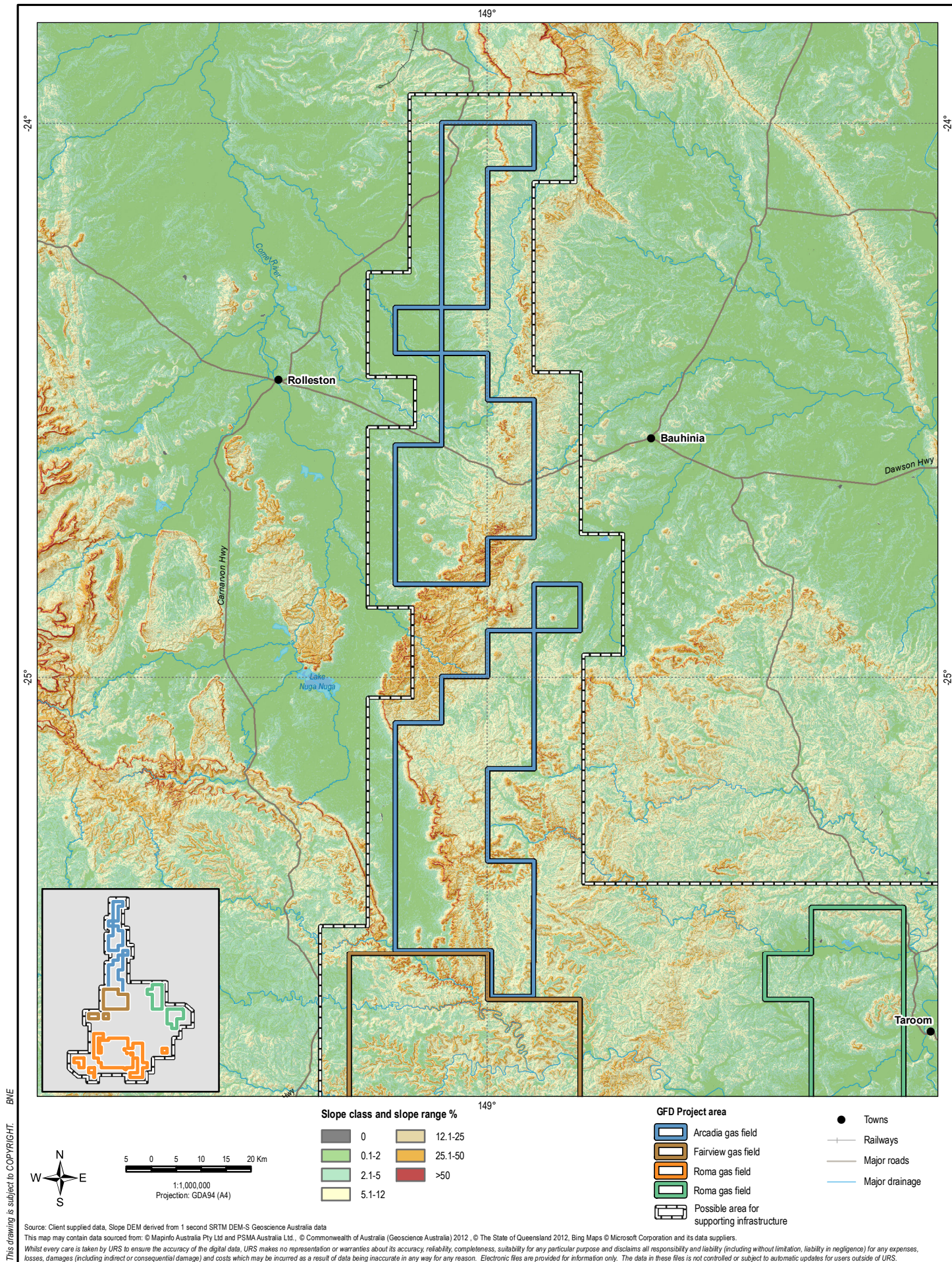


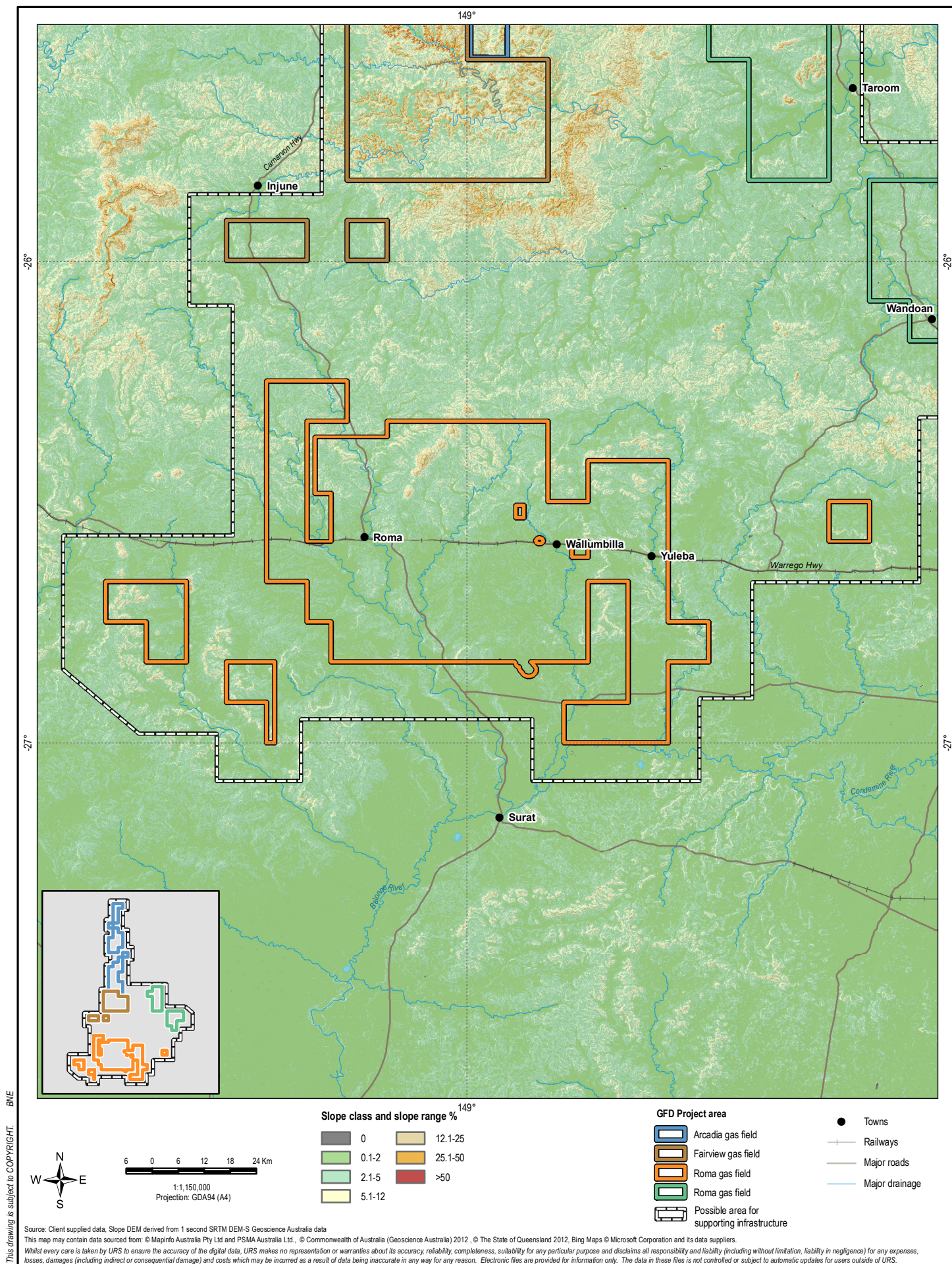


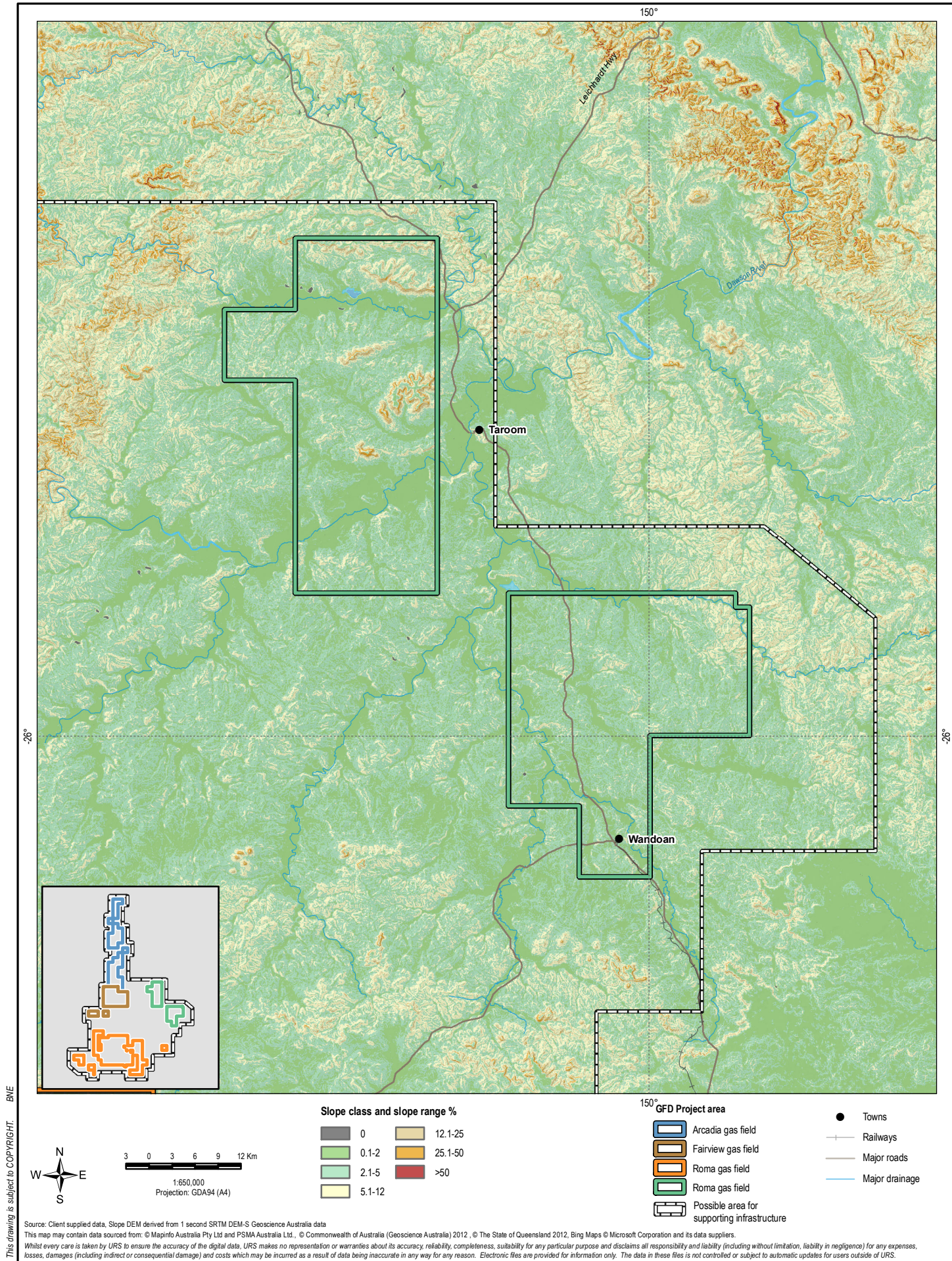












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4.2 Geomorphology

On a regional scale, sediments generated from the weathering of sedimentary rocks within higher elevations and steeper topography areas are transported by the streams that drain the GFD Project area. The sediments types are dominated by the source rocks, with erosive levels and sediment transport loads intermittent due to the climatic conditions and occur following extreme storm events and in excessive wet years when flooding occurs. In alternate years, the sediments are temporarily stored on the slopes, on the flood plains and within the stream channels. Abandoned river terraces of inferred Tertiary age along the northern edge of the Balonne River system, for example indicate that past climates allowed for the removal of large volumes of sediments, which are now stored as terrace materials which are occasionally reworked by streams.

Streams in general have well defined channels that are incised into the surrounding terrain to various degrees. This, combined with a relatively dry climate, has resulted in a low degree of lateral channel migration. Meander characteristics vary depending on localised geological and topographic conditions but the meanders are generally confined to the lowest floodplain level. Lateral channel migration is generally by either planar failure of sand dominated stream banks or erosion of flood return channels and relocation of the channels.

Most of the GFD Project area is considered “erosional”, except the alluvial plains where temporary sediment accumulation (deposition) occurs before re-mobilisation.

Isolated mesas with steep slopes and escarpments occur where resistant sandstones or silicified rocks form remnant topographic highs.

4.3 Geology

4.3.1 Regional geology

The GFD Project area is located within the extensive Bowen and Surat basins, which are south-dipping basins formed through the inflow and deposition of sediment in a depression within the Earth's crust, between the Permian (259 to 251 million years ago (ma)) to Cretaceous (141 ma to 65 ma) periods. These basins have structurally separate sedimentary depositional centres, but are stratigraphically and hydraulically connected (Habermehl, 2002). Most of the basins' sedimentary units dip at shallow angles (generally less than 10°) to the southwest.

The Early Permian to Mid-Triassic Bowen Basin geological units occur in the northern half of the GFD Project area, to about 100 km north of Taroom and about 50 km northeast of Injune. South of this area, sedimentary rocks of the Early Jurassic to Early Cretaceous Surat Basin sequence overlie the older Bowen Basin units. The geological setting of the GFD Project area is described in Table 4-2. The GFD Project area in relation to the two regional geological basins is shown in Figure 4-11.

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Bowen Basin

The Bowen Basin began as an extensive north-south trending back-arc basin developed on the landward (west) side of a continental arc associated with continent-ocean plate convergence. During the Early Permian period (~299 ma), the back-arc extended on the western margin of the basin producing a series of half-grabens, such as the Denison Trough, where initial deposition commenced. At the same time, andesite and volcanoclastics were deposited on the basin's eastern margin. Following the incursion of the sea over the arc, deltaic facies developed, with the subsequent accumulation of extensive coal deposits. Compressive deformation during the Late Permian period resulted in the deposition of volcanolithic sediments. Subsequent infilling of the sea by prograding deltas translated into the formation of wetlands and associated fluvial systems. Compressive tectonics in Middle to Late Triassic (251 ma to 141 ma) times terminated sediment accumulation and caused uplifting of the entire area.

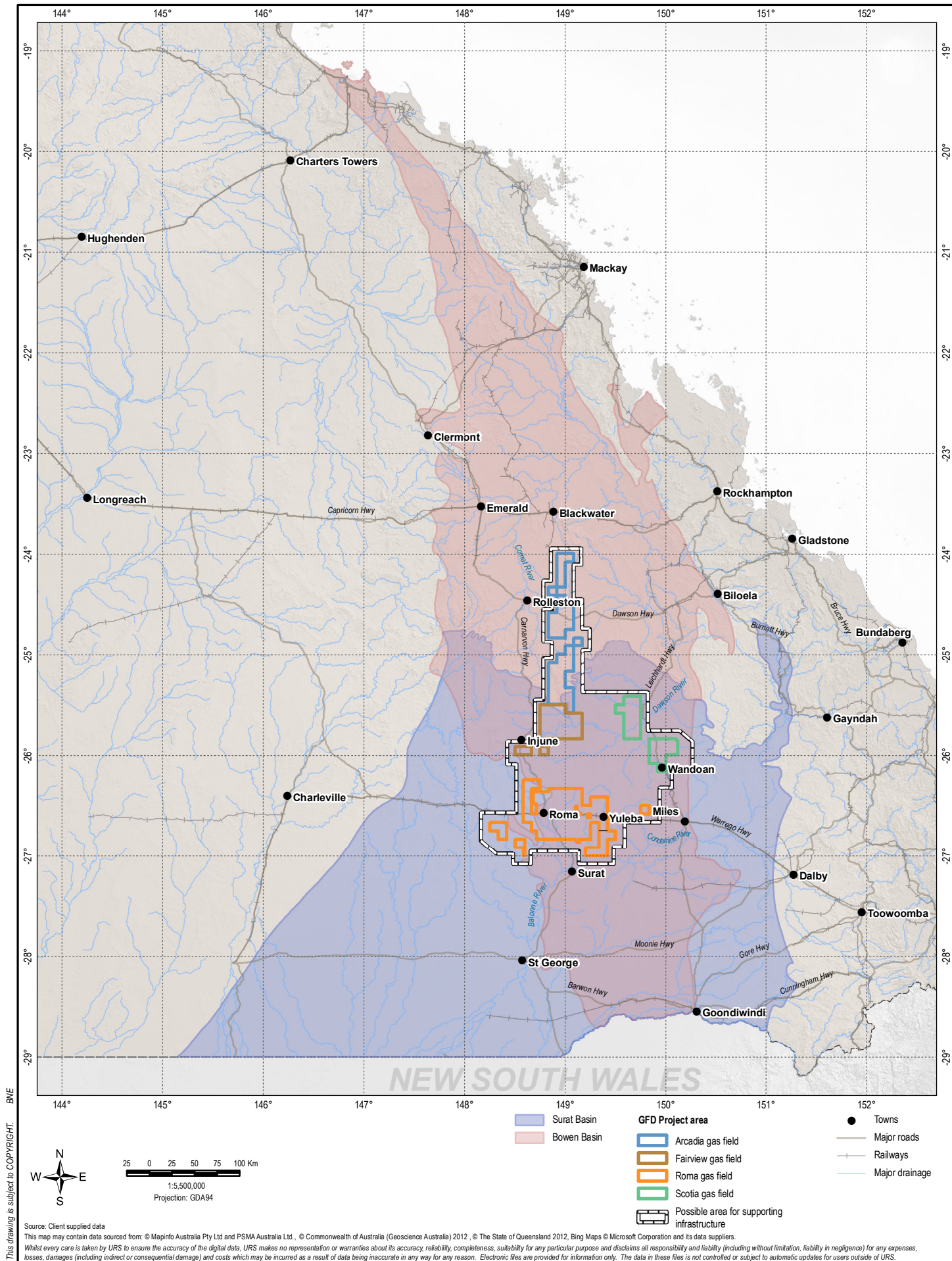
Surat Basin

The Surat Basin sequence formed during a widespread subsidence phase subsequent to an extensive period of uplift and erosion during the Middle to Late Triassic periods (251 ma to 141 ma) (Schlumberger, 2010). Sedimentation started in the Triassic and ceased in the Middle Cretaceous period (141 ma to 65 ma).

The geologic succession consists of braided stream deposits, followed by meandering stream and paludal coal-bearing sediments in the Jurassic age, shifting to coastal plain and shallow marine sediment accumulation as a result of the increase in sea level deposits in the Cretaceous period. Thick, semi-impervious units separate the complex multilayered system of aquifers. The lower part of each cycle is therefore predominantly sandstone with mostly siltstone, mudstone and coal in the upper parts.

Target coal seams

The primary coal seams of interest to the GFD Project area are located within Jurassic-age Walloon Coal Measures (Surat Basin) and the late Permian Bandanna Formation (Bowen Basin). The target coal seams are interbedded with mudstone, siltstone and sandstone.



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Table 4-2 Geological stratigraphy

Period	Basin	Group	Formation	Description
Quaternary			Alluvium / colluvium	Clay, silt, sand and gravel deposits; includes areas of colluvium and residual soils.
Tertiary			Main Range Volcanics	Alkali-olivine basalt, minor tuff, sandstone, mudstone.
			Sediments	Undifferentiated poorly consolidated sedimentary rocks; sub-labile to quartzose sandstone, siltstone, mudstone, minor conglomerate, coal, and limestone.
Cretaceous		Rolling Downs	Wallumbilla Formation – Coreena Member	Glauconitic siltstone, mudstone, very fine-grained sandstone, shelly fossils.
			Wallumbilla Formation – Doncaster Member	Mudstone, siltstone, minor quartz sandstone in part glauconitic, silty limestone, gypsum.
		Blythesdale	Bungil Formation	Glauconitic, labile to quartzose, siltstone, mudstone.
			Mooga Sandstone	Sandstone, siltstone, mudstone.
Jurassic			Orallo Formation	Sandstone, siltstone, mudstone, conglomerate, coal.
			Gubberamunda Sandstone	Sandstone, minor conglomerate, siltstone.
		Injune Creek	Westbourne Formation	Fluvial-lacustrine sediments; fine-grained sandstone interbedded with siltstone, claystone, minor coal.
			Springbok Sandstone	Clayey lithic sublabile to very lithic sandstone; calcareous in part; interbedded with carbonaceous mudstone and siltstone.
	Surat		Birkhead Formation/Walloon Coal Measures	Carbonaceous siltstone and mudstone, minor labile sandstone, coal. The Walloon Coal Measures transgressively grade into the siltstone and sandstone units of the Birkhead Formation.
			Eurombah Formation	Shale, siltstone, sandstone.
	Bundamba		Hutton Sandstone	Sublabile to quartzose sandstone, siltstone, mudstone, minor conglomerate and coal.
			Evergreen Formation	Labile and sublabile, sandstone, carbonaceous mudstone, siltstone and minor coal; local oolitic ironstone.
			Precipice Sandstone	Thick-bedded, cross-bedded, pebbly quartzose sandstone; minor lithic sublabile sandstone, siltstone, mudstone.
Triassic		Mimosa	Moolayember Formation	Micaceous lithic sandstone, micaceous siltstone.
			Clematis Sandstone	Quartz rich sandstone, conglomerate, siltstone, mudstone.
			Rewan Formation	Lithic sandstone, green to reddish brown mudstone, minor volcanilithic pebble conglomerate.
Permian		Blackwater	Bandanna Formation	Sandstone, siltstone, shale, mudstone, coal, tuff, conglomerate.
			Black Alley Shale	Shale, siltstone, tuff bentonite, labile sandstone.
	Bowen	Back Creek	Peawaddy Formation	Carbonaceous mudstone and siltstone, lithic sublabile sandstone, coquinitic siltstone.

Note: The zig-zag line is the geological symbol for unconformity – which refers to a gap in the geological record.

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4.3.2 Geological cross-sections

In order to illustrate the stratigraphy and present the target coal seams across the GFD Project, simplified geological cross-sections, presenting the main geological units presented in Table 4-2, were compiled and are presented in Appendix A: Geological cross sections.

4.3.3 Surficial geology

Most of the surface geology is dominated by geological units belonging to the two basins, with the addition of Tertiary (65 ma to 2.6 ma) and Quaternary (2.5 ma to 0 ma) age volcanic and sedimentary rocks, as well as unconsolidated sediments. The surface and near surface layers can be deeply weathered and laterised or more commonly, silicified profiles that formed erosion-resistant surficial silcrete.

Sedimentary deposition in the Tertiary consisted mostly of quartzose sandstone and conglomerate in small and isolated basins. Poorly consolidated siliciclastic sediments (mudrocks) occur in the northernmost portion of the GFD Project area, as well as in a roughly east-west belt along the Condamine-Balonne River system, south of the Warrego Highway. The second group of Tertiary rocks in the GFD Project area comprise alkali basaltic to trachytic intrusive and extrusive rocks. The basalts and trachytes, small plugs and flows, generally form topographic highs and plateaux within the northern part of authority to prospect (ATP) 745 and outside of the GFD Project tenure near Roma.

Quaternary alluvium and soil occur in the lower-lying areas throughout the GFD Project area. The area covered by these sediments generally forms elongated belts along existing streams and very gently sloping alluvial plains or slightly elevated terraces. The alluvium sourced from Permian age sedimentary rocks, Mesozoic (252 ma to 66 ma) age fine grained rocks, and Tertiary age volcanics are generally dispersive high shrink-swell clay dominated. Alluvium sourced from sandstone dominated Mesozoic age rocks and silicified or laterised Tertiary age sedimentary rocks generally comprises sand or clayey sand.

No known sites of paleontological significance or geomorphological significance occur in the GFD Project area. It is not expected that significant fossil specimens (such as dinosaur tracks) will be encountered during construction or operational activities on the project area. However if there is a significant find the Queensland Museum will be notified.

4.3.4 Structural geology

Near the northern margin of the Surat Basin, the main geological units do not indicate deformation or complex faulted geology. Faulting and folding, recognised in the older subsurface strata, is either absent or attenuated in the outcropping Jurassic-Cretaceous sediments. Some features are visible in the outcrop including the Alicker and Eurombah Anticlines, the Hutton-Wallumbilla Fault and a number of west-northwest trending faults.

The northwest trending Hutton-Wallumbilla Fault is located west of Roma and is downthrown to the west with a displacement of ~450 m in the basement, but just 30 m in the overlying sediments. Small northwest trending faults elsewhere in the GFD Project area are likely related to the movements that formed the Hutton-Wallumbilla Fault (Santos GLNG, 2009).

West-northwest trending faults also occur in the Roma area. These faults are likely a result of gradual uplift or subsidence related to the Surat Basin through the Tertiary period (Santos GLNG, 2009).

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These faults have limited or no vertical displacement.

The central part of the GFD Project area near Injune is situated between two large reverse fault systems that are oriented approximately north-south. Immediately to the east of Injune is an anticline, which plunges to the south-southeast and corresponds to a southerly extension of the Comet Ridge in the geological basement.

The major structural feature in the north of the GFD Project area is the Comet Ridge, which comprises mainly Devonian (410 ma to 354 ma) age rocks, and is covered by a relatively thin sequence of Permian and Triassic rocks. The Permian and Triassic sequence of sediments was folded during the late Triassic Period. Resultant fold axes are generally parallel trending northwest to the Comet Ridge axis. The Permian-Triassic folds are truncated by the erosional unconformity surface on which the Precipice Sandstone was deposited. The overlying Jurassic and Cainozoic (65.5 ma to the present) rocks are not folded (Golder, 2009).

4.3.5 Seismic activity

According to Geoscience Australia (2012), the highest seismicity hazard region in Queensland is along the eastern coast and near offshore regions, and along the Queensland/New South Wales border. The largest earthquakes recorded in Queensland occurred offshore of Gladstone in 1918 (Richter Magnitude 6.3) and near Gayndah in 1935 (Richter Magnitude 6.1). Structural damage to buildings was reported in the Rockhampton region during the Gladstone earthquake.

The GFD Project area is at a considerable distance from the most seismically-active areas of Queensland, and no earthquakes greater than Richter Magnitude 3 have occurred in the region of the GFD Project area in the last 50 years.

4.3.6 Geological environmental values

The key environmental values with the potential to be impacted by the GFD Project include:

- Geology, being the physical attributes of the geological structure underlying and relating to the GFD Project and its intrinsic value
- Fossils.

4.4 Landscape units

The identification of landscape units (LSU) provides the basis for the description of the physical environment and as mapped, shows the occurrence and distribution of geological regimes, landscape units and associated soil types occurring within the GFD Project area. Soil LSUs are reoccurring soil mapping units with similar geology, landforms, soils and vegetation associations. LSUs are often comprised of more than one soil type, generally with a dominant and several subdominant soil types likely to occur within a particular unit.

The soil LSUs described for the GFD Project area have been sourced from the Atlas of Australian Soils (Northcote *et al*, 1960-68), compiled by the CSIRO to provide a consistent national description of Australia's soils. With the mapped units being soil landscapes published at a scale of 1:2,000,000 compiled from a series of 10 maps at scales from 1:250,000 to 1:500,000.

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The data indicates that several soil landscapes occur within the GFD Project area. The soil landscape units that occur within each of the individual gas fields and across the whole of the GFD Project area are presented in Table 4-3 and shown in Figure 4-12 to Figure 4-15. The approximate areal extent (ha) of each LSU within each of the gas fields is provided, together with the areal extent of each LSU occurring within the GFD Project area, outside of the gas field tenure within the possible supporting infrastructure area (remaining area).

Table 4-3 GFD Project landscape units

LSU	Description	Dominant soil types	Gas field area (ha)		Remaining area* (ha)	Total (ha)
Bz1	High hilly to mountainous, strongly dissected, sandstone ranges and plateaux with strong scarps and often deep narrow ravines	Rudosols, with dark sandy or loamy-surfaced duplex soils on valley floors	Arcadia	86,375	98,600	197,000
			Fairview	12,020		
			Roma	0		
			Scotia	0		
Bz4	High plateaux with steep-scarped margins and relatively narrow dissected valleys	Sands, mostly shallow with frequent sandstone outcrops	Arcadia	11,014	62,010	157,820
			Fairview	84,801		
			Roma	0		
			Scotia	0		
Bz5	Elevated undulating to low hilly lands with many large rock outcrops	Rudosols, mostly shallow and often uniform textured stony sands	Arcadia	8,295	30,150	38,440
			Fairview	0		
			Roma	0		
			Scotia	0		
Cb3	Dunes of leached sands and exposed limestone. Swamps in low-lying situations	Sandy alkaline yellow mottled soils	Arcadia	0	7,150	7,150
			Fairview	0		
			Roma	0		
			Scotia	0		
CB3	Gentle to moderately undulating or rolling lands.	Vertosols, moderate to shallow depth, grey to brown cracking clays, with associate loamy duplex soils	Arcadia	0	437,530	557,480
			Fairview	14,422		
			Roma	105,525		
			Scotia	0		
CB4	Broadly undulating lands with occasional high ridges or low flat-topped hills	Cracking clays of moderate depth associate with loamy red duplex soils	Arcadia	0	4,920	4,920
			Fairview	0		
			Roma	0		
			Scotia	0		
CC17	Plains of slightly gilgaied (few inches) cracking clays associated with major and minor functional and non-functional drainage ways	Vertosols. Dominant soils are grey cracking clays and brown cracking clays	Arcadia	0	14,990	16,000
			Fairview	0		
			Roma	0		
			Scotia	1,015		
CC20	Gently undulating cracking clay plains	Vertosols. deep grey cracking clays	Arcadia	0	21,350	33,410
			Fairview	0		

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LSU	Description	Dominant soil types	Gas field area (ha)	Remaining area* (ha)	Total (ha)
	with moderate to strong (up to 1 m) gilgai microrelief	and some brown cracking clays associate with yellow duplex soils	Roma 0		
			Scotia 12,059		
CC21	Gently undulating or level plains	Vertosols. Deep, grey, cracking clays with a moderate to strong gilgai microrelief (0.5 to 1 m). with, associated thin-surfaced dark loamy duplex soils,	Arcadia 6,089		
			Fairview 0		
			Roma 0		
			Scotia 0	6,730	12,820
CC23	Level alluvial flood-plains associated with major streams, often dissected by numerous braided channels and mostly subject to irregular flooding:	Vertosols Dominant soils are deep grey clays	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 0	350	350
Fp1	Floodplains adjacent to stream lines, often dissected by present or prior drainage channels	Kandosols. Uniform loamy soils underlain by deep alluvial deposits	Arcadia 0		
			Fairview 0		
			Roma 18,208		
			Scotia 0	13,530	31,740
Fz1	Hills, ranges of hills, low hilly ridges, or dissected tableland remnants (mesa, butte, or cuesta forms)	Rudosols. Dominant soils are shallow loams with siliceous gravel, Associated soils include shallow sands and red earths	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 3,918	23,920	27,840
Fz2	Low hills and stony ridges, some mesa and butte-like residuals with shallow mostly stony soils	Rudosols. Dominant soils are shallow uniform loams and clays, with red and dark duplex soils.	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 14,607	42,020	56,620
Fz3	Undulating pediments on sandstone, shale, and dolomite with some dolerite and much rock outcrop	Main soils are shallow loams and sandy loams	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 0	17,170	17,170
Fz6	High hills, strongly dissected low ranges with some mesas	Dominant soils are shallow stony loams, Associated with shallow sandy soils	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 0	110,450	123,950
Fz9	Strongly undulating or low hilly areas, the hills mostly of mesa- or cuesta-like form	Dominant soils are gravelly mostly shallow loams associated with	Arcadia 7,800		
			Fairview 0		
			Roma 0	11,820	19,620

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LSU	Description	Dominant soil types	Gas field area (ha)	Remaining area* (ha)	Total (ha)
	with steep-scarped dissected margins	shallow sandy soils	Scotia	0	
li2	Former lake beds and flood-plains	Cracking yellow-grey clays in association with low eroded and scalded mounds of crusty loamy soils	Arcadia	0	
			Fairview	5,054	
			Roma	3,234	
			Scotia	0	
				7,470	15,760
li3	Alluvial plains associated with major drainage lines	Dominant soils are deep grey clays with a slight gilgai microrelief	Arcadia	1,717	
			Fairview	0	
			Roma	0	
			Scotia	0	
				11,780	13,500
Kb10	Gentle or moderately undulating plains with occasional higher stony ridges or broad low hill crests	Vertosols. Dominant soils are shallow to moderately deep dark cracking clays, often with linear gilgai on slopes	Arcadia	2,411	
			Fairview	0	
			Roma	0	
			Scotia	0	
				3,130	5,540
Kb7	Low hills and high steep-sided plateau remnants	Mostly shallow stony dark clays and rock outcrop	Arcadia	0	
			Fairview	0	
			Roma	0	
			Scotia	4,089	
				0	4,090
Kd7	Level alluvial plains adjacent to drainage lines	Dominant soils are deep dark clays	Arcadia	0	
			Fairview	0	
			Roma	378	
			Scotia	0	
				6,270	6,640
Kd8	Gentle or moderately undulating lands.	Primarily Vertosols. Dominant soils are mostly deep dark cracking clays with important areas of deep red-brown cracking clays	Arcadia	5,188	
			Fairview	0	
			Roma	0	
			Scotia	0	
				6,160	11,350
Me4	Undulating or occasionally low hilly lands with some residual mesas	Dominant soils are brown friable earths	Arcadia	567	
			Fairview	0	
			Roma	0	
			Scotia	0	
				7,550	8,110
Mm13	Very gently undulating outwash fan-plains	Dominant soils are deep sandy red earths	Arcadia	0	
			Fairview	0	
			Roma	0	
			Scotia	0	
				2,990	2,990
MM4	Undulating plains. This landscape unit occurs in the lower	Vertosols. Dominant soils are brown cracking clays with a very slight (up to	Arcadia	0	
			Fairview	0	
			Roma	0	
				102,530	167,180

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LSU	Description	Dominant soil types	Gas field area (ha)		Remaining area* (ha)	Total (ha)
	RL undulating land within	10 cm) gilgai microrelief; Associated with deeper brown or grey cracking clays	Scotia	64,647		
MM6	Gently undulating or almost level plains. This landscape unit occurs in the steeper undulating land	Primarily Vertosols. Dominant soils are brown/grey cracking clays, slight (15 to 30 cm) gilgai microrelief, associated soils are loamy brown and dark duplex soils	Arcadia	0	30,920	97,130
			Fairview	0		
			Roma	0		
			Scotia	66,215		
MM7	Low hilly to hilly terrain on volcanic rocks and appearing as open valleys in steep hilly to mountainous land, gentle to moderate side slopes to shallow streams with significant flats	Chief soils are neutral dark and yellow friable earths with friable brown soils	Arcadia	52,291	43,150	95,520
			Fairview	81		
			Roma	0		
			Scotia	0		
My21	Undulating elevated plains with some steep-scarped dissected margins and occasional low hills	Chromosols and Kandosols. Dominant soils are loamy red earths	Arcadia	0	100	100
			Fairview	0		
			Roma	0		
			Scotia	0		
My3	Gently undulating plains with occasional high ridges and cuesta-like scarps.	Kandosols. Dominant soils red earths with some yellow earths, shallow uniform loams occur on the higher ridges and scarps	Arcadia	0	31,840	34,950
			Fairview	0		
			Roma	0		
			Scotia	3,111		
Mz3	Undulating low plateau, occasionally with low scarped margins, Low hilly to hilly lands with very occasional conical basalt peaks	Dominant soils are loamy, or occasionally sandy	Arcadia	12,380	0	12,380
			Fairview	0		
			Roma	0		
			Scotia	0		
Mz5	Undulating to gently undulating elevated plains often bounded by steep lateritic scarps, smaller residual occurrences of the unit often occur as scarp-bordered low mesas. A small area of this landscape unit occurs in the northern area	Kandosols. Dominant soils are slightly acid loamy red earths which may occasionally contain nodular gravels	Arcadia	0	2,710	4,830
			Fairview	0		
			Roma	2,120		
			Scotia	0		

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LSU	Description	Dominant soil types	Gas field area (ha)	Remaining area* (ha)	Total (ha)
of ATP 803					
Oa4	Moderately undulating lands with some low hills	Dominant are red loamy duplex soils	Arcadia	0	1,770
			Fairview	0	
			Roma	0	
			Scotia	0	
Oc21	Very gently undulating plains or occasional low flat terraces fringing drainage lines.	Sodosols. Hard alkaline red soils. associated with red earths on elevated areas, and cracking clays in the lower-lying sites	Arcadia	0	25,660
			Fairview	0	
			Roma	0	
			Scotia	12,183	
Oc22	Undulating lands with some plains fringing drainage-ways	Sodosols. Dominant soils are red loamy duplex soils with brown duplex soils	Arcadia	0	66,990
			Fairview	0	
			Roma	0	
			Scotia	3,918	
Oc23			Arcadia	0	0
			Fairview	0	
			Roma	0	
			Scotia	11,979	
Oc24	Broadly undulating lands	Dominant soils are red loamy duplex soils with brown duplex soils	Arcadia	15,045	10,760
			Fairview	0	
			Roma	0	
			Scotia	0	
Rf3	Moderately undulating lands with some rounded low hills and occasional higher closely dissected hilly areas	Dominant soils are brown loamy duplex soils with associated loamy red soils	Arcadia	28,684	21,120
			Fairview	0	
			Roma	0	
			Scotia	0	
Rf5	Moderate or occasionally strongly undulating lands; some areas of gently sloping small plains	Loamy-surfaced brown duplex soils are dominant soils	Arcadia	4,937	15,250
			Fairview	0	
			Roma	0	
			Scotia	0	
Rf6	Level or very gently undulating alluvial plains fringing drainage-ways	Dominant soils are loams with weakly developed brown clay subsoils	Arcadia	4,808	3,060
			Fairview	0	
			Roma	0	
			Scotia	0	
Ro4	Gently undulating plains	Sodosols. Dominant soils are hard alkaline duplex brown soils.	Arcadia	0	123,950
			Fairview	0	
			Roma	0	

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LSU	Description	Dominant soil types	Gas field area (ha)		Remaining area* (ha)	Total (ha)
		associated with red, dark and yellow duplex soils	Scotia	158,049		
Ro5	Undulating lands	Sodosols. Dominant are brown loamy duplex Associated are red duplex soils and cracking clays	Arcadia	0	63,290	89,760
			Fairview	0		
			Roma	0		
			Scotia	26,466		
Rq1	Strongly undulating or low hilly lands	Dominant are gravelly shallow loamy duplex soils with mottled clay subsoils	Arcadia	0	83,670	83,670
			Fairview	0		
			Roma	0		
			Scotia	0		
Rt1	Level or very gently undulating alluvial plains fringing major drainage lines	Dominant loamy soils with uniform deep sands	Arcadia	0	0	2,510
			Fairview	0		
			Roma	0		
			Scotia	2,512		
Si3	Moderately undulating lands with some small level flood-plains associated with minor streams	Sodosols. Dominant soils are fairly shallow (25 to 60 cm.) yellow-grey duplex soils with thin-surfaced loams or clay loams overlying dense grey clay subsoils	Arcadia	0	143,090	197,360
			Fairview	8,281		
			Roma	0		
			Scotia	45,985		
Si5	Alluvial flood-plains mostly associated with major streams; sometimes dissected by broad shallow drainage lines	Most common are loamy duplex soils and grey-brown clay subsoils	Arcadia	3,696	14,111	17,800
			Fairview	0		
			Roma	0		
			Scotia	0		
SI12	Low hilly lands consisting of undulating or level plateaux, often with steep-scarped margins, and lower dissected areas that are moderate to strongly undulating	Complex range of soils occurs-- dominant are sandy to loamy duplex soils	Arcadia	0	1,880	1,880
			Fairview	0		
			Roma	0		
			Scotia	0		
SI4	Small stream floodplains that rise gradually to moderately undulating marginal valley slopes	Sodosols. Dominant soils are yellow-grey hard-setting loamy duplex soils. Associated are similar brown and dark soils cracking clays	Arcadia	0	132,570	159,240
			Fairview	0		
			Roma	2,6671		
			Scotia	0		
SI5	Moderate to strongly undulating lands	Dominant are sandy to loamy-surfaced	Arcadia	0	100	100
			Fairview	0		

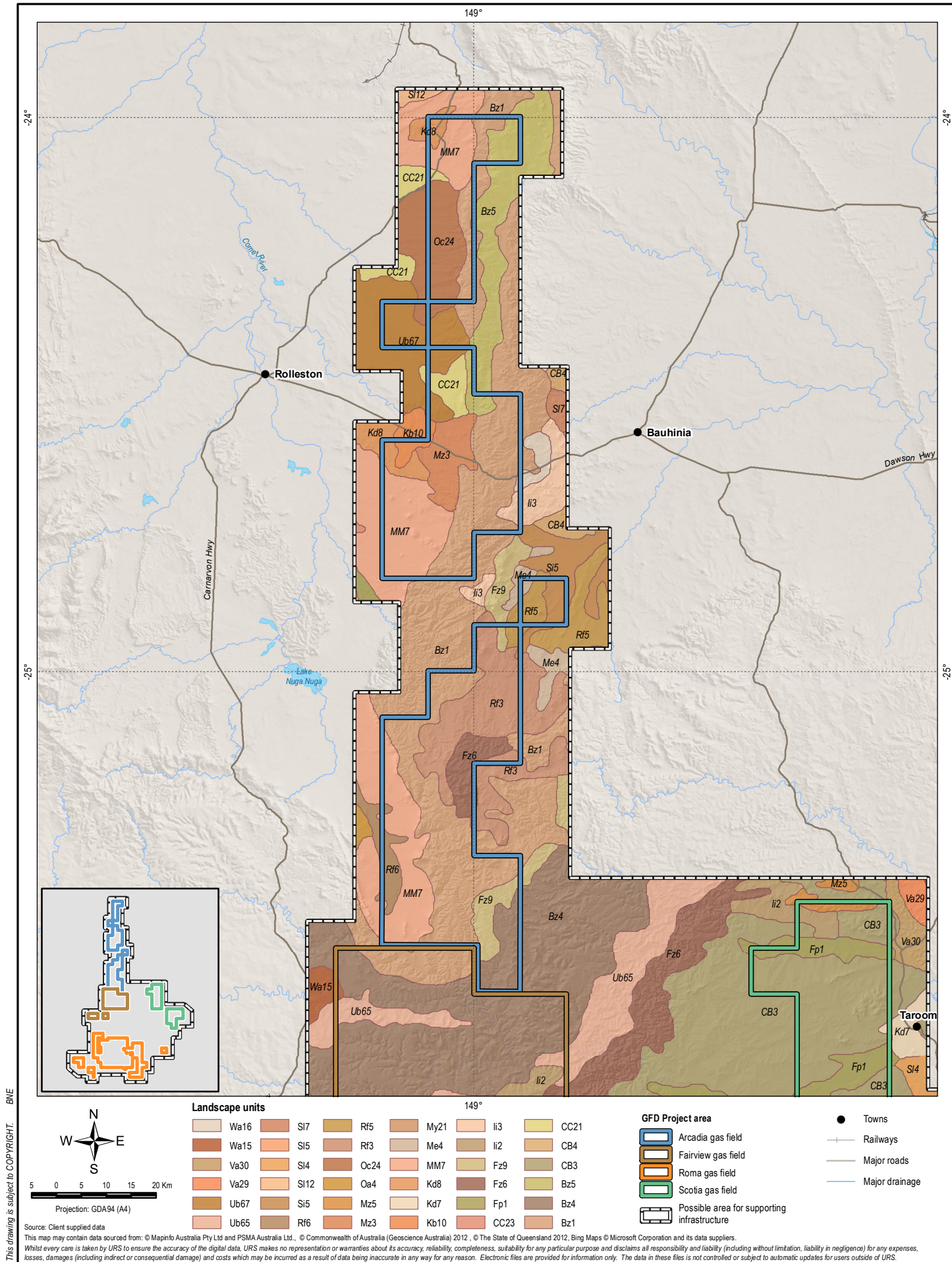
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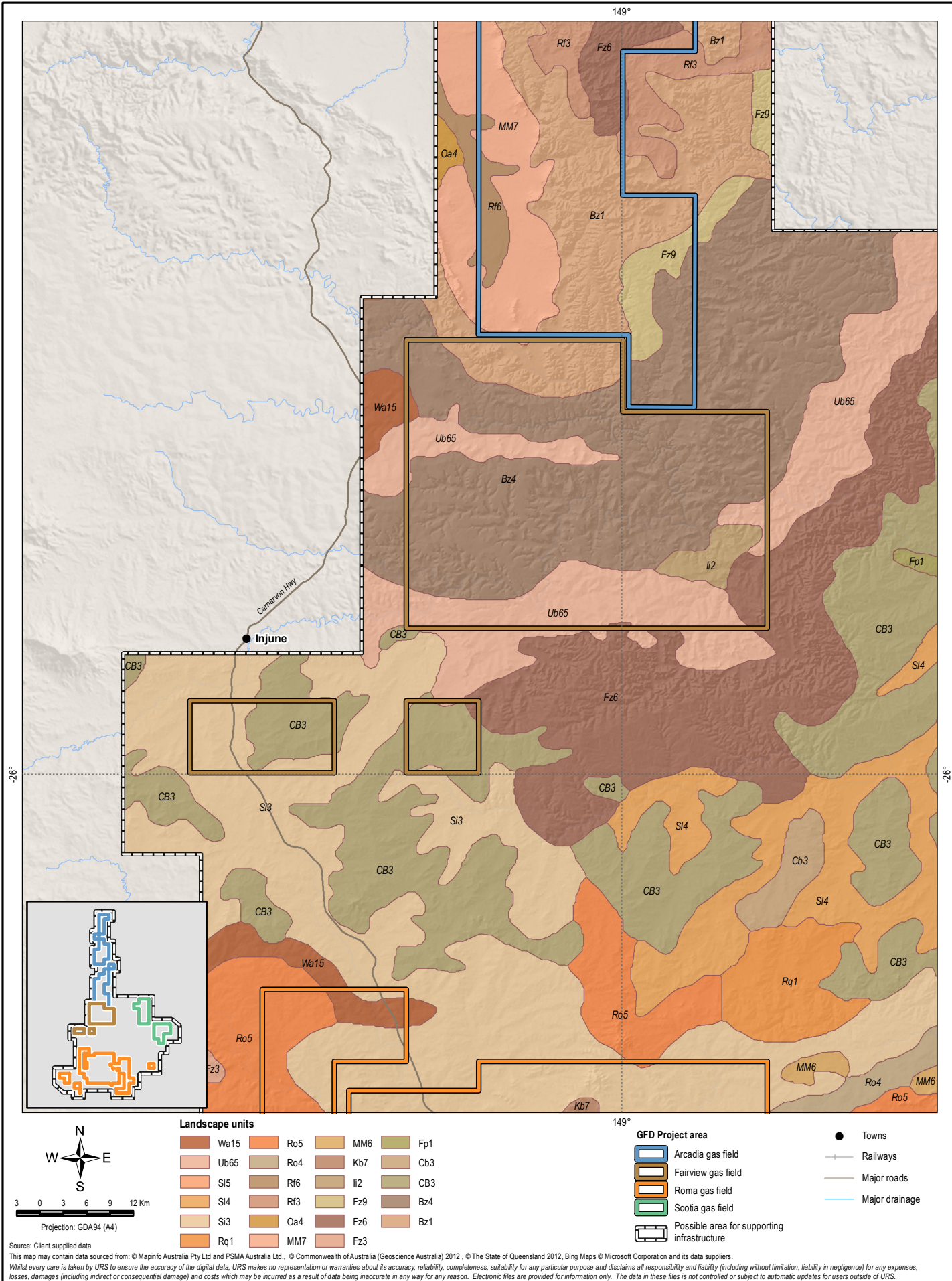
LSU	Description	Dominant soil types	Gas field area (ha)	Remaining area* (ha)	Total (ha)
		duplex soils	Roma 0		
			Scotia 0		
SI7	Very gently undulating or level alluvial plains	Dominant are loamy duplex soils with grey or grey-brown heavy clay subsoils	Arcadia 0		
			Fairview 0		
			Roma 0	2,540	2,540
			Scotia 0		
Ub64	Moderately undulating lands	Sandy-surfaced mottled duplex soils, some areas of alkaline duplex soils on lower slopes	Arcadia 0		
			Fairview 0		
			Roma 0	36,390	36,390
			Scotia 0		
Ub65	Moderate to strongly undulating lands	Dominant soils are sandy-surfaced mottled duplex soils. Associated stony ridges have shallow sands	Arcadia 0		
			Fairview 32,780		
			Roma 0	52,610	85,390
			Scotia 0		
Ub67	Gentle to moderately undulating plains	Vertosols. Dominant soils are shallow grey cracking clays with areas of dark or brown clays. Associated soils are mainly loamy duplex soils	Arcadia 11,255		
			Fairview 0		
			Roma 0	24,300	35,550
			Scotia 0		
Va24	Gently undulating plains	Sodosols. Main soils are hard alkaline and neutral yellow mottled soils. Associated are: brown duplex soils; sandy yellow duplex soils near drainage lines; and small areas of red duplex soils	Arcadia 0		
			Fairview 0		
			Roma 0		
			Scotia 134,27	49,060	62,480
Va29	Undulating or rarely strongly undulating lands with an occasional isolated low hill	Dominant soils have fine loamy A horizons overlying mottled clay	Arcadia 0		
			Fairview 0		
			Roma 0	3,830	3,830
			Scotia 0		
Va30	Undulating or moderately undulating lands with occasional low hilly areas	Sodosols on moderate slopes loamy-surfaced duplex soils are dominant, and cracking clays with associated duplex soils on more gentle slopes	Arcadia 0		
			Fairview 0		
			Roma 4,252		
			Scotia 0	34,450	38,700

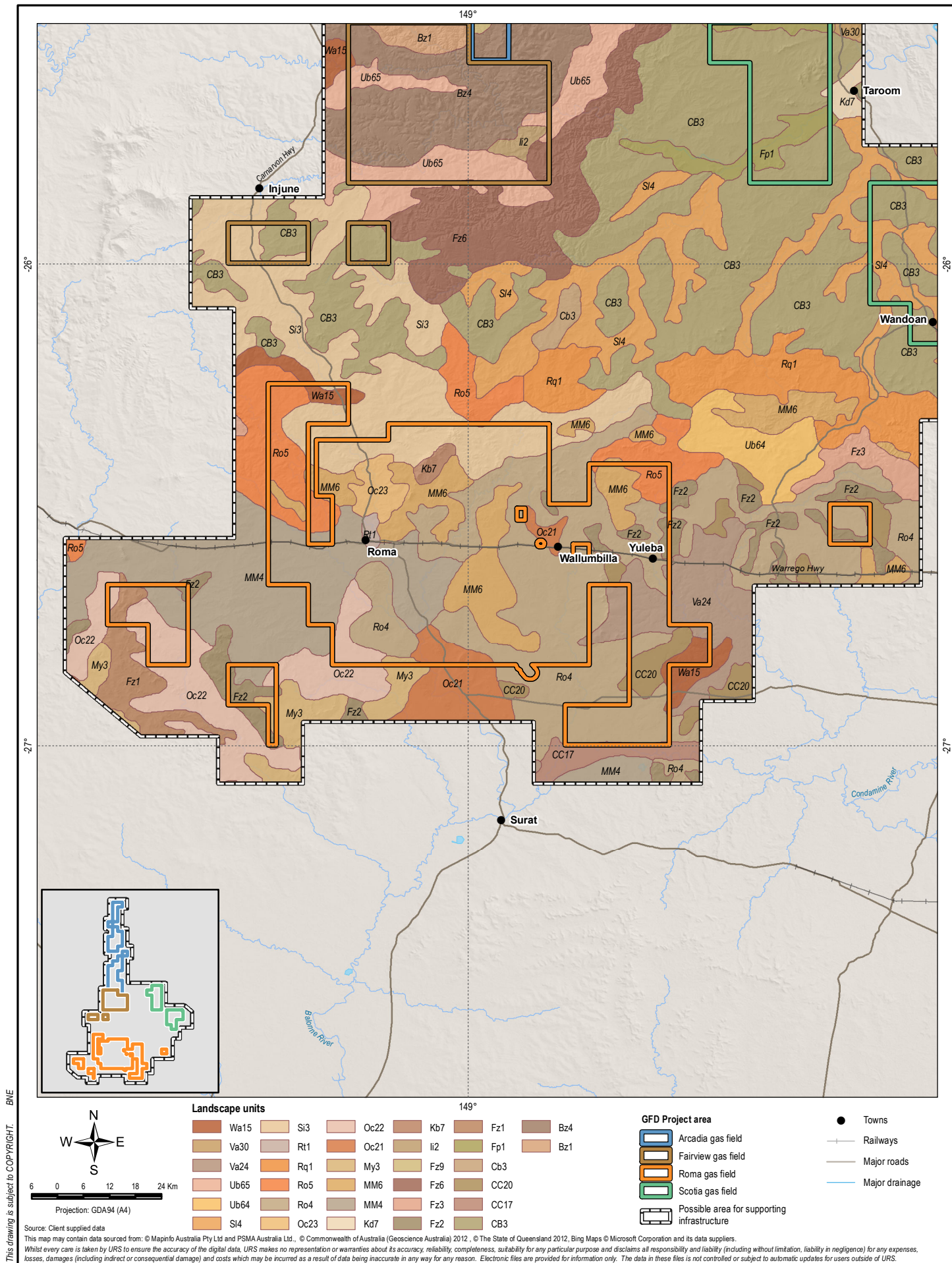
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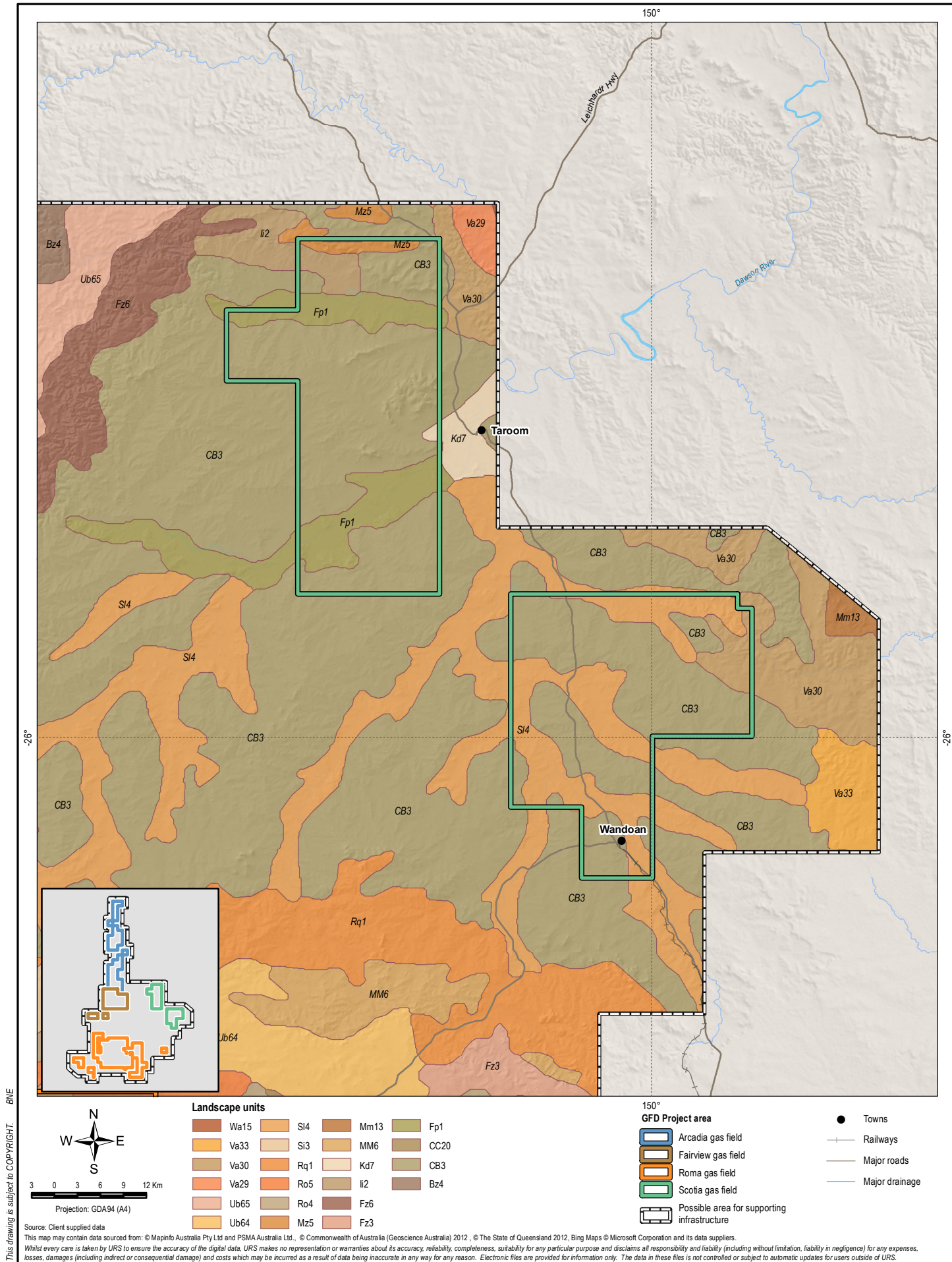
LSU	Description	Dominant soil types	Gas field area (ha)	Remaining area* (ha)	Total (ha)
Va33	Low concave convex hills with some mesas of lateritized rock	Chief soils are hard alkaline yellow mottled soils. Hard acidic yellow and red mottled soils. Small areas of other soils may occur	Arcadia	0	11,040
			Fairview	0	
			Roma	0	
			Scotia	0	
Wa15	Moderate to strongly undulating lands with occasional low mesa-like hills	Primarily Kandosol. Dominant soils have deep sandy A horizons (30 to 60 cm) overlying strongly mottled acid yellow sandy clays. Associated are hard sandy yellow duplex soils and deep uniform sand soils	Arcadia	0	18,470
			Fairview	420	
			Roma	0	
			Scotia	7,986	
Wa16	Undulating or moderately undulating lands	Dominant soils have deep sandy A horizons overlying mottled clay or sandy clay	Arcadia	351	3,840
			Fairview	0	
			Roma	0	
			Scotia	0	

*Remaining area of each of the LSU within the GFD Project boundary excluding the areas within each of the gas fields









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4.5 Soils

4.5.1 Soils in the GFD Project area

Eight major soil groups (Stace *et al*, 1968) occur within the GFD Project area (Table 4-4). Typical soil profile characteristics have been mapped as 13 soil mapping units (SMUs), which have been determined from various sources including the regional land system and soil mapping conducted by CSIRO (1967, 1968 and 1974), the Australian Soil Resource Information System (Department of Agriculture, Fisheries and Forestry, 2012), the Digital Atlas of Australian Soils (Digital Atlas, Bureau of Rural Science, 1991) and the 2009 EIS, which collectively cover the GFD Project area.

4.5.2 Major soil groups

The major soil groups identified cover a wide range of soil types and include uniform coarse textured (sandy) soils, uniform and gradational medium-textured (loamy) soils (in particular uniform loams), gravelly loams, red and yellow earths and lateritic red earths. Also included are sandy and loamy surface texture contrast (duplex) soils, uniform or gradational fine textured grey and brown non-cracking clays and black, dark grey and brown cracking clay soils. The soil groups are characterised by increasingly finer texture and higher plasticity in the subsoil layers with increasing soil group number (Table 4-4).

Table 4-4 Description of major soil groups

Soil group	Soil description	Soil classification		
		Aust. Soil Group ⁽¹⁾	P.P.F. ⁽²⁾	ASC ⁽³⁾
1	Skeletal, rocky or gravelly soils (>60% coarse fragments) with sandy, silty, loamy or clayey soil matrix	Shallow rocky soils; Lithosols	K- Uc1, Um1, Gn1, Uf1	Rudosols
2	Sandy soils; shallow to deep uniform or weakly gradational profiles; includes stratified alluvial soils, residual sand soils, earthy sands	Siliceous sands Earthy sands Lithosols	(Ucl-Uc6)(2)	Rudosols, Tenosols
3	Coarse to medium-textured soils; uniform or gradational profiles; predominantly sandy earths with sand, silty or clayey sand over clayey sand-sandy clay soil profiles	Sandy Earths Sandy Red-Yellow Earths	(Uc4-5, Uml-3); Gn2.11, Gn2.12	Tenosols
4	Medium-textured sandy, sandy loam or silt to clay loamy surface uniform or gradational profiles with clay loam, light clay or medium clay subsoils, in places with siliceous stone and/or ferruginous gravelly lenses included	Shallow Loams, Gravelly Loams, Red and Yellow Massive Earths, Lateritic Red-Yellow Earths	Um2.12 K Um2.12 Um4.11 Gn2.12 Gn2.22	Tenosols, Kandosols or Ferrosols

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Soil group	Soil description	Soil classification		
		Aust. Soil Group ⁽¹⁾	P.P.F. ⁽²⁾	ASC ⁽³⁾
5	Sand, loamy sand, sandy loam or loamy surface duplex soils over acidic to locally strongly acidic, in places neutral or slightly alkaline sandy clay to medium to heavy clay subsoils	Red, Yellow & Brown Podzolic Soils ; Grey & Brown Soloths	Dr2.12, 2.22 Dy3.42, 3.22 Dy3.12, 3.32 Db1.41	Red-Brown Chromosols; Sodic Yellow & Brown Kurosols
6	Fine sandy, silty or clay loamy surface duplex soils with neutral to alkaline often calcareous, sodic and locally saline medium to heavy clay or heavy clay subsoils	Yellow, Brown, Red-brown Solodic Soils; Solodized Solonetz	Db1.33, 1.13 Dr2.13, Dy2.23, Dd1.13	Brown Sodosols, Chromosols, or Calcarosols
7	Shallow uniform often gravelly fine textured soils, medium to deep uniform fine-textured (non-cracking) clay soils or gradational often stony or gravelly clay loam or light clay surface soils over alkaline medium to heavy clay subsoils, locally sodic and saline in the deeper subsoils – some deep incipient cracking clays	Alluvial Soils Dark brown Grey-brown or Dark Reddish brown (Non-Cracking) Clay Soils, some Solonchaks	Uf6.31, 6.32 Uf6.61, 6.63 Uf6.32, 6.21 Gn3.22, 3.42 Gn3.93, 3.13 Gn3.12	Dermosols
8	Shallow to medium to deep uniform fine-textured (cracking) clay soils, locally with thin self-mulching surficial soils with dark grey, brown or black mostly alkaline or alkaline over acidic heavy clay subsoils in areas with Gilgai micro-relief	Black Earths Grey, Brown and Black	Ug5.12, 5.21 Ug5.24, 5.25 Ug5.38, Ug5.15, 5.16	Vertosols

Notes: ⁽¹⁾ Soil Group (Stace et.al, 1968), ⁽²⁾ Principal Profile Form (Northcote, 1974), ⁽³⁾ Dominant Australian Soil Classification (Isbell, 2002).

4.5.3 Soil types

Each soil group is further comprised of one or more soil profile variants (soil types) described to occur within each of the particular soil groups, in order to differentiate between similar soils which may potentially occur within the individual groups (Santos GLNG, 2009).

Soil Types in Soil Group 1 – Group 1 soils comprise mainly shallow to medium deep stony, gravelly and rocky soils, typically with >60% coarse fragments in a sandy, silty, loamy or clayey soil matrix. Only the one general soil type was identified within this group.

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Soil Types in Soil Group 2 – Group 2 soils comprise uniform or weakly gradational coarse-textured sandy soil profiles. Three soil types identified within the group are as follows:

- **Soil Type 2.1** - These soils occur mainly on the eroded plateau margins, on steep dissected scarps and hilly lands mainly in the sandstone plateau areas and comprise mainly shallow (<0.5 m) acidic sands and gravelly sands underlain by weathered sandstone or colluvium derived there-from. In terms of Australian Soil Taxonomy (Great Soil Groups), these soils are classified as – lithosols; Principal Profile Form (PPF –Northcote, 1974) -Uc1.21; Australian Soil Classification (ASC Isbell, 1996) – acidic rudosols.
- **Soil Type 2.2** - These soils comprise mainly alluvial, in places stratified alluvial or colluvial deposits comprising medium deep (>0.5 m) uniform slightly acidic brown single-grain loose sand soils. These soils are classified as - Alluvial soils; (Uc1.22); stratic rudosols.
- **Soil Type 2.3** - These soils occur mainly on the mid to lower slopes in hilly sandstone lands and comprise medium to deep (0.5->1.0 m) sands and loamy sand soils with organic humic surface soils over red-brown or yellowish red slightly too moderately acidic sandy subsoils underlain by weathered rock. These soils may be classified as deep leached sands; (Uc1.23, Uc1.41); leptic rudosols.

Soil Types in Soil Group 3 – Group 3 soils comprise uniform or gradational coarse to medium-textured uniform or gradational predominantly sandy earth soil profiles. Two soil type variants identified within this group are as follows:

- **Soil Type 3.1** - This soil occur on upper slopes and crests in hilly lands and comprise shallow uniform or weakly gradational bleached massive earthy sands and ferruginous gravelly sandy loam soils with neutral to acidic subsoils transitional to the weathered rock substrate. These soils are classified as – earthy sands-sandy red and yellow earths; (Gn2.12, Gn2.22); bleached orthic tenosols.
- **Soil Type 3.2** - As mapped these soils occur on banks and levees along alluvial drainage-ways and comprise medium to deep (0.5->1.0 m) gradational massive earthy sand soils with neutral to slightly acidic brown sandy light clay or clayey sand subsoils. These soils are classified as – alluvial earthy sands-sandy earth soils; (Gn2.22); stratic rudosol-tenosol.

Soil Types in Soil Group 4 – Group 4 soils include medium-textured frequently stony or gravelly uniform or gradational loam to clay loam soil profiles with massive to weakly to moderately structured clay loam, light clay or medium clay subsoils. Three soil type variants have been identified within this soil group, details of which are as follows:

- **Soil Type 4.1** - These soils occur on the higher parts of strongly undulating to low hilly lands and on the cretal areas and upper marginal slopes of hilly and high hilly lands where they comprise mainly shallow (<0.5 m) stony and/or ferruginous gravelly uniform or weakly gradational brownish black, brown, red-brown or red massive loams and clay loam soil profiles underlain by weathered rock. These soils are classified as lithosols – shallow gravelly loams; leptic rudosols, red-brown kandosols.
- **Soil Type 4.2** - As mapped these soils occur on the mid slopes of low rises in strongly undulating plains underlain by Permian sediments. They comprise medium to deep (0.5->1.0 m) gradational loamy surface red earth soils with clay loam to light clayey subsoils often with lateritic gravel included. These soils are classified as loamy red earths; (Gn2.12); red kandosols; ferric red kandosols.
- **Soil Type 4.3** - As mapped these soils occur on low rises and on levees and alluvial terraces in the upper parts of narrow valley floors. They comprise medium to deep (0.5->1.0 m) gradational sandy loam to loamy surface soils over red and brown weak to moderately well-structured neutral to moderately alkaline clay loam to light clayey subsoils. These soils are classified as loamy red earths; (Gn3.13, 4.12); red kandosols.

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For the group 4 soils, calcium and magnesium are reported by R. H. Gunn – CSIRO (1967) to be the dominant cations; cation exchange capacity (CEC) is low (<8 m-equiv./100g soil), plant available water capacity (PAWC) is low. Soil salinity levels are low and indicative testing of the fines content of the soils indicates non to very low dispersion characteristics.

Soil Types in Soil Group 5 – Group 5 soils comprise sand, loamy sand and loamy surface duplex soils with mostly acidic to neutral or slightly alkaline sandy clay to medium to heavy clay subsoils.

Three soil type variants have been identified within this soil group, details of which are as follows:

- **Soil Type 5.1** - These soils occur mainly in hilly lands underlain by sandstone bedrock and in particular on the eroded margins of dissected sandstone plateau areas. They comprise shallow (<0.5 m) sandy, sandy loam or loamy surface duplex soils with yellow-brown, grey-brown or red-brown often gravelly, weak to moderately strongly structured acidic to neutral, in parts strongly acidic sandy clay or medium to heavy clay subsoils with hard dry consistence. These soils are classified as soloths; red-brown chromosols; red-brown kurosols.
- **Soil Type 5.2** - These soils occur in undulating and gently to moderately sloping lands underlain by sandstone bedrock and in parts by intrusive (granitic) bedrock. They comprise medium to deep (0.5->1.0 m) duplex soils with thick (>0.3 m) sand or loamy sand surface (A) horizon, often with a pale or bleached sub-surface (A2) horizon with an abrupt change to yellowish-brown, grey-brown or reddish-brown, locally prominently mottled sandy clay to medium clay sub-soils. The subsoils are poorly drained, mostly moderately to strongly acidic with massive tending to coarse blocky or columnar structure with depth. These soils are classified as red-yellow-brown chromosols and sodic kurosols.
- **Soil Type 5.3** - These soils occur on slopes of up to 5% and are similar to Soil Type 5.2 except that they have thinner (<0.3 m) sandy, sandy loam or loamy surface soils that tend to be hard-setting, usually with a pale or bleached (A2) sub-surface horizon underlain by brown or yellowish brown sandy clay or medium clay neutral to moderately acidic hard, medium to coarse blocky structured subsoils. These soils are classified as red-brown earths, red-brown chromosols, red-brown sodosols.

The available data indicates these soils are acidic in the surface soil horizons, tending to neutral in the deeper subsoils. CEC is low in the surface soils (<5 m-equiv./100 g soil) and <20 m-equiv./100 g soil in the subsoil horizons. Magnesium is the dominant metal cation throughout the profile. Total soluble salts and salinity levels were low in the surface soils but tend to increase to moderate levels in the deeper subsoils. The less gravelly (more clayey) soil variants tend to be non-sodic to slightly sodic in the surficial soil layers, becoming strongly sodic in the subsoils below a depth of about 0.6 m. The high levels of sodium and magnesium indicate potential soil structural instability and potential for dispersion of the deeper clay materials. Total nitrogen and available phosphorus are mostly deficient in the surface soil horizons.

Soil Types in Soil Group 6 – Group 6 soils comprise mostly thin fine sandy loam, silt loam or clay loamy surface duplex soils with neutral to alkaline, often strongly alkaline, usually with carbonate present in the medium to heavy clay or heavy clay subsoils. Two soil type variants were identified within this soil group, details of which are as follows:

- **Soil Type 6.1** - These soils occur mainly on undulating plains, rolling rises and low hilly lands underlain by siltstone or mudstone bedrock. They comprise shallow (<0.5 m), gravelly, sandy or loamy surface duplex soils with yellow-brown, grey-brown or red-brown often gravelly, strongly alkaline sandy clay, light clay or medium to heavy clay subsoils with hard dry consistence and weak to moderate blocky to columnar soil structure. These soils are classified as solodic soils; (Dr2.23, Dy2.43, 2.23, Db1.23); red-yellow-brown sodosols.
- **Soil Type 6.2** – These soils occur on gently to moderately inclined foot-slopes, on undulating plains and lowlands and on alluvial plains, stream terraces and floodplains associated with major streams and rivers, where they often occur in association with non-cracking clays and

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cracking clay soils of Group 7 and Group 8 respectively. Type 6.2 soils comprise medium to deep (0.5->1.0 m) mainly thin (<0.3 m) hard-setting slightly acidic, fine sandy to silt loamy or clay loamy surface duplex soils in places with a pale or bleached sub-surface (A2) horizon. There is a sharp transition to the subsoil (B) horizon which comprises brown, yellow-brown or red brown alkaline to strongly alkaline medium to heavy clay subsoils which have moderates amounts of soft carbonate inclusions and weak to moderate blocky to columnar soil structure with hard dry consistence. The deeper subsoils tend to become more massive, apedal and strongly cohesive heavy clays with low to moderate levels of sodicity and salinity usually present. These soils may be classified as red-yellow-brown sodosols.

The soils are non-saline and non-sodic in the surficial soil layers becoming sodic, moderately dispersive and moderately saline in the deeper subsoils. The ratio of calcium to magnesium is low (<1.0) throughout the profile. Reference to R. H. Gunn – CSIRO (1967) with respect to these soils, further indicates that calcium is the dominant metal cation in the surface soils whilst magnesium is dominant in the subsoils. Exchangeable sodium is high in the subsoils and the preponderance of sodium and magnesium accounts for the poor physical properties and dispersive characteristics of the subsoil layers.

Soil Types in Soil Group 7 – As a group these soils comprise shallow and deep uniform fine-textured (noncracking) clay soils and gradational clay loam or light clayey surface soils with either acidic or alkaline, often sodic and in places saline medium to heavy clay or heavy clay subsoils. Locally the soils tend to exhibit characteristics of (incipient) cracking clay soils. Three soil variants have been identified, details of which are as follows:

- **Soil Type 7.1** – These soil profiles occur mainly on low hilly, hilly and higher hilly lands where mainly developed on argillaceous sedimentary rock types and intermediate to basic volcanic rock lithologies. They comprise mainly shallow to medium deep (0.5-0.7 m) uniform light to medium acidic clays, or gradational clay loam, gravelly clay loam or gravelly clay surface soils with 30-50% fine gravel and coarse stone over gravelly acidic or alkaline dark brown, grey-brown clays or medium to heavy clay subsoils underlain by weathered rock generally below about 0.6-0.8 m. These soils are classified as dark brown and grey-brown (non-cracking) clays: (Uf6.31, 6.32); gravelly grey-brown and red-brown dermosols. Analytical data from two sites tested (Appendix L3 of the 2009 EIS) indicates the clayey subsoils contain slightly to moderately sodic and dispersive soil layers. The ratio of calcium to magnesium in samples tested was very low, indicating potential soil structural stability problems.
- **Soil Type 7.2** – These soils occur mainly on undulating alluvial plains and on undulating lowlands and gently inclined slopes adjacent to and along drainage lines. They comprise medium to deep uniform clay soil profiles with light to medium clay texture throughout, or grade from clay loam at the surface to light to medium clay subsoils below about 0.3- 0.5 m. The surface soils have granular structure becoming sub-angular blocky in the subsoils, tending to massive in the deeper subsoils. The surface soils are mostly dark brown and neutral to moderately acidic, with a gradual change to brown, yellowish or reddish-brown moderately to strongly alkaline clay subsoils. These soils are classified as Dark Brown and Grey-brown (Non-cracking) Clay Soils: (Uf6.31, 6.21); Grey, Brown or Red Dermosols. Limited available analytical data from two sites (Appendix L3 of the GLNG Project EIS) indicates these soils tend to be slightly sodic and dispersive in the upper soil layers and strongly sodic and dispersive in the deeper subsoils. Soil salinity levels are low near the surface and in places become moderately high in the deeper subsoils.
- **Soil Type 7.3** – These soil profiles occur locally in association with soils of Group 5 on the lower foot-slopes. The soils comprise deep uniform clays or gradational brown to yellowish red silty clay or heavy clay surface soils with diffusely mottled reddish-brown, brown or yellow-brown neutral to acidic, in places strongly acidic, sodic and locally approaching the coast, moderately to highly saline in the medium to heavy or heavy clay subsoils. These soils are classified as acidic sodic mottled grey, brown and red-brown dermosols. Indicative soil testing and analytical data indicates that these soils are sodic and tend to become increasingly sodic to

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very high levels in the deeper heavy clay subsoils. However the samples tested from similar depths for dispersion class were non-dispersive, possibly related to the strong levels of acidity throughout the profile. Calcium/magnesium ratios were all very low and soil salinity levels were moderate increasing too high in the deeper medium to heavy clay subsoil layer.

Soil Types in Soil Group 8 – In general, Group 8 soils include shallow, medium and deep to very deep uniform fine-textured (cracking) clay soils with dark grey, brown or black mostly alkaline medium to heavy clays throughout, or alkaline over acidic heavy clay subsoils in areas with intensive gilgai surface micro-relief. The soils are strongly reactive and prone to substantial horizontal and vertical movement and associated cracking in the upper parts of the soil profile due to seasonal wetting and drying cycles. Three soil type variants have been identified, details of which are as follows:

- **Soil Type 8.1** – These soils occur on slopes, mostly 2-3% locally up to 5% on gently undulating erosional plains and lowlands and undulating low plateau surfaces underlain by Tertiary volcanic rock types mainly basalt and on low rises underlain by argillaceous Permian sedimentary and volcanic rock types. They comprise shallow (<0.6 m) mainly uniform light to heavy clays formed in situ. Surface soils when dry to just moist, have a friable, self-mulching granular structure becoming hard with medium to coarse angular blocky below (0.25 m) approximately. Soil reaction trend is neutral to slightly acidic near the surface and moderately to strongly alkaline in the subsoil where soft carbonate is usually present. Soil colour near the surface is dark grey or grey brown, becoming lighter with depth approaching the underlying weathered rock zone. These soils are classified as Black Earths; (Ug5.12, 5.27, 5.32); Self-mulching Black or Brown Epicalcareous Vertosols.
- **Soil Type 8.2** – These soils occur on rises and mid to upper slopes (2-5%) in gently to moderately undulating plains and lowlands formed on Triassic, Permian and some Tertiary mudstone, shale and calcareous sandstones. They comprise medium to deep (0.6->1.0 m) uniform sandy medium to heavy clays, colours are dark grey or grey-brown at the surface becoming gradually lighter with depth. Soil reaction at the surface is acidic to moderately alkaline and moderately to strongly alkaline in the deeper subsoils where soft carbonate is usually present. The surface soils generally have a thin crusty to weak granular friable self-mulching surface layer grading through hard coarse blocky structure in the subsoil tending to massive soil structure in the deeper subsoils (>0.6-0.8 m). These soils may be classified as Black Earths or Grey and Brown Soils of Heavy Texture; (Ug5.12, 5.15, 5.27, 5.32); Self-mulching Black or Brown Vertosols.
- **Soil Type 8.3** – These soils occur in the lower-lying older alluvial plains and river floodplain areas with near level to gently undulating relief. They are deep to very deep (typically >1.5 m), uniform medium to heavy clay soils typically with strongly developed gilgai micro-relief with vertical intervals between gilgai mounds and troughs ranging from 0.3 to 1.0 m. Surface soils are dark grey-brown, dark grey or brown, which generally become lighter in colour with depth. Black manganiferous staining is common below a depth of 1.0 m and prominent coarse red, yellow or brown mottling occurs in the deeper subsoils. When dry, there is usually a thin surface crust present on the gilgai mounds, underlain by hard coarse blocky structured subsoils. Large cracks form in the gilgai depressions and there is usually a thin self-mulching granular surface layer present. Soil reaction is variable but frequently moderately to strongly alkaline near the surface, with soft carbonate present in the subsoil layer, becoming acidic to strongly acidic in the deeper subsoil layers. Surface and internal profile drainage is poor and water may be retained in the gilgai depressions for lengthy periods. These soils may be classified as Grey and Brown Soils of heavy texture; Dark Grey, Black or Brown Vertosols.

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Analytical data for Soil Type 8.3 from R. H. Gunn – CSIRO (1967), indicates salinity levels are low in the surficial (0.6 m) soil layers, becoming higher in the lower subsoils. Soil exchangeable sodium percentage (ESP) levels are <10% in the surficial soils but become high (15-25%) in the subsoils and extremely high (>25%) in the deeper subsoils. Calcium is the dominant metal cation in the surface soil layers, with magnesium becoming dominant in the deeper subsoils indicating potential soil structural instability and dispersion in the deeper subsoil layers. Nitrogen, phosphorus and potassium levels are variable but generally at moderately high levels and clay mineral determinations indicate that montmorillonite and kaolinite are the co-dominant clay minerals.

4.5.4 Soil mapping units

For mapping purposes, 13 individual SMUs were developed for the GFD Project area based on the eight soil groups, which describe the soil distribution across the GFD Project area (GLNG Project EIS, 2009), at an appropriate scale. Each SMU is comprised of more than one of the soil type (described for each of the eight soil groups), and provides an indication of which soil types are likely to occur and also guides appropriate soil management practices within a particular SMU. A description of the SMUs is presented in Figure 4-16, with the distribution of SMUs shown in Figure 4-17 to Figure 4-20. Area totals for the individual SMUs within each gas field and for the whole GFD Project area are summarised in Table 4-5.

Table 4-5 GFD Project area soil mapping unit areas

SMU	Description	Gas field area (ha)		Remaining area (ha)*	Total (ha)
1	Rudosols – Skeletal and shallow rocky soils	Arcadia	125,074	6,898	233,744
		Fairview	92,944		
		Roma	8,828		
		Scotia	-		
2	Rudosols – Uniform coarse textured sandy soils	Arcadia	-	1,686	1,686
		Fairview	-		
		Roma	-		
		Scotia	-		
3	Tenosols and Kandosols – Sandy Red and Yellow Earths & Red and yellow massive earths – shallow to medium deep <0.6m	Arcadia	-	477	8,771
		Fairview	-		
		Roma	8,294		
		Scotia	-		
4	Tenosols and Kandosols – Sandy Red and Yellow Earths & Red and yellow massive earths –medium to deep 0.6- >1.0m	Arcadia	1,214	3,545	39,763
		Fairview	-		
		Roma	29,231		
		Scotia	5,773		
5	Chromosols, Kurosols & Sodosols – Duplex soils with neutral to moderately acidic, locally strongly acidic subsoils – shallow to medium deep <0.6m	Arcadia	-	-	-
		Fairview	-		
		Roma	-		
		Scotia	-		

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SMU	Description	Gas field area (ha)		Remaining area (ha)*	Total (ha)
6	Chromosols, Kurosols & Sodosols – Duplex soils with neutral to moderately acidic, locally strongly acidic subsoils – medium to deep 0.6- >1.0m	Arcadia	19,648	-	84,097
		Fairview	2,777		
		Roma	61,672		
		Scotia	-		
7	Chromosols, Kurosols & Sodosols – Duplex soils with neutral to moderately alkaline, locally strongly alkaline subsoils – shallow to medium deep <0.6m	Arcadia	20,924	-	27,540
		Fairview	1,476		
		Roma	-		
		Scotia	5,140		
8	Chromosols, Kurosols & Sodosols – Duplex soils with neutral to moderately alkaline, locally strongly alkaline subsoils – medium to deep 0.6- >1.0m	Arcadia	4,1693	4,105	424,637
		Fairview	46,502		
		Roma	308,862		
		Scotia	23,475		
9	Dermosols – Dark Brown & Grey Brown Soils - shallow to medium deep <0.6m	Arcadia	-	-	6,185
		Fairview	-		
		Roma	6,185		
		Scotia	-		
10	Dermosols – Dark Brown & Grey Brown Soils - medium to deep 0.6- >1.0m	Arcadia	4,223	-	111,032
		Fairview	10,801		
		Roma	-		
		Scotia	96,008		
11	Vertosols – cracking clay soils - shallow to medium deep <0.6m	Arcadia	-	-	-
		Fairview	-		
		Roma	-		
		Scotia	-		
12	Vertosols – cracking clay soils - medium to deep 0.6- >1.0m	Arcadia	60,891	3,732	150,815
		Fairview	7,910		
		Roma	48,290		
		Scotia	29,992		
13	Vertosols – cracking clay soils - medium to very deep 0.6- >1.5m	Arcadia	-	2,487	2,487
		Fairview	-		
		Roma	-		
		Scotia	-		

*Remaining area of each of the SMU within the GFD Project boundary excluding the areas within each of the gas field tenure

Skeletal and shallow rocky soils (rudosols)

1

Shallow to very shallow (mostly <0.3 m) rocky, stony or gravelly soils (>60% coarse fragments) with a sandy, loamy or clayey soil matrix; as mapped includes Soil Types 1-2.1, 1-4.1, 1-7.1 and some occurrences of shallow to medium deep (<0.6 m) stony or gravelly sand, sandy loam and loamy soils (Types 2.1, 3.1 & 4.1).

Uniform coarse-textured sandy soils (rudosols)

2

Mostly medium to deep (0.6->1.0 m), some shallow yellow, brown and red sandy soils (Type 2.2 and 2.3), some shallow sands (Type 2.1) and medium to deep thick sandy duplex soils (Type 5.2 & 6.3) occur locally.

Sandy red and yellow earths & red and yellow massive earths (tenosols & kandosols)

3

Shallow to medium deep (<0.6 m) sandy red-yellow earths-earthly sand soils (Type 3.1), shallow gravelly loam soils and gravelly loamy red-yellow earth soils (Type 4.1); rock outcrop, broken rock and boulders may occur in parts.

4

Medium to deep (0.6->1.0 m) loamy red-yellow earths and lateritic red-yellow earth soils (Type 4.2); some occurrences of shallow gravelly red earth soils (Type 4.1); minor occurrences of sandy to loamy surface duplex soils (Type 5.2, 5.3 & 6.2), minor deep red sandy soils (Type 2.2).

Texture contrast (duplex) soils (chromosols, kurosols & sodosols)

- Duplex soils with neutral to moderately acidic, locally strongly acidic subsoils

5

Shallow to medium deep (<0.6 m) sandy to loamy surface red, red-brown, brown or dark grey-brown acidic duplex soils (Type 5.1); in parts similar but slightly acidic to alkaline duplex soils (Type 6.1) may also occur; minor deeper duplex soils (Type 5.3 & 6.2) may also occur locally.

6

Medium to deep (0.6->1.0 m) thick sandy surface duplex soils (Type 5.2) with grey-brown, yellow-brown or red-brown coarsely mottled subsoils; similar but thinner sandy to loamy surface duplex soils (Type 5.3) also occur; some uniform sandy soils (Type 2.1, 2.3) and massive red-yellow earth soils (Type 4.1, 4.2) in parts.

- Duplex soils with neutral to moderately alkaline, locally strongly alkaline subsoils

7

Shallow to medium deep (<0.6 m) sandy to loamy surface red, red-brown, brown or dark grey-brown alkaline duplex soils (Type 6.1); in parts, similar neutral to slightly acidic duplex soils (Type 5.1) may also occur together with some deeper duplex soils (Type 6.2); some cracking clay soils (Type 8.2) in lower-lying parts

8

Medium to deep (0.6->1.0 m) fine sandy to silt and clay loamy surface duplex soils (Type 6.2) with dark brown, brown, yellow-brown or red-brown alkaline clay subsoils; may include some occurrences of red and yellow earth soils (4.1 & 4.2) on rises and dark brown and grey-brown soils (Type 7.3) and cracking clay soils (Type 8.2) in lower-lying parts.

Dark brown & grey-brown soils (dermosols)

9

Shallow to medium deep (<0.6 m) mainly uniform fine-textured gravelly clay soils (Type 7.1) often in association with shallow cracking clay soils (Type 8.1); some deeper uniform clays or gradational clay loam over clay soils (Type 7.3) and cracking clay soils (Type 8.2) on mid to lower slopes.

10

Medium to deep (0.6->1.0 m) mainly uniform clays or gradational clay loam over clay soils (Type 7.2 & 7.3); some shallow gravelly uniform or gradational clay soils (Type 7.1) and shallow cracking clays soils (Type 8.1) on upper slopes and rises; some deeper dark grey-brown cracking clay soils (Type 8.2) in lower-lying parts.

Cracking clay soils (vertosols)

11

Shallow to medium deep (<0.6 m) cracking clay soils (Type 8.1) occurring mainly on crests and upper slopes and underlain by basalt and argillaceous sedimentary rock types, in places with shallow gravelly loams and clay loam soils (Type 4.1) and uniform gravelly clay soils (Type 7.1); some medium to deep cracking clay soils (Type 8.2) may occur on mid to lower slopes.

12

Medium to deep (0.6->1.0 m) dark grey-brown, brown or black cracking soils (Type 8.2), locally in association with uniform (non-cracking) clay soils (Type 7.3) and some shallow gravelly uniform clay soils (Type 7.1) on rises; minor shallow to medium deep loamy surface duplex soils (Type 5.1, 5.3 & 6.2) may occur locally.

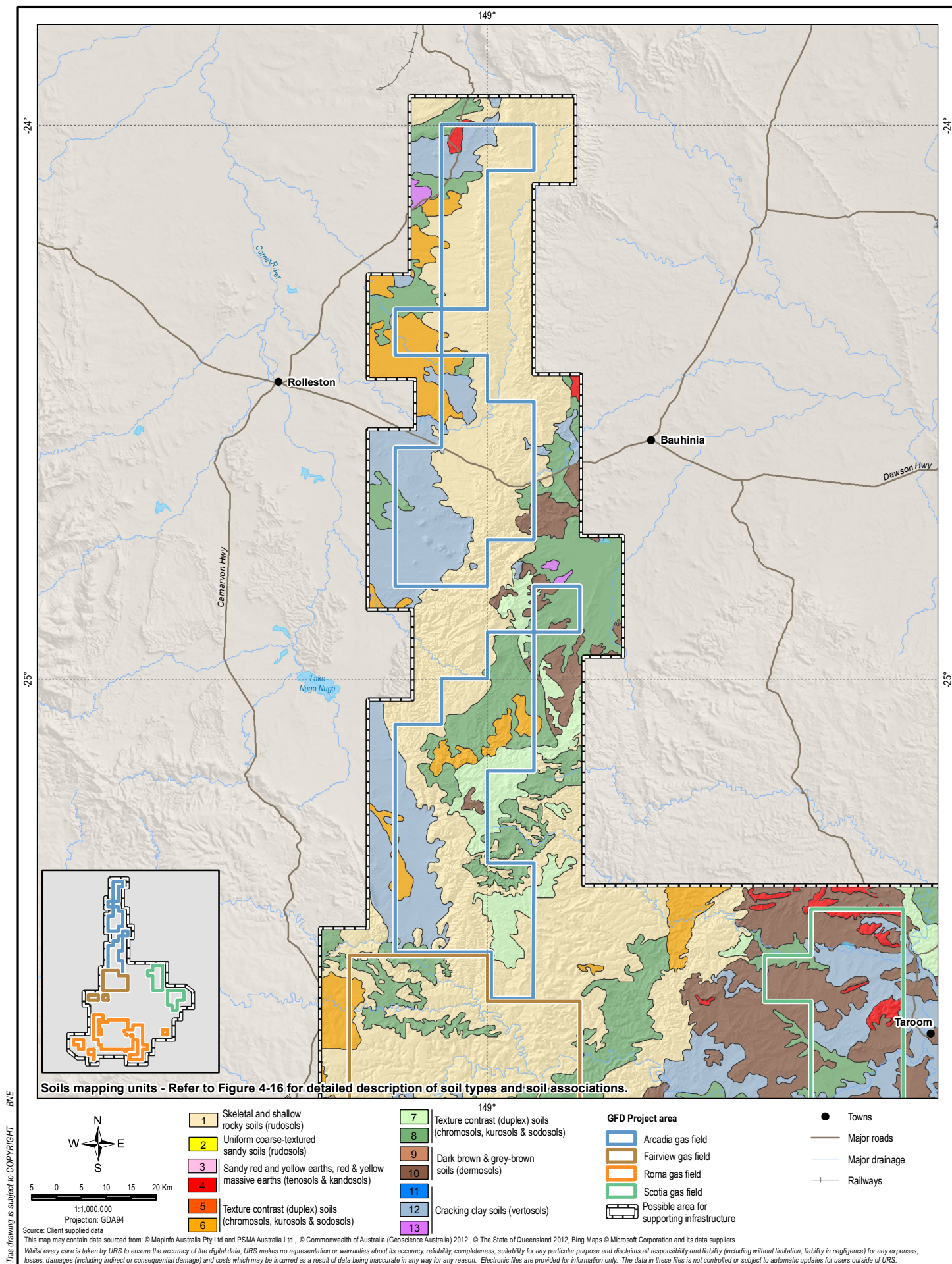
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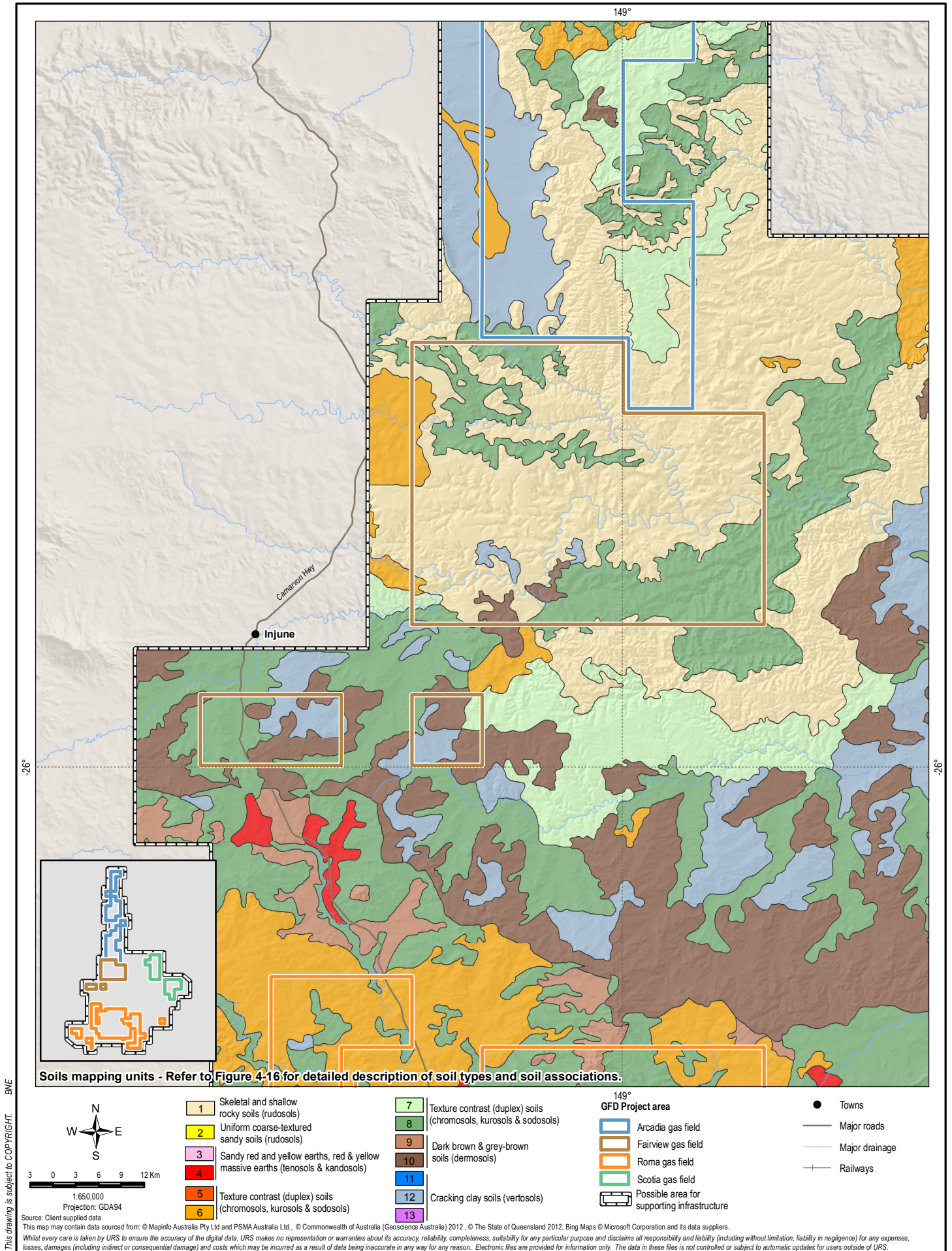
Medium to deep or very deep (0.6->1.5 m) dark grey-brown or black cracking clay soils (Type 8.3) with intensive gilgai micro-relief, often in association with silt to clay loamy surface duplex soils (Type 6.2) on the gilgai mounds; areas of uniform (non-cracking) clay soils (Type 7.3) are also associated; some loamy red earth soils (Type 4.2) may occur locally on low rises.

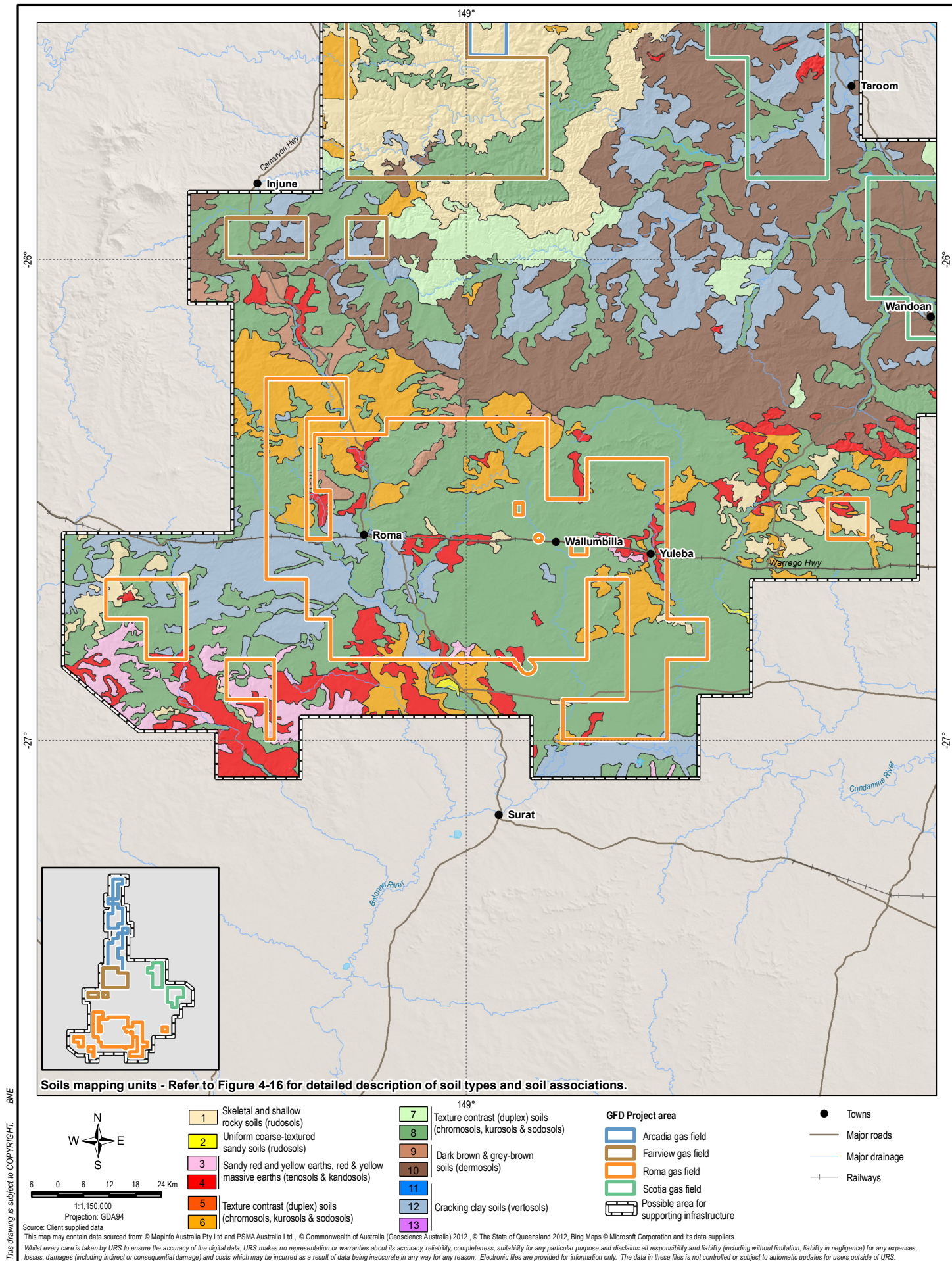
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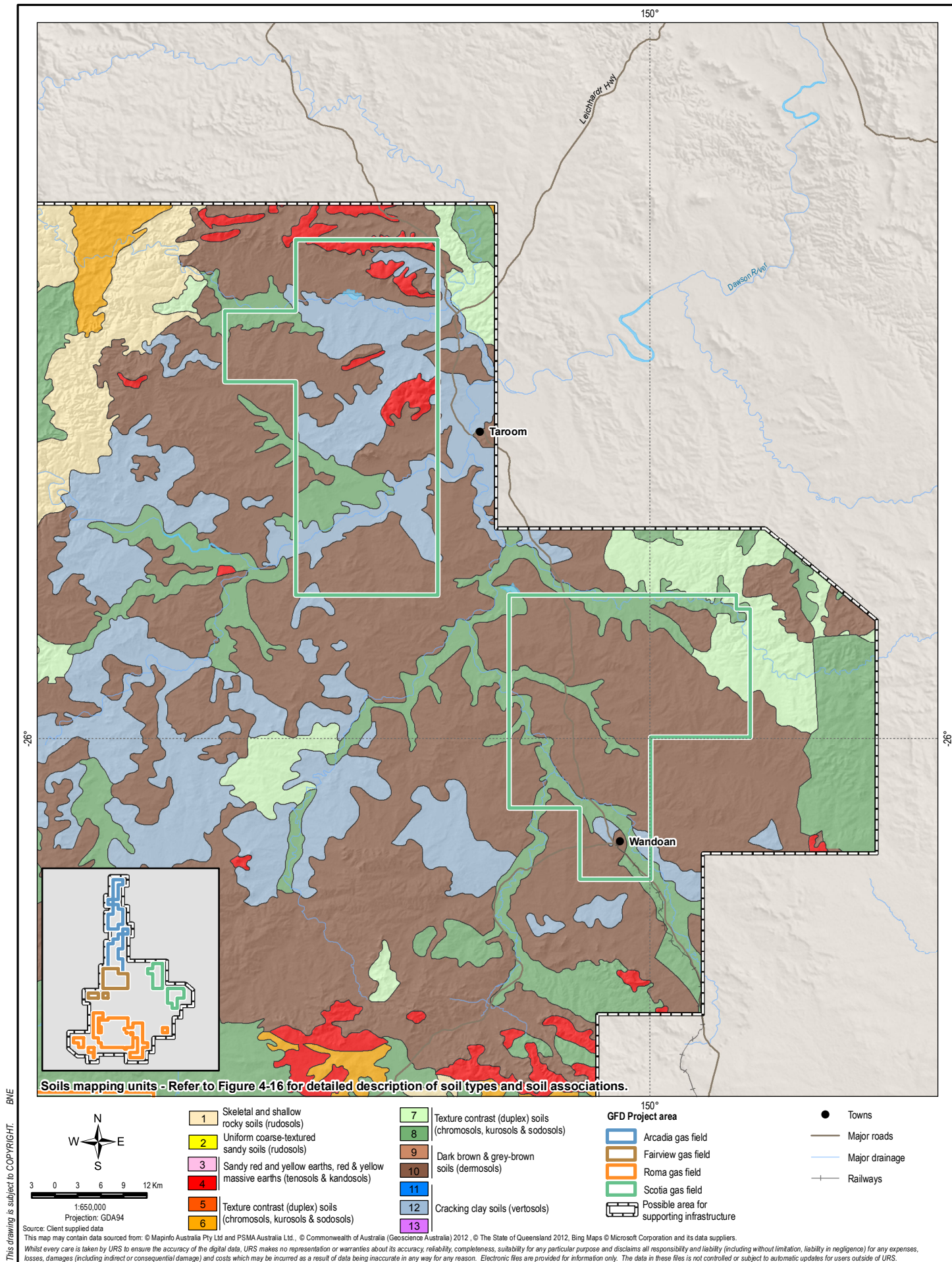
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4.5.5 Problem soils

Consistent with the 2009 EIS, three types of 'problem soils' have been identified within the GFD Project area. These include:

- Reactive soils – cracking clays (Appendix B)
- Sodic and/or dispersive soils – soils with an ESP greater than 6%
- Saline soils – soils with a high level of natural or induced salinity.

Based on the setting (topography and elevation), acid sulfate soils are not anticipated to occur in the GFD Project area.

Reactive soils (high shrink – swell capacity) are the cracking clay soils (Vertosols), with a moderate to high CEC, which become compacted if trafficked when wet. These soils may cause damage to infrastructure, foundations and buried services such as pipelines due to differential ground movement if appropriate management such as engineering practices are not used.

Sodic and/or dispersive soils – soil with a exchangeable sodium percentage (ESP) greater than 6%, can occur in cracking and non-cracking clays, together with the majority of the duplex soils within the GFD Project area are dispersive and highly susceptible to degradation if disturbed and managed incorrectly. These soils are susceptible to rill, gully or tunnel erosion if exposed and left unprotected from rainfall impact or excessive water infiltration. Disturbance on these soils should be avoided or be minimised and managed and ground cover established as soon as practicable following disturbance. Amelioration with gypsum and/or lime (Kurosols) can improve soil structure, infiltration and soil aeration can promote vegetation establishment.

Saline soils (often also sodic) – soils with a high level of natural or induced salinity, are common throughout the GFD Project area. Saline soils can impact plant growth and have the potential to corrode buried steel or concrete products.

In addition, a number of the sandy duplex soils within the GFD Project area have surface textures which have the potential to be hard-setting. When disturbed these soils are prone to slaking when wet and when allowed to dry out, set hard and become massive, as a result handling properties, infiltration and the establishment of vegetation become difficult. Minimising the area of disturbance and the establishment of vegetative cover as soon as practicable following disturbance is important to protect these soils.

4.5.6 Topsoil resources

Suitable growth media available for rehabilitation is usually confined to the surficial topsoil (A) horizon and in some situations the upper portion of the B21 horizon. Soil A horizons contain the majority of the seed reserves, micro-organisms, organic matter and soil nutrients necessary for successful plant growth. Levels of these parameters are limited by factors such as the climatic conditions, geology, vegetation and management practices. In general, levels of these parameters decrease with profile depth, while soil properties affecting soil handling and plant growth increase with depth, for example soil sodicity, salinity and excessive structure.

The suitability of material for use as growth media for rehabilitation of areas to be disturbed during development, construction and operation phases of the GFD Project has been assessed from the broad soil characterisation, indicative testing and results of some analytical data obtained during the gas transmission pipeline and compression and water treatment facility field investigations (GLNG

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Project EIS, 2009). Additional soil data was also obtained from reference to and interpretation of the land systems and soils mapping by the CSIRO (1967, 1968 and 1974). The indicative topsoil thickness of suitable growth media has been determined for the SMUs and soil types identified (Table 4-6).

Soil structure, soil depth, texture and soil chemistry (salinity, ESP and pH) are the major factors limiting the suitability of some soils within the GFD Project area.

The indicative topsoil thickness should be used only as a guide and more detailed, location specific soil investigations may need to be conducted at an appropriate scale and sampling intensity to inform soil management requirements. This may include more detailed soil information on the specific soil properties and soil chemistry (Appendix B). Topsoil thickness can be used to estimate topsoil reserves suitable for use as growth media for rehabilitation of areas of disturbance during development, construction and operations phases of the GFD Project.

Table 4-6 Indicative topsoil thickness

SMU	Soil type	Indicative stripping depth (m)	Remarks
1	1	0	Skeletal to shallow rocky soils (>60% coarse fragments); rock outcrop and surface boulders
1,2,6	2.1	0.1	Utilise seedstock and organics
2	2.2	0	Potential source of bedding sand
2,6	2.3	0.25	Humic surface soil, strongly acidic subsoils
1,3	3.1	0.2	Strongly acidic subsoils (>0.2 m)
	3.2	0.3	Texturally suitable (0.3-0.6) but low levels of soil nutrients
	3.3	0.3	Dense gravel may occur in the subsoil (A2) horizon (>0.3 m)
1,3,4,6,8	4.1	0.2	Excess gravel/stone below 0.2 m
4,6,8,13	4.2	0.3	Texturally suitable (0.3-0.6) but high gravel content may occur
	4.3	0.3	Texturally suitable (0.3-0.6), but low soil nutrients
7,12	5.1	0.2	Strongly acidic in deeper subsoils
2,4,6	5.2	0.3	Bleached (A2) horizon (>0.3 m), source of bedding sand (0-0.6 m)
4,6,12	5.3	0.2	Bleached (A2) horizon (>0.2 m),
7	6.1	0.15	Shallow soils, bleached (A2) horizon, strongly alkaline subsoils
4,7,8,12,13	6.2	0.15	Thin pale or bleached layer over hard clay subsoils
2	6.3	0.25	Thick sandy A horizon, bleached A2 horizon (>0.25 m)
9,10,12	7.1	0.2	Excess gravel/stone below 0.2 m
10	7.2	0.3	Texturally suitable (0.3-0.6 m), highly alkaline/calcareous below
8,9,10,12,13	7.3	0.2	Locally strongly acidic sodic and moderately highly saline in the subsoil below about 0.2 m
9,10	8.1	0.2	Medium to coarse blocky structure (>0.15-0.2 m); some rock cobbles and gravel included
7,8,9,10,12	8.2	0.25	Medium to coarse hard blocky structure below 0.2-0.3 m
13	8.3	0.2 to 0.3	Medium to coarse hard blocky structure and mod; saline below 0.2 m on gilgai mounds

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4.5.7 Existing and potential soil erosion

The 2009 EIS reported that substantial areas of land are subject to accelerated soil erosion, in particular areas of extensive surface sheet and rill erosion. Areas of gully erosion mainly exist on the approaches or adjacent to the more major stream lines. The areas mostly affected include a range of landform types associated with the Jurassic and Triassic sandstone geological regimes, the Silurian volcanics and Permian sedimentary and intrusive rock types and in parts, in the Tertiary sediments geological regimes. Landforms tend to have sand or sandy medium-textured surface soils, which in many parts have been subjected to extensive grazing and grazing related land use activities (clearing of woody vegetation). Clearing of vegetation and stripping of topsoil resources exposes the land to potential erosion due to the combined effects of surface slope and form, soil physical and chemical properties, as well as surface run on/runoff potential and the effects of wind erosion over time. This is exacerbated by agricultural practices including prolonged dry periods that lead to defoliation/denudation of land through heavy grazing with the subsequent increase in surface runoff due to heavy summer rainfalls. Accordingly, a quantitative estimate of the potential erosion rates has been made on a SMU basis.

4.5.7.1 Estimating rates of soil loss

Erosion of soil generally removes the fine particles and organic matter from the surface soils and decreases the soils productive capacity to sustain vegetative cover. Natural rates of soil erosion have the potential to be accelerated due to localised impacts of activity-based disturbances such as farming, off-road traffic movements, etc. Fine particles comprise clay and organic matter that hold a large portion of the nutrient storing capacity of a soil. Loss of these particles reduces the productive capacity of soil, which has implications for rehabilitation. Additionally, soils with high sand and low organic matter content in the surface soils have low cohesion between soil particles, and are susceptible to erosion. Eroded soil particles enter watercourses, increasing the suspended solids and turbidity degrading water quality and impeding flow.

It should be noted that the term “watercourse” refers to a river, creek or other stream, including a stream in the form of an anabranch or a tributary, in which water flows permanently or intermittently, regardless of the frequency of flow events (Water Act 2000).

Estimates of the potential soil loss have important applications to both soil and water management at specific locations. Estimates enable the planning of erosion and sediment control measures during disturbance, decommissioning and rehabilitation phases of specific developments.

An estimate of the long-term soil loss from both sheet and rill erosion can be calculated using the Revised Universal Soil Loss Equation (RUSLE), (*IECA Best Practice Erosion and Sediment Control, International Erosion Control Association, Australasia, 2008*), (Appendix E).

The RUSLE uses five factors to calculate potential soil loss:

$$A = R * K * LS * P * C$$

Where:

- A = Estimated soil loss
- R = Rainfall erosivity factor
- K = Soil erodibility factor
- LS = Slope length/gradient factor
- P = Erosion control practice factor
- C = Ground cover and management factor.

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Rainfall erosivity factor (R)

The rainfall erosivity factor (R), is a measure of the ability of rainfall to cause erosion, and is the product of the total energy of the rainfall event (R) for maximum 30 minute intensity (I30) for each storm.

$$R = 164.74(1.1177)^S S^{0.64444}$$

Where S is the two year ARI (average rainfall intensity), six hour rainfall event (mm).

The R-factor used for the calculations is 2,210, the mean of all the R-factor values calculated for the GFD Project area (ESC Risk Management Assessment – Soil Loss GIS Study (O2 Environmental, 2012)).

Soil erodibility factor (K)

Soil erodibility (K), is the relative measure of how susceptible a particular soil is to erosion. Soil texture is the principal component that affects erodibility, but soil structure, organic matter and profile permeability are also contributing factors. The K factor has been estimated based on the texture of the upper subsoil of each SMU (IECA, 2008). For SMUs, containing dispersive soils (sodosols and to a lesser extent, kurosols), the K factor was increased by 20%.

Table 4-7 Estimated soil erodibility K-factors based on soil texture class (IECA, 2008)

Soil mapping unit	Dominant soil (ASC)	Likely texture	K factor*
1	Rudosols	Clay Loam (CL)	0.030
2	Rudosols	Clay Loam (CL)	0.030
3	Tenosols	Clay Loam (CL)	0.030
4	Kandosols	Clay Loam (CL)	0.030
5	Sodosols & Kurosols	Medium Clay (MC)	0.018*
6	Sodosols & Kurosols	Medium Clay (MC)	0.018*
7	Sodosols & Chromosols	Medium Clay (MC)	0.018*
8	Sodosols & Chromosols	Medium Clay (MC)	0.018*
9	Dermosols	Light Clay (LC)	0.025
10	Dermosols	Light Clay (LC)	0.025
11	Vertosols	Medium Clay (MC)	0.015
12	Vertosols	Medium Heavy Clay (MHC)	0.015
13	Vertosols	Medium Heavy Clay (MHC)	0.015

*K-factor increased by 20% for dispersive soils

Slope length/gradient factor (LS)

The slope/gradient factor (LS), is a description of the combined effect that slope gradient and slope length have on soil loss. It is the ratio of soil loss per unit area at a particular location to the corresponding loss from a specific experimental plot of known length and gradient. Chosen LS factors are based on an assumed slope length of 80 m for all SMUs (80 m is the maximum slope length were sheet and rill flow is estimated to become concentrated or gully flow, the RUSLE equation does not take into account soil loss due to gully flow). The mean slope (%) for each of the SMUs, have been used in the calculations.

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Erosion control practice factor (P)

The erosion control practice factor (P) is the ratio of soil loss with a nominated soil condition, and the estimated soil loss from a field ploughed down a slope. On construction and rehabilitation areas, it reflects the soil surface condition or smoothing of the soil surface by machinery following disturbance (topsoil stripping). Based on this, these initial bare surfaces following disturbance generally have a compacted and smooth surface condition, with a P factor of 1.3, the default construction phase condition.

Cover factor (C)

The ratio of soil loss from land under specified crop or mulch conditions to a corresponding loss from continuously tilled bare soil is represented by the ground cover and management factor (C). A cover factor of 1 (soil recently disturbed, e.g. stripped bare ground), has been assumed in the calculation.

Estimate of potential soil loss

Estimates for the potential soil loss have been calculated for the dominant soil type occurring within each SMU. The estimated rates of soil loss ranged from 9 tonnes per hectare per annum (t/ha/annum) to 12 t/ha/annum for the SMUs on slopes of 1%, to 279 t/ha/annum for the steeply sloping landforms.

The shallow rocky rudosols (skeletal soils) are the most erodible of the SMUs, with a potential annual soil loss of 280 t/ha/annum. As vegetative cover is established, the potential for erosion will decrease rapidly, for example, with 17% to 18% grass cover, the potential soil loss from an area will be halved (C – factor of 0.5).

Table 4-8 Estimated soil loss

SMU	Slope range (%)	Rainfall erosivity factor (R)	Soil erodibility factor (K)	Slope/length gradient factor (LS)	Erosion control practice factor (P)	Cover factor (C)	Annual soil loss (t/ha/annum)
1	11	2,210	0.030	3.25	1.3	1	280
2	1	2,210	0.030	0.19	1.3	1	17
3	3	2,210	0.030	0.65	1.3	1	56
4	3	2,210	0.030	0.65	1.3	1	56
6	3	2,210	0.018	0.65	1.3	1	34
7	7	2,210	0.018	1.76	1.3	1	91
8	3	2,210	0.018	0.65	1.3	1	34
9	4	2,210	0.025	0.91	1.3	1	66
10	4	2,210	0.025	0.65	1.3	1	47
12	3	2,210	0.015	0.41	1.3	1	18
13	1	2,210	0.015	0.19	1.3	1	8

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Erosion risk

The Santos GLNG Erosion and Sediment Control Management Plan (ESCMP, 2013) groups erosion risk into three categories of low (0 to 75 t/ha/annum), medium (75 to 150 t/ha/annum) and high (> 150 t/ha/annum) erosion risk. The majority of the GFD Project area has a low erosion risk as shown in Table 4-9. The area with the highest erosion risk is within the Expedition National Park on the escarpment adjacent to the Arcadia Valley, primarily due to the steeper topography.

Table 4-9 Estimated erosion risk

Erosion risk	Soil loss (t/ha/annum)	GFD Project area (%)
Low	0 to 75	66
Medium	75 to 150	3
High	>150	21

Limitations

Limitations and assumptions on this method of soil loss estimation are outlined below:

- Calculated estimate of soil loss per soil mapping unit is an “indicator” only of potential soil loss
- Calculation addresses sheet and rill erosion only and excludes erosion caused by concentrated flow
- Slopes are the calculated mean slope % within each of the SMUs
- A slope length of 80 m has been used for SMUs
- Estimate does not take into consideration chemical dispersion, which will potentially increase following the disturbance of sodic soils
- K factor is based on an estimate of the soil texture class (IECA, 2008)
- Rainfall intensity is based on an average for the GFD Project area.

4.6 Good quality agricultural land

The Good Quality Agricultural Land (GQAL) method is a four-class system, used primarily in land use planning. It is supported by legislation and previously by the State Planning Policy (SPP 1/92), repealed in December 2012. However, the outcomes sought by the SPP are still valid and are covered within the State Government’s single SPP, which replaced the State’s 12 existing planning policies in December 2013.

The GFD Project area was assessed to identify the potential GQAL in accordance with Guidelines for the identification Good Quality Agricultural Land (Department of Primary Industry and Department of Housing, Local Government and Planning, 1993). Agricultural land is land that is suitable for crop and animal production, excluding areas of existing intensive livestock production, such as feedlots. GQAL is land that is capable of supporting sustained levels of agricultural production, with reasonable amounts of inputs and without causing degradation.

4 Environmental values

The description of the agricultural land classes (ALCs) is provided below and the distribution across the GFD Project area is provided in Table 4-10.

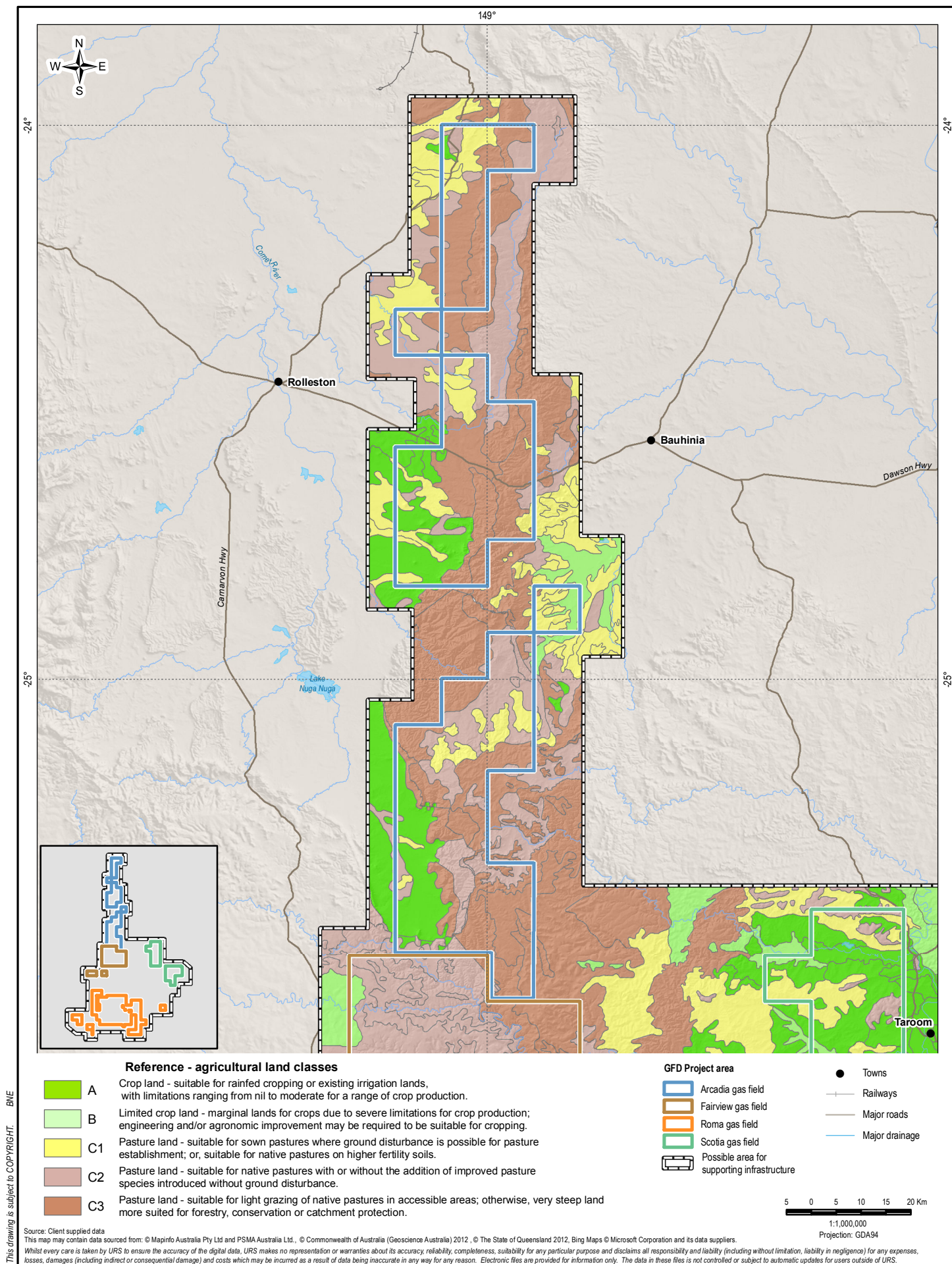
- Class A - Arable land (Cropping land):
 - Land that is suitable for current and potential crops, with limitations to production which range from none to moderate levels
- Class B - Limited arable land (Limited cropping land):
 - Land that is marginally suitable for current and potential crops due to severe limitations; however, it is suitable for pastures. Engineering and/or agronomic improvements may be required before the land is considered suitable for cropping
- Class C – Pastoral Land (Grazing land):
 - Pasture land – Land that is suitable only for improved (Class C1) or native pastures (Class C2) due to limitations which preclude continuous cultivation for crop production; but some areas may tolerate a short period of ground disturbance for pasture establishment. This also includes land suitable for light grazing of native pastures in inaccessible areas (Class C3)
- Class D - Non-agricultural land:
 - Land 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 (Department of Primary Industry and Department of Housing, Local Government and Planning, 1993).

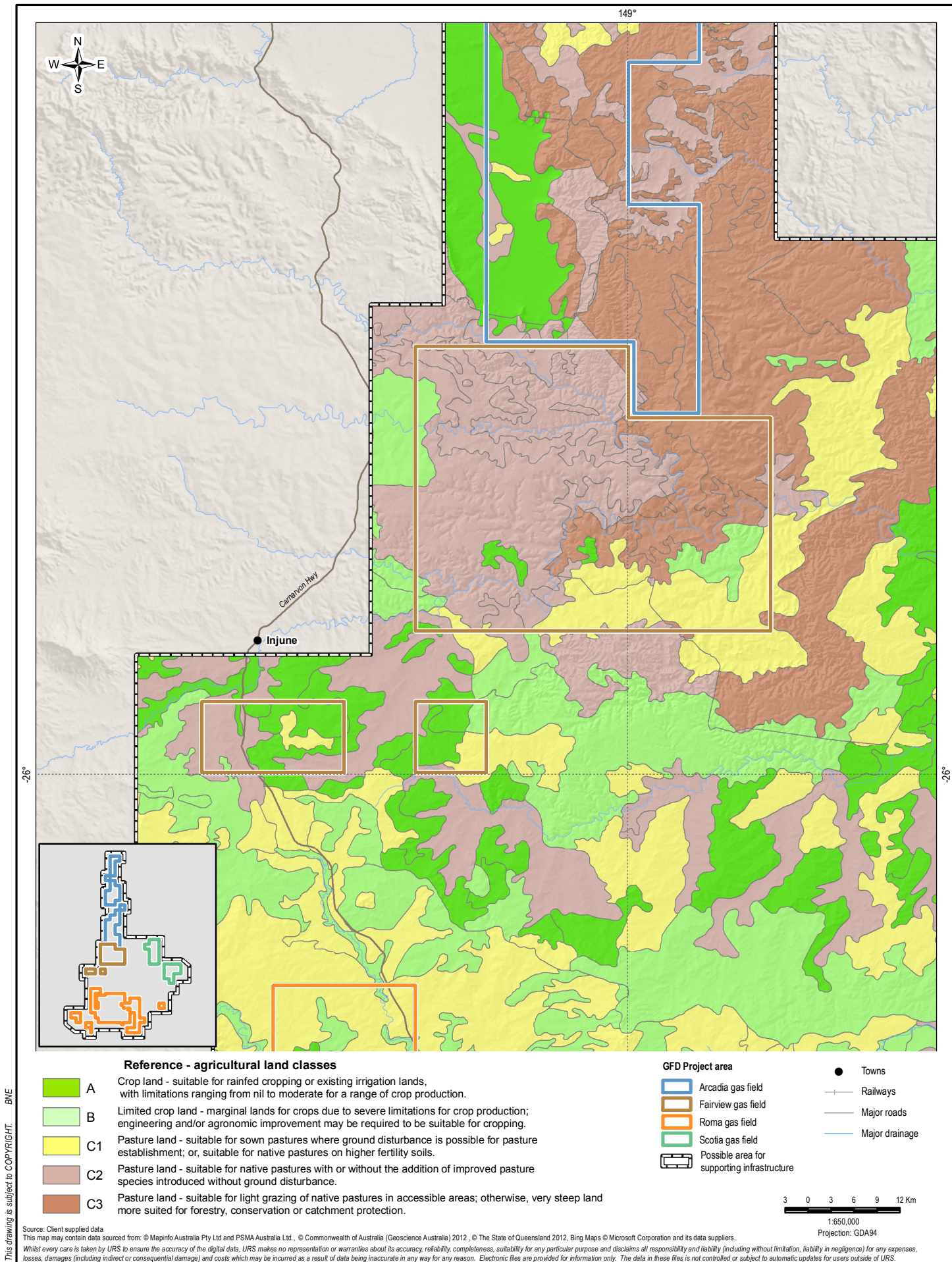
For the purpose of this report, Land Classes A, B and C1 are considered GQAL, with the remaining classes, non -GQAL. Table 4-10 details the amount (ha) and classification of GQAL within the four gas fields, with the extent and distribution of GQAL across the GFD Project area presented in Figure 4-21 to Figure 4-24.

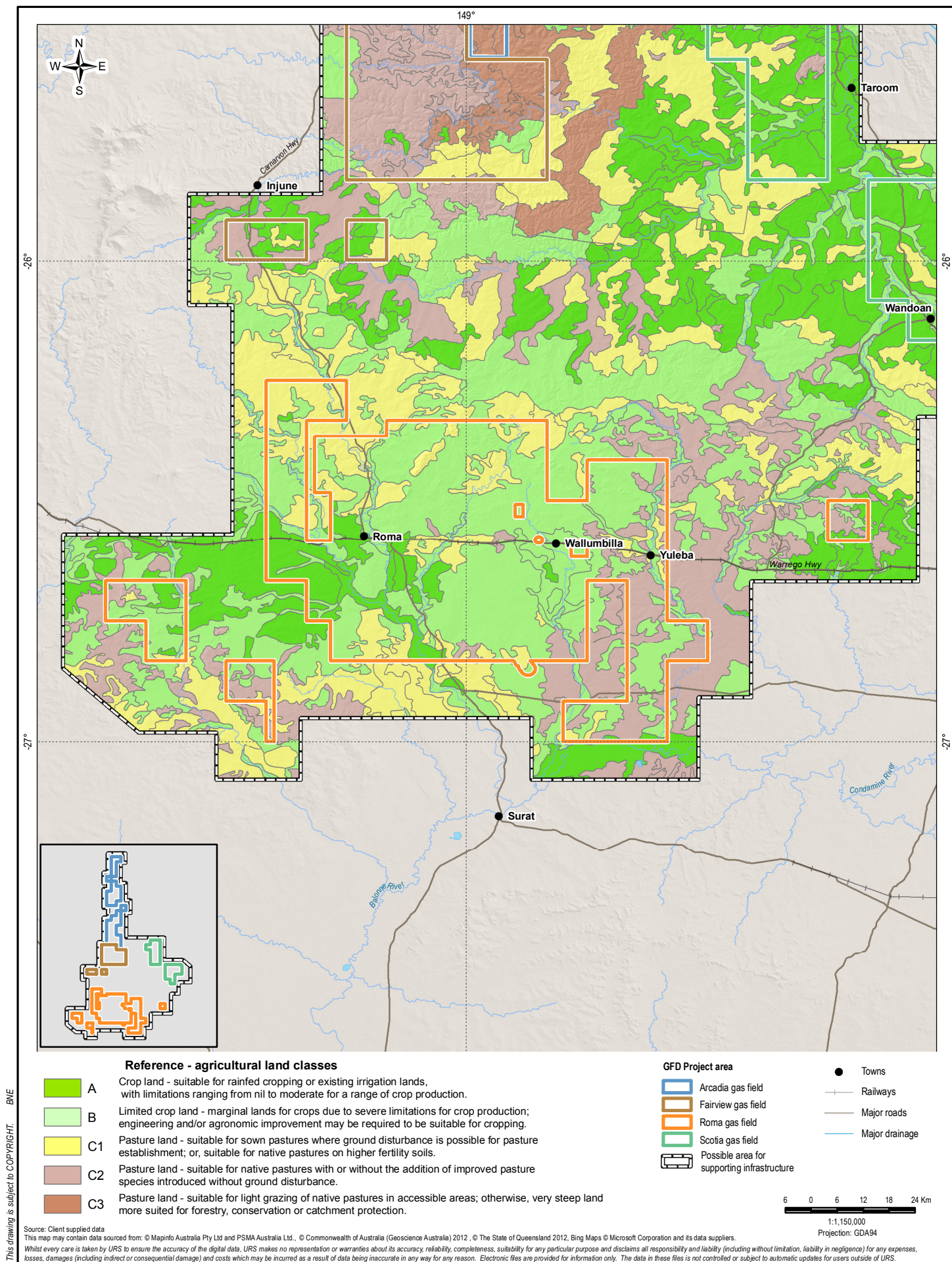
Table 4-10 Distribution of agricultural land classes (GQAL)

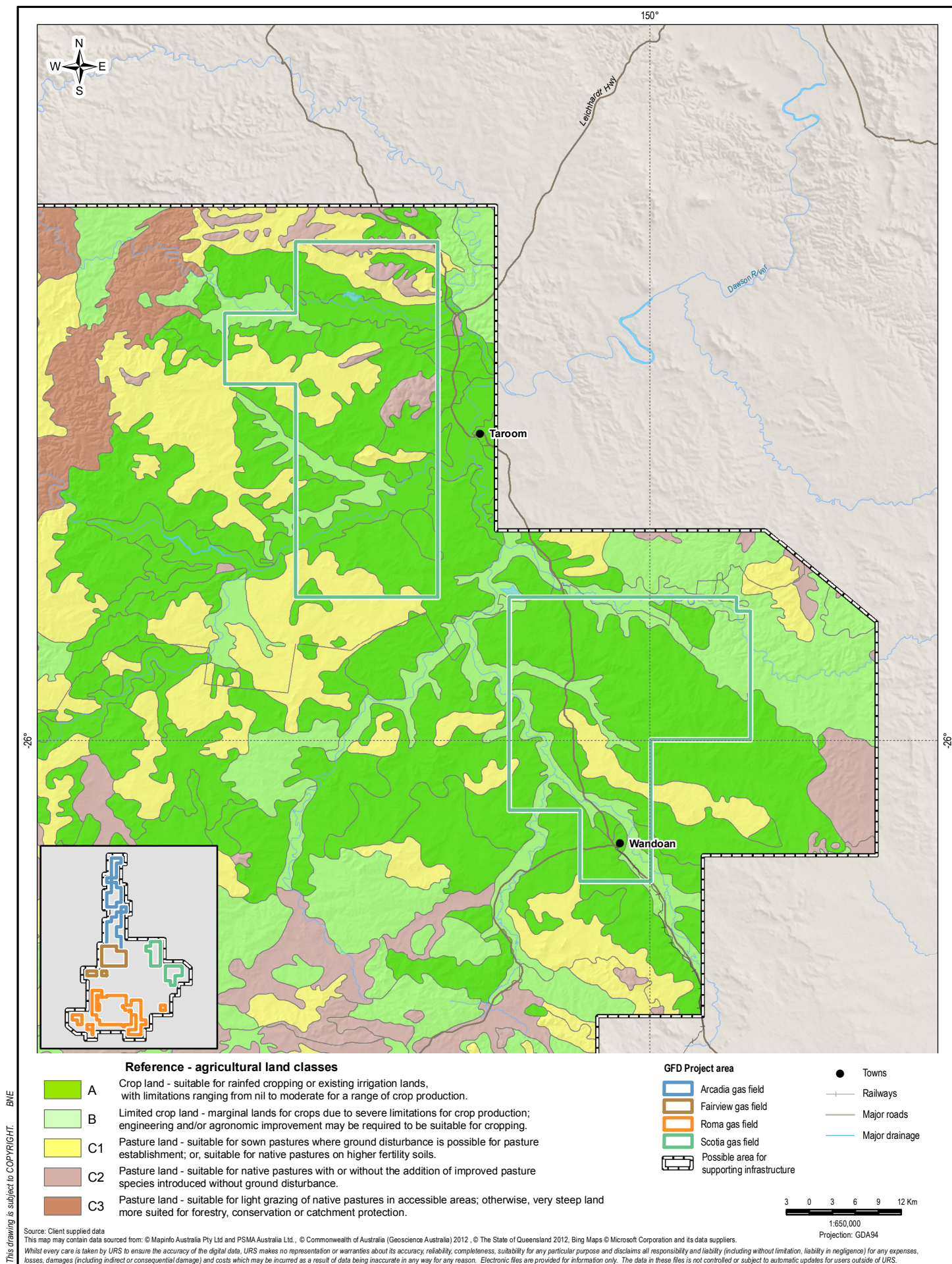
GFD Project gas field	Class A (cropping)	Class B (Ltd arable & grazing)	Class C1 (grazing)	Class C2 (grazing)	Class C3 (grazing)
Arcadia	41,795	2,751	38,145	60,704	128,723
Fairview	13,096	9,445	23,278	86,699	29,627
Roma	53,817	277,028	82,486	58,101	0
Scotia	104,906	24,724	24,886	5,865	0
Remainder*	459,688	524,794	465,251	432,830	226,465
Totals	673,302	838,742	634,046	644,199	384,815

*Additional land area within the GFD Project possible area for supporting infrastructure boundary, outside of the individual gas fields.









4 Environmental values

4.7 Strategic cropping areas

The *Regional Planning Interests Act 2014 (Qld)* (RPI Act) and *Regional Planning Interests Regulation 2014* (RPI Regulation) commenced on 13 June 2014. The RPI Act repealed the *Strategic Cropping Land Act 2011* (SCL Act) but integrates the SCL Act policy framework for 'on-tenure' resource activities.

Strategic cropping areas (SCA) are an area of regional interest under the RPI Act. SCA consists of the areas shown on the Department of Natural Resources and Mines (DNRM) SCL trigger map as SCL. This trigger map is based on soil, climate and land information; and indicates areas where SCL is likely to exist, with the trigger maps being the starting point for determining if an area includes SCL.

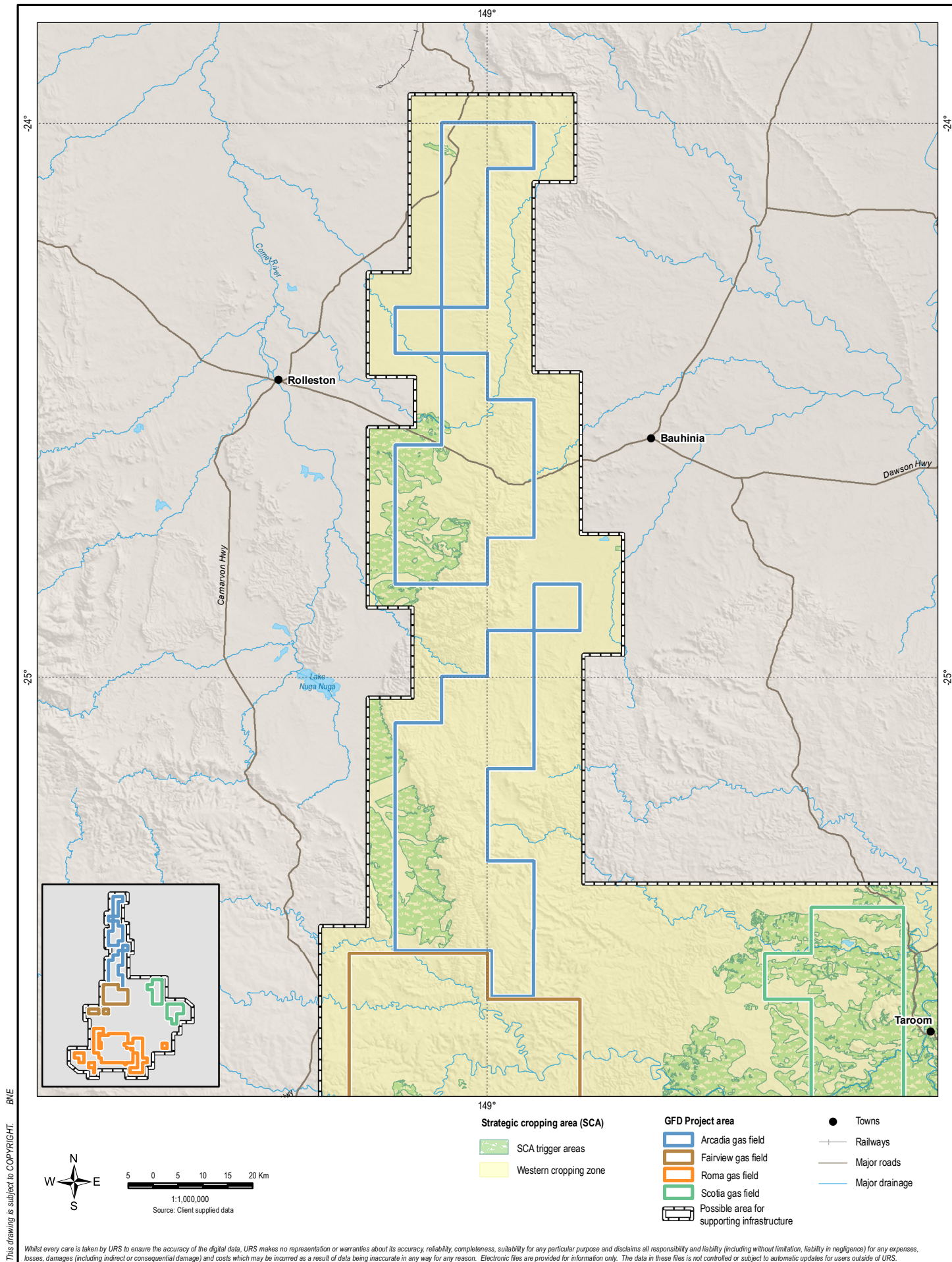
The RPI Act has various implications for resource projects proposed within an area of regional interest and is dependant on the status of tenure and environmental approvals at various prescribed dates, the location and the type of proposed development. If a resource activity is proposed within an area of regional interest and an exemption under the RPI Act does not apply to the project, a Regional Interests Development Approval (RIDA) will be required.

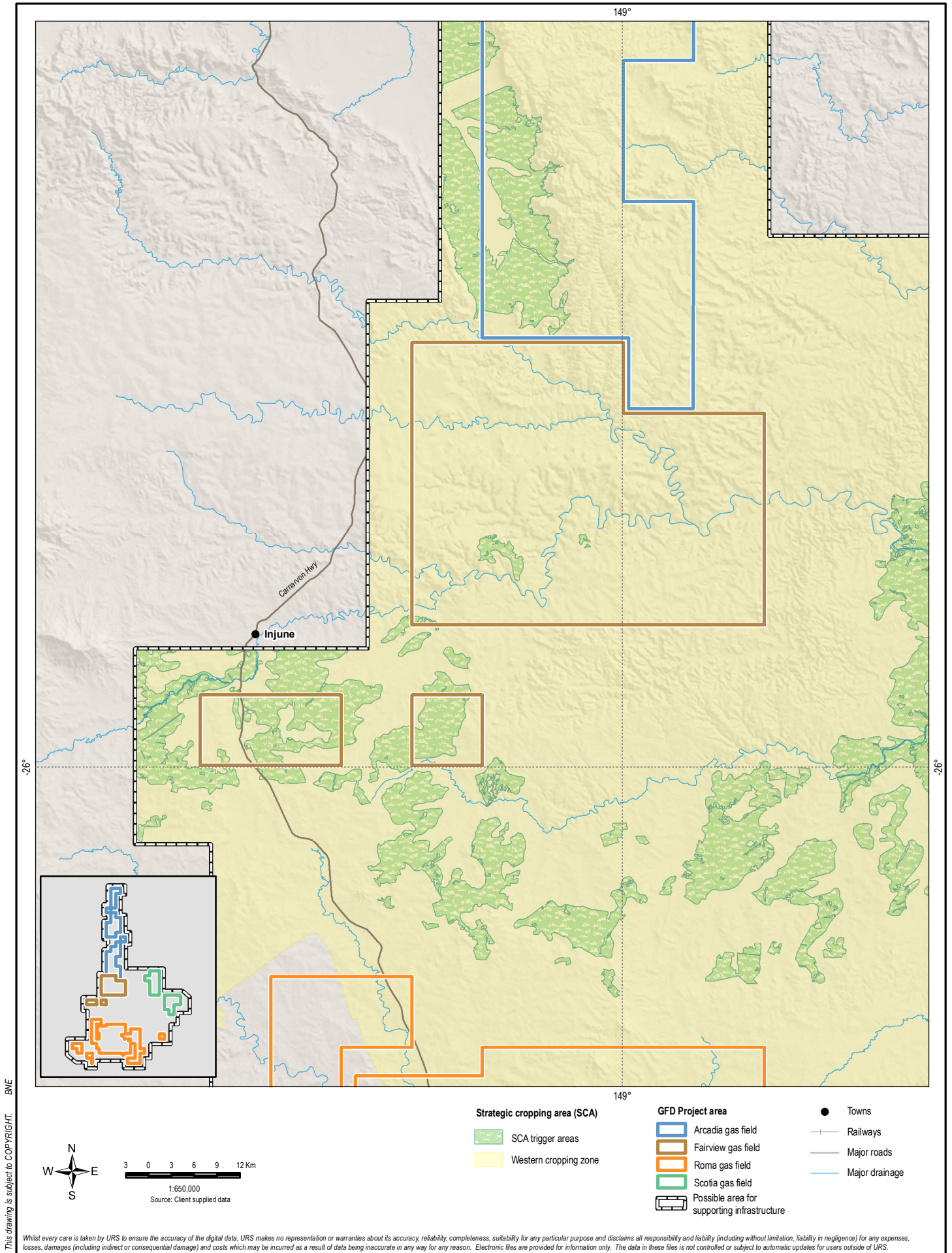
Five SCL zones have been established based on differences in regional climate, landforms and cropping systems within the eastern part of the state. The majority of SCA within the GFD Project area is located within the the Western Cropping Zone (Figure 4-25 to Figure 4-28), with a smaller proportion located within the Central Protection Area, in the extreme north east of the GFD Project area. Table 4-11 details the extent of SCA within the GFD Project area.

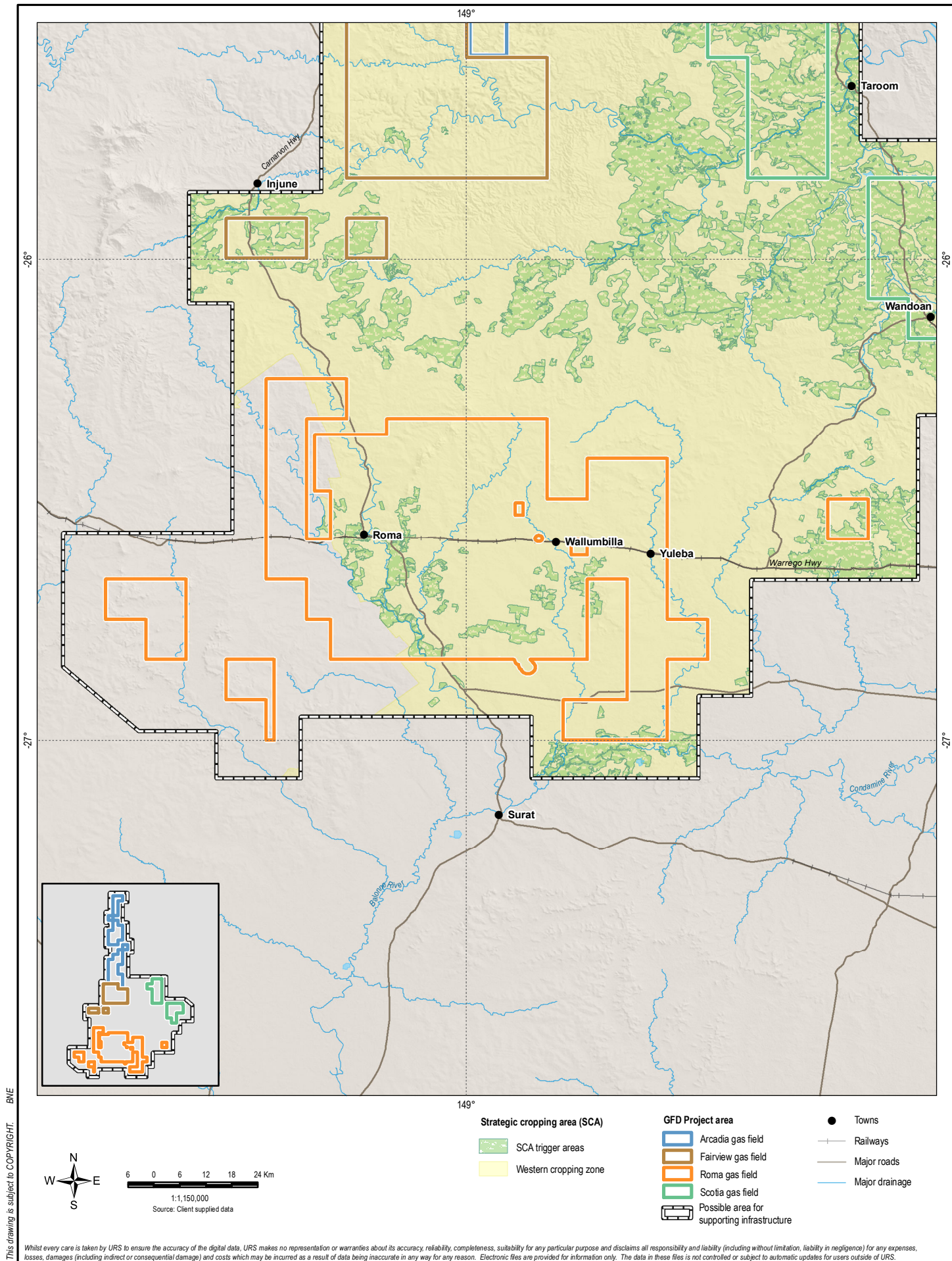
Table 4-11 Distribution of strategic cropping areas within the GFD Project area

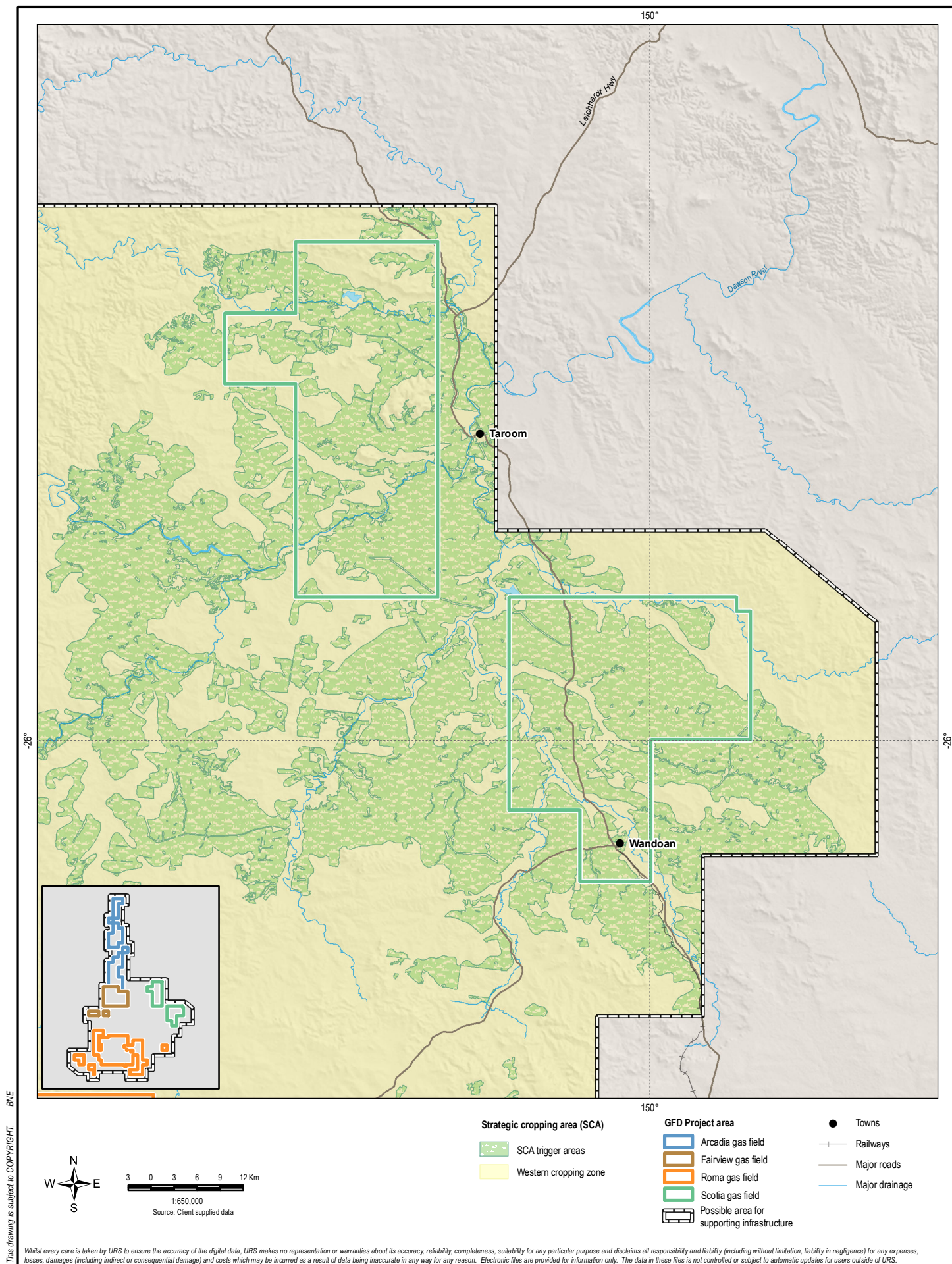
Gas field	Total SCL trigger area (ha)
Arcadia	36,244
Fairview	12,576
Roma	34,451
Scotia	101,304
Remainder*	411,225
Total	595,799

*Additional land area within the GFD Project possible area for supporting infrastructure boundary, outside of the individual gas fields.









4 Environmental values

4.8 Priority agricultural areas

Priority Agricultural Areas (PAAs) are among the areas of regional interest defined in Part 1, Section 7 of the RPI Act. They have also been introduced in the recently released *Darling Downs Regional Plan* and *Central Queensland Regional Plan* to address the competing State interests affecting the agricultural and resources sectors. PAAs are strategic areas identified on a regional scale that contain significant clusters of what are considered to be the region's high value, intensive agricultural land uses. Within PAAs, certain agricultural land uses, termed Priority Agricultural Land Uses (PALUs), have been given additional protection from incompatible resource activities while maximising opportunities for the co-existence of resource and agricultural land uses.

Within the Darling Downs and Central Queensland regional planning areas the following agricultural activities are considered PALUs:

- Cropping
- Grazing irrigated modified pastures
- Horticulture (including intensive, irrigated perennial, irrigated plantation, irrigated seasonal and perennial)
- Irrigated cropping
- Irrigated land in transition
- Irrigated plantation forestry.

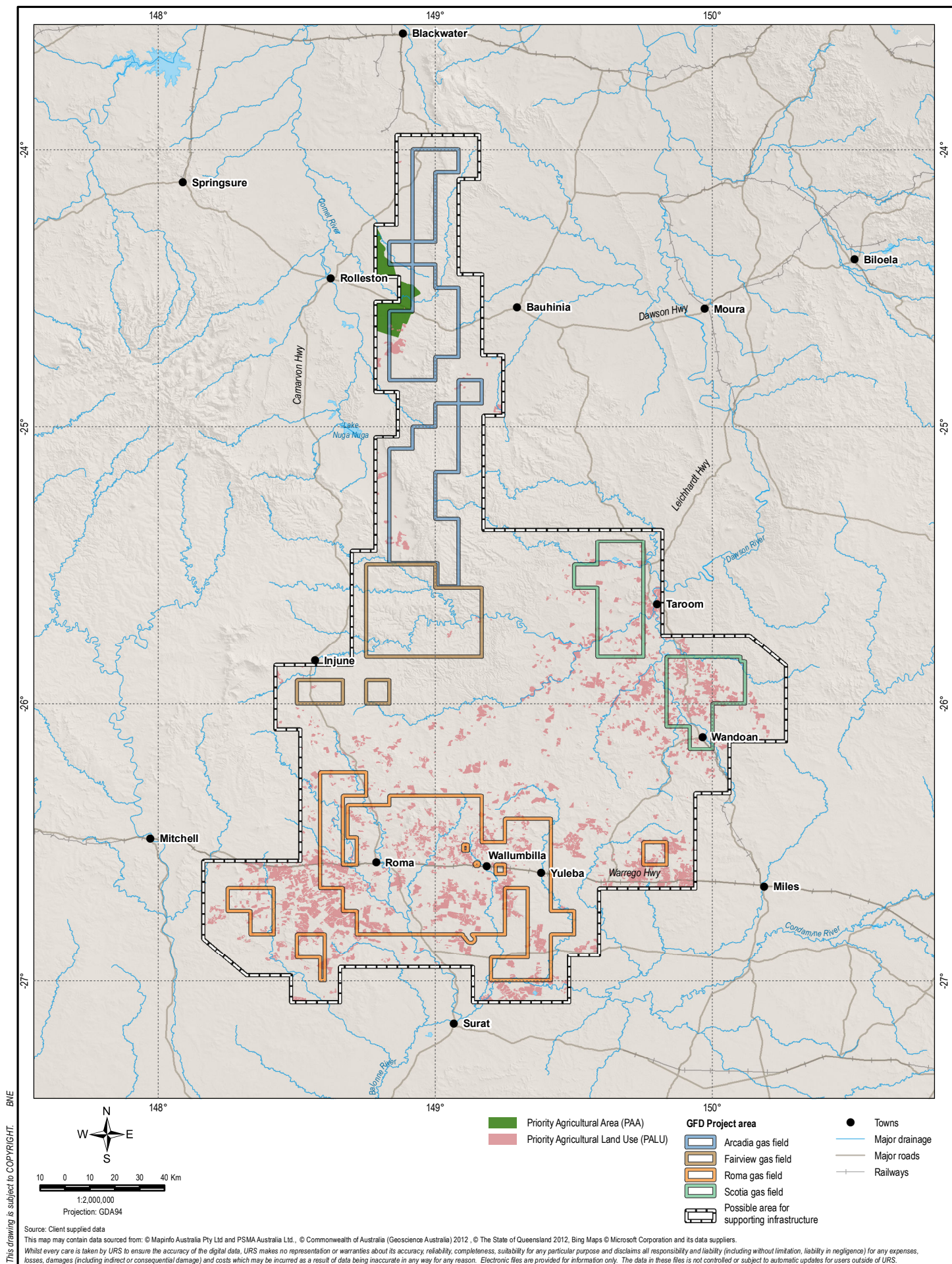
Areas have been designated as PAAs if they contain PALUs (ones that have significant infrastructure or have limited capacity to modify their agricultural practices in response to resource activities) and are within existing SCL Protection Areas (Section 4.7). It is understood that only PALUs existing within PAAs, will generate the application of the PAA Co-existence Criteria.

The extent of PALUs and PAAs within the GFD Project area are summarised in Table 4-12 and shown on Figure 4-29.

Table 4-12 Priority agricultural land uses within the GFD Project area

Gas field	PAA (ha)	PALU (ha)
Arcadia	6,992	4,867
Fairview	0	629
Roma	0	74,316
Scotia	0	25,946

PAA Co-Existence Criteria are still to be defined for each of the plans and will provide an assessment tool for determining how potentially compatible resource activities may operate on land currently being used for a PALU within a PAA.



4 Environmental values

4.9 Acid sulphate soils

The – State Planning Policy (Department of State Development, Infrastructure and Planning, 2014) sets out the State's interests concerning development involving acid sulphate soils in low-lying coastal areas. The policy applies only to certain types of development assessments, located in a strict list of local government areas as outlined in glossary of the policy.

The surface elevation of the GFD Project area is well above 5 m AHD and inconsistent with the presence of low-land acid sulphate soils. Inland acid sulphate soils generally occur in poorly drained inland swamps above 5 m AHD. These areas are not anticipated to be disturbed during proposed developments within the GFD Project area.

Given that the GFD Project falls outside of these areas and is above 5 m AHD, an assessment of the risk of acid sulphate soils is not required.

Impact assessment and mitigation

5.1 Overview

Infrastructure and activities that are expected to occur during construction, operation and decommissioning phases of the GFD Project (identified in Section 1.2) have the potential to impact on land resources environmental values. This section identifies the potential impacts and the associated activities for each phase of the GFD Project (i.e. construction, operation and decommissioning). A high level review of management frameworks applied to existing Santos GLNG operations was conducted to identify suitable mitigation measures that would also apply to the similar infrastructure and activities being developed for the GFD Project. Each potential impact is assessed in terms of its significance on the identified land resources value(s), and mitigation applied as needed to reduce this significance. Further location-specific assessments will be conducted once the specific detail regarding the location and form of infrastructure is confirmed.

5.2 Impact assessment methodology

The potential impacts on land resources environmental values that may arise from the GFD Project have been assessed on the basis of the sensitivity of the environmental values described in Section 4. A significance assessment methodology was employed, whereby the following aspects were considered:

- Relevant land resources environmental values (as discussed in Section 4), and their perceived sensitivity and/or vulnerability to development activities
- The magnitude of impacts that may occur as a result of GFD Project activities based on understanding of the GFD Project set out in Section 1.1 and 1.2
- The significance of potential impacts as a function of sensitivity and magnitude
- Relevant management framework and appropriate mitigation measures that may be employed to reduce the significance of impacts
- Residual significance of impacts, following effective use of mitigation measures.

The criteria for quantifying the sensitivity of environmental values to potential impacts are outlined in Table 5-1, while criteria for assessment of the magnitude of potential impacts are included in Table 5-2.

A significance assessment methodology has been adopted to assess the sensitivity or vulnerability of the environmental values of land resources and the magnitude of the perceived impact. The process is similar to that applied to a risk assessment process, but the criteria applied are related to sensitivity and magnitude rather than to likelihood and consequence. These criteria are summarised in Table 5-1 and Table 5-2.

Table 5-1 Sensitivity criteria

Sensitivity	Description
High	The environmental value is listed on a recognised or statutory state, national or international register as being of conservation significance. The environmental value is intact and retains its intrinsic value. The environmental value is unique to the environment in which it occurs. It is isolated to the affected system/area which is poorly represented in the region, territory, country or the world. It has not been exposed to threatening processes, or they have not had a noticeable impact on the integrity of the environmental value. GFD Project activities would have an adverse effect on the value.

5 Impact assessment and mitigation

Sensitivity	Description
Moderate	The environmental value is recorded as being important at a regional level, and may have been nominated for listing on recognised or statutory registers. The environmental value is in a moderate to good condition despite it being exposed to threatening processes. It retains many of its intrinsic characteristics and structural elements. It is relatively well represented in the systems/areas in which it occurs but its abundance and distribution are limited by threatening processes. Threatening processes have reduced its resilience to change. Consequently, changes resulting from GFD Project activities may impact on the prescribed value. Replacement of unavoidable losses is possible due to its abundance and distribution.
Low	The environmental value is not listed on a recognised or statutory register. It might be recognised locally by relevant suitably qualified experts or organisations e.g., historical societies. The environmental value is in a poor to moderate condition as a result of threatening processes that have impacted on its intrinsic value. It is not unique or rare and numerous representative examples exist throughout the system / area. It is abundant and widely distributed throughout the host systems / areas. There is no detectable response to change or change does not result in further impact on the environmental value. The abundance and wide distribution of the environmental value ensures replacement of unavoidable losses is achievable.

Table 5-2 Magnitude criteria

Magnitude	Description
High	An impact that is widespread, long lasting and results in substantial and possibly irreversible change to the environmental value. Avoidance through appropriate design responses or the implementation of site-specific environmental management controls are required to address the impact.
Moderate	An impact that extends beyond the area of disturbance to the surrounding area but is contained within the region where the GFD Project is being developed. The impacts are short term and result in changes that can be ameliorated with specific environmental management controls.
Low	A localised impact that is temporary or short term and either unlikely to be detectable by monitoring or could be effectively mitigated through standard environmental management controls.

The significance of each environmental impact was determined by combining the sensitivity and magnitude criteria in a risk assessment process as shown in Table 5-3.

Table 5-3 Significance matrix

Magnitude	Sensitivity		
	High	Moderate	Low
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Negligible

5 Impact assessment and mitigation

The significance classifications used in Table 5-3 (major, high, moderate, low and negligible) are defined as follows:

- **Major significance** arises when an impact will potentially cause irreversible or widespread harm to an environmental value that is irreplaceable because of its uniqueness or rarity. Avoidance through appropriate design responses is the only effective mitigation.
- **High significance** occurs when the proposed activities are likely to exacerbate threatening processes affecting the intrinsic characteristics and structural elements of the environmental value. While replacement of unavoidable losses is possible, avoidance through appropriate design responses is preferred to preserve its intactness or conservation status.
- **Moderate significance** results in degradation of the environmental value due to the scale of the impact or its susceptibility to further change even though it may be reasonably resilient to change. The abundance of the environmental value ensures it is adequately represented in the region, and that replacement, if required, is achievable.
- **Low significance** occurs where an environmental value is of local importance and temporary or transient changes will not adversely affect its viability provided standard environmental management controls are implemented.
- **Negligible significance** does not result in a noticeable change and hence the proposed activities will have negligible effect on environmental values. This typically occurs where the activities are located in already disturbed areas.

5 Impact assessment and mitigation

5.3 Potential impacts to land resources

Potential impacts to land resources have been identified with consideration of the Santos GLNG constraints planning process. Section 2.2 describes how the Santos GLNG constraints planning process is implemented to guide the placement of infrastructure. For example, Santos GLNG has prohibited development of intrusive activities in areas classified as no-go or surface development exclusion areas. Table 5-4 provides an outline of the level of constraint, constraint type and associated prohibited activities that will be applied to protect land resources environmental values. Through the constraints planning process, avoidance has been used to identify the potential (pre-mitigated) impacts to the land resources of the GFD Project area.

Table 5-4 Land resource related constraints

Level of constraint	Constraint layer
No-go area	Category A environmentally sensitive areas including national parks, conservation parks, and forest reserves (NC Act).
	EPBC Act-listed spring vents and complexes including primary 200 m buffer.
	Wetlands of national importance including 200 m buffer.
	Wetlands of high ecological significance or high conservation value (<i>Map of Referrable Wetlands</i>).
Surface development exclusion area	Primary 200 m buffer for Category A environmentally sensitive areas.
	The following Category C environmentally sensitive areas: • Nature refuges (NC Act) • Koala habitat areas (<i>Nature Conservation (Koala) Conservation Plan 2006</i>) • Declared catchment areas (<i>Water Act 2000 (Qld)</i>).
	The following Category B environmentally sensitive areas: • Coordinated conservation areas (NC Act). • State forest park/special forestry areas (<i>Forestry Act 1959 (Qld)</i> (<i>Forestry Act</i>)) • Ramsar sites listed as wetlands of international importance.
High constraint area	Watercourses (stream orders) including 100 m buffer.
	Wetland defined as 'general ecologically significant wetland' or 'wetland of other environmental value' (<i>Map of Referrable Wetlands</i>).
	Spring vents and complexes (not protected under the EPBC Act) including primary 200 m buffer.
Moderate constraint area	Secondary 100 m buffer for Category A environmentally sensitive areas.
	Secondary 100 m buffer for spring vents and complexes (EPBC Act).
	Matters of national environmental significance including habitats (threatened species habitat and migratory species habitat), threatened ecological communities (derived from state regional ecosystem mapping or verified from field surveys), flora species.
	State forests and timber reserves.
	Endangered regional ecosystems including primary 200 m buffer.

5 Impact assessment and mitigation

Level of constraint	Constraint layer
	The following Category C environmentally sensitive areas: • Essential habitat including primary 200 m buffer (NC Act). • Essential regrowth habitat including primary 200 m buffer (NC Act). • Of concern regional ecosystems including primary 200 m buffer. • Resource reserve (NC Act). • State forests / timber reserves (Forestry Act).
	Endangered, vulnerable and near-threatened species (NC Act).
Low constraint areas	High value regrowth (endangered and of concern regional ecosystems). No concern at present regional ecosystems. Type A species (NC Act). Existing Santos GLNG infrastructure. Existing road, rail, pipeline and other infrastructure. Remaining areas once other constraints have been applied.

¹ **Low impact petroleum activities** means petroleum activities that do not result in the clearing of native vegetation, earthworks or excavation work that cause either: a significant disruption to the soil profile; or permanent damage to vegetation that cannot be easily rehabilitated immediately after the activity is completed. Examples of such activities include (but are not necessarily limited to): chipholes, coreholes, geophysical surveys, seismic surveys, soil surveys, topographic surveys, cadastral surveys, ecological surveys, and installation of environmental monitoring equipment (including surface water).

² **Limited petroleum activities** mean any low impact petroleum activity and single well leases (includes observation, pilot, injection and production wells) and associated infrastructure (water pumps and generators, sumps, flare pits or dams) located on the well lease; multi-well leases and associated infrastructure (water pumps and generators, sumps, flare pits, dams or tanks) located on the well leases; construction of new access tracks that are required as part of the construction or servicing a petroleum activity; upgrading or maintenance of existing roads or tracks, power and communication lines, gas gathering lines from a well lease to the gas compression facility; water gathering lines from a well lease to water storage; and camps within well lease that may involve sewage treatment works that are a no release works.

³ **Petroleum activities** include low impact petroleum activities, limited petroleum activities, and all other GFD Project activities including major facilities such as permanent accommodation camps, gas treatment facilities, air strips, gas compression facilities, water management facilities such as water storage and water treatment facilities.

⁴ **Linear infrastructure** means linear infrastructure including (but not limited to) gas and water gathering lines, low and high pressure gas and water transmission pipelines, power lines, communication, roads and access tracks.

The pre-mitigated impacts discussed below have been determined after the application of the avoidance measures set out in the constraints table.

The potential impacts to land resources from the construction, operation and decommissioning phases of the GFD Project include:

- **Altered geological setting** – localised in coal seam or adjacent geological formations near to depressurised or stimulated wells; although these changes are not easily reversed, they may be similar to natural geological processes that occur over time.
- **Change to landform** – localised to area of disturbance (e.g. earthworks), may be temporary (well lease areas that can be easily rehabilitated to stable landform conducive with surrounding environment) or a more substantial change (e.g. quarry or borrow pit) may be long lasting.

5 Impact assessment and mitigation

- **Aquifer depressurisation resulting in subsidence** – extraction of groundwater is an integral part of the production of natural gas from coal seams and has the potential for regional scale aquifer depressurisation. Aquifer depressurisation can result in subsidence, altering groundwater flow and aquifer storage, and causing ground surface displacement and altering surface water flow paths.
- **Loss of soil resources** – can occur for the duration of the disturbance and may extend beyond the area of disturbance to the surrounding area, impacts can be long lasting and result in substantial and possibly irreversible change to the environmental value.
- **Degradation of soil resources** – structural breakdown or biological degradation of soil resources localised to infrastructure area or activity, but generally short term and easily rehabilitated.
- **Restricted access to productive (agricultural or forestry) land** – occurs for the duration of the infrastructure or activity (mostly short term but may be long-term, exceeding 30 years), but easily reversed at end of infrastructure life.
- **Authorised release of contaminants to soil** – localised impact from authorised release of coal seam water or sewage effluent to land, but impacts generally short term and easily rehabilitated.
- **Uncontrolled release of contaminants to soil** – localised impact from uncontrolled release of coal seam water / brine, sewage effluent, fuel or chemical to land, but impact generally short term and able to be rehabilitated.
- **Sterilisation of coal reserves** – localised and temporary for duration of gas production.
- **Damage to fossils** – localised but irreversible.

The potential impacts on the land resources environmental values can be allocated to each project phase (i.e. construction, operations and decommissioning). A summary of the identified potential impacts to land resources values and related GFD Project activity, and applicable management plans are outlined in Table 5-5.

Mitigation measures for reducing the significance of potential impacts on environmental values were developed on the basis of existing management frameworks utilised by Santos GLNG, and best practice methods within the industry as a whole. Detail on the relevant mitigation measures within each management plan is summarised in Table 5-6.

5 Impact assessment and mitigation

Table 5-5 Potential impacts to land resources and associated GFD Project activities

Potential impact	Activity by GFD Project phase			Applicable management plans
	Construction	Operation	Decommissioning	
Altered geological setting	Drilling and well stimulation	- Depressurising coal seams - Well work over	-	- Environmental protocol for constraints planning and field development - Hydraulic fracturing risk assessment - Water resource management plan, including stimulation monitoring program
Change to landform	- Earthworks (including drilling lease formation) - Borrow pits and quarries - Construction of water course diversion or crossings for roads, pipelines, power lines, discharge points, etc.	- Maintenance of access tracks, power lines and gathering line, and inspection and monitoring of waterways - Traffic movement, particularly near waterways and at water course crossings	- Demolition activities and earthworks (e.g. re-contouring landform) - Traffic movement, particularly near waterways and at water course crossings	- Environmental protocol for constraints planning and field development - Decommissioning and abandonment management plan - Rehabilitation management plan - Water resource management plan - Ground deformation monitoring and management plan
Aquifer depressurisation resulting in subsidence	-	Extraction of groundwater	-	- Water resource management Plan - Joint industry plan for an early warning system for the monitoring and protection of EPBC springs - Ground deformation monitoring and management plan
Loss of soil resources	- Vegetation clearing - Earthworks - Dust suppression	- Maintenance of access tracks, power lines and gathering line, and inspection and monitoring of waterways - Traffic movement, particularly near waterways and at water course crossings - Discharge of treated water to stream channel	- Demolition activities and earthworks (e.g. re-contouring landform) - Traffic movement, particularly near waterways and at water course crossings - Incomplete rehabilitation of disturbed areas	- Environmental protocol for constraints planning and field development - Erosion and sediment control management plan - Land release management plan - Decommissioning and abandonment management plan - Rehabilitation management plan

5 Impact assessment and mitigation

Potential impact	Activity by GFD Project phase			Applicable management plans
	Construction	Operation	Decommissioning	
Degradation of soil resources	- Vegetation clearing - Construction activities (e.g. compaction of hard stand)	- Placement of infrastructure - Discharge to land	- Disposal of concentrated brine products e.g. salts if not properly contained - Incomplete rehabilitation of disturbed areas	- Environmental protocol for constraints planning and field development - Decommissioning and abandonment management plan - Rehabilitation management plan
Restricted access to productive (agricultural or forestry) land	Construction of surface infrastructure	Placement of surface infrastructure	-	- Environmental protocol for constraints planning and field development - Decommissioning and abandonment management plan - Rehabilitation management plan
Authorised release to soil	- Dust suppression - Vehicle wash down - Application of treated sewage effluent to land	- Dust suppression - Vehicle wash down - Application of treated sewage effluent to land - Application of coal seam water to land (irrigation)	- Dust suppression - Vehicle wash down	- Environmental protocol for constraints planning and field development - Coal seam water management strategy - Water resource management plan - Land release management plan - Decommissioning and abandonment management plan - Erosion and sediment control management plan
Uncontrolled release to soil	- Vehicle wash down - Storage and use of chemicals - Storage and use of fuels - Water storage - Sewage treatment	- Waste management (e.g. containment, disposal, etc.) - Water storage - Sewage treatment - Vehicle wash down - Storage and use of fuels	- Disposal of concentrated brine products - Vehicle wash down - Storage and use of fuels	- Environmental protocol for constraints planning and field development - Chemical and fuel management plan - Coal seam water management strategy - Contingency plan for emergency environmental incidents - Decommissioning and abandonment management plan

5 Impact assessment and mitigation

Potential impact	Activity by GFD Project phase			Applicable management plans
	Construction	Operation	Decommissioning	
Sterilisation of coal reserves	Construction of surface infrastructure	Placement of surface infrastructure	-	- Environmental protocol for constraints planning and field development - Decommissioning and abandonment management plan
Damage to fossils	- Earthworks and construction activities - Drilling and well stimulation - Borrow pits and quarries	- Traffic movement - Access and maintenance of water course diversion or crossings - Well work over	- Demolition activities and earthworks - Traffic movement	- Environmental protocol for constraints planning and field development - Draft Environmental management plan (Draft EM Plan)

5 Impact assessment and mitigation

5.4 Management framework

Santos GLNG has developed and successfully implemented a management framework for the GLNG Project. This framework has proven to be effective in addressing issues known to be relevant to the GFD Project and the process developed complies with the government's regulatory requirements for petroleum projects. The process includes systems and procedures captured in management plans, which can be applied to the GFD Project to achieve predictable and sustainable outcomes.

The suite of management plans outlined in Table 5-6 captures the primary means of managing land resources impacts over the life of the GFD Project.

This EIS seeks to obtain primary approvals for the project including the Queensland Government Coordinator-Generals Report and Commonwealth Government approval. Approval of this EIS will trigger a number of subsequent approvals required for the GFD Project to proceed. Subsequent approvals will include any necessary approvals under the RPI Act. Consultation on the subsequent approvals will be ongoing with the administering authorities.

Table 5-6 Management framework

Management plan	Commitment
GFD Project environmental protocol for constraints planning and field development (the Constraints protocol)	The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to: • Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation • Support Santos GLNG's environmental policies and the General Environmental Duty (GED) as outlined in the Environmental Protection Act • Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances • Minimise cumulative impacts on environmental values. The Constraints protocol provides a framework to guide placement of infrastructure and adopts the following management principles: • Avoidance — avoiding direct and indirect impacts • Minimisation — minimise potential impacts • Mitigation — implement mitigation and management measures • Remediation and rehabilitation — actively remediate and rehabilitate impacted areas • Offset — offset residual adverse impacts in accordance with regulatory requirements. The Constraints protocol enables the systematic identification and assessment of environmental values and the application of development constraints to effectively avoid and / or manage environmental impacts. Areas identified as SCA will be avoided wherever practicable in accordance with the Constraints protocol (Santos, 2013). Where unavoidable, the provisions of the RPI Act will be adhered to and the necessary approval obtained prior to works commencing. Impacts to GQAL will be minimised through implementation of the Constraints protocol.
Chemical and fuel management plan (CFMP)	The CFMP details the appropriate storage and handling practices of chemicals and fuels. The objectives of the plan are to: • Facilitate compliance with relevant legislation, regulations and approvals • Provide a framework for Santos GLNG to store and handle bulk chemicals and fuels in a way that minimises risk to the environment and human health • Assess the potential risk of a chemical or fuel prior to its use • Identify and implement appropriate mitigation measures.

5 Impact assessment and mitigation

Management plan	Commitment
Contingency Plan for emergency environmental incidents (Contingency plan)	The Contingency plan details the management practices in place within Santos GLNG to minimise environmental harm during an emergency environmental incident. The plan identifies potential incidents, and provides response actions, including escalation, communication, reporting and monitoring.
Decommissioning and abandonment management plan (DAMP)	The DAMP describes the management framework in place for when petroleum activities cease. The objectives of the plan are to: • Undertake decommissioning of assets in a manner that complies with regulatory requirements and minimises the risk of environmental harm • Undertake decommissioning activities in a manner that meets stakeholder expectations • Leave a landform that is stable and compatible with intended post-closure land use • Provide for the beneficial reuse of Santos GLNG infrastructure constructed to third parties (e.g. landholders or local authorities) where an appropriate agreement has been signed by both parties and regulatory authorities are satisfied.
Draft environmental management plan (Draft EM Plan)	The Draft EM Plan identifies the environmental values potentially affected by the GFD Project and proposes measures to manage the risk of potential adverse impact to these environmental values. The Draft EM Plan comprises: • Environmental values potentially affected by the GFD Project • Environmental management objectives and associated management measures • Environmental monitoring and reporting • Coal seam water management • Proposed conditions.
Erosion and sediment control management Plan (ESCMP)	The ESCMP identifies erosion and sedimentation risk and provides an erosion and sediment control strategy that incorporates understanding of the risk inherent to local land resource characteristics. The ESCMP is supported by the Erosion and sediment control manual, which provides erosion, sediment and drainage controls in line with best practice guidelines.
Ground deformation monitoring and management plan (GDMMP)	The GDMMP details how Santos GLNG monitors and manages the risk from subsidence across its tenure. The plan includes monitoring methodology, exceedance management and response, and reporting requirements.
Hydraulic fracturing risk assessment: compendium of assessed fluid systems	The Hydraulic fracturing risk assessment report synthesises the hydraulic fracturing risk assessments completed on various hydraulic fracturing fluids and provides a framework for including new fluid systems within the risk assessment document. The body of the report provides generalised information, including the geology and hydrogeology of the area, risk assessment methodologies (qualitative and quantitative) and a high level understanding of current results. The appendices include risk assessments of individual hydraulic fracturing fluid systems.
Rehabilitation management plan	The Rehabilitation management plan outlines the rehabilitation objectives for Project-related disturbances within the GFD Project area. This includes the phasing of rehabilitation to first achieve stabilisation and subsequently final rehabilitation for disturbances to land (i.e. ground surface). The Rehabilitation management plan: • Describes Santos GLNG's approach to rehabilitation • Identifies key rehabilitation objectives and criteria to deem rehabilitation success • Outlines general rehabilitation actions to be undertaken by Santos GLNG when rehabilitation a disturbance • Provides an overview of monitoring and maintenance actions to be conducted on rehabilitated areas.

5 Impact assessment and mitigation

Management plan	Commitment
Joint industry plan for an early warning system for the monitoring and protection of EPBC springs (Joint industry plan)	The joint industry plan has been collaboratively developed by Santos GLNG, Origin Energy and Queensland Gas Company (the Proponents). The objectives of the joint industry plan are to: - Summarise the monitoring requirements that have been requested of the Proponents in the <i>Surat Underground Water Impact Report for the Surat Cumulative Management Area</i> (Queensland Water Commission, 2012) and in the Proponents' approval conditions by the Department of the Environment - Propose an early warning system monitoring network and escalating levels of triggers to manage EPBC Act-listed springs from adverse impacts associated with coal seam water extraction - Demonstrate that the Proponents will endeavour to identify potential adverse impact early and adequately respond to prevent adverse impact to EPBC Act listed springs - Identify which Proponent is responsible for management actions for each spring - Demonstrate the Proponents' commitments to meet the requirements of the EPBC Act approval.
Land release management plan (LRMP)	The LRMP addresses the management of releases of water to land in Santos GLNG's gas fields, including: - Coal seam water use for irrigation, construction and operations purposes - Treated sewage effluent releases to land - Use of treated sewage effluent for construction and operational purposes - Low point drain water releases to land - Hydrostatic test water releases to land. - The document includes the principles, methods and controls to effectively manage and minimise the risk environmental harm being caused by release of water to land.
Water resource management plan (WRMP)	The WRMP has been developed to proactively detail how Santos GLNG manages and monitors potential adverse impacts to water resources, recently defined as a matter of national environmental significance.
Pest and weed management plan (PWMP)	The management of pest and weed species will be undertaken in accordance with the PWMP. The plan includes measures such as: - Identification of pest and weed species and areas of infestation - Avoidance of traversing and placing infrastructure in areas of known infestation - Prevention of the spread of pest and weed species by implementing appropriate work practices and promotion of risk awareness - Control of identified pest and weeds through containment, reduction or eradication as required by legislation. - Engage stakeholders including landholders and local communities in assisting Santos GLNG in the identification and management of pests and weeds at Santos GLNG assets and activities. Santos GLNG will review local government's pest and weed management plans and apply measures from these to the PWMP where it is appropriate.

5 Impact assessment and mitigation

Table 5-7 Land resources impact assessment

Potential impact	Phase	Pre-mitigated significance			Mitigation measures	Residual significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
Altered geological setting	Construction	Moderate	Moderate	Moderate	The Constraints protocol and hydraulic fracturing risk assessment will be implemented to avoid, minimise and mitigate impacts to existing geological structures (e.g. faults) and long-term effects on geological settings (e.g. subsidence). The Water Resource Management Plan will be implemented to monitor impacts on geology and associated land and water resources.	Low	Low
	Operations		Moderate	Moderate		Low	Low
	Decommissioning		Low	Low		Low	Low
Change to landform	Construction	Moderate	Moderate	Moderate	The Constraints protocol will be implemented to avoid, minimise and mitigate impacts in line with the DAMP and Rehabilitation management plan, the GFD Project will create final landforms that are stable, conducive to the surrounding landform and drainage patterns are restored. While some changes to landforms may be permanent, rehabilitated areas will be returned to a comparable productivity and land use of what previously occurred or otherwise mutually agreed upon.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low
Aquifer depressurisation resulting in subsidence	Construction	Moderate	Low	Low	Subsidence caused by aquifer depressurisation will be managed in accordance with the Joint industry plan, Water resource management plan and Ground Deformation monitoring and management plan, which includes measures such as: - Dedicated regional groundwater monitoring s targeting specific aquifers, monitoring water pressure - Dedicated groundwater level monitoring of selected private bores (targeting a single known aquifer) - On-going interferometric synthetic aperture radar (InSAR) measurements of ground motion.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low
Loss of soil resources	Construction	Moderate	Moderate	Moderate	Soil loss via erosion from exposed surfaces will be mitigated through implementation of the ESCMP, which will include mitigation measures such as: Application of the erosion risk assessment process for well pads, bores, camps, pipelines and power lines to identify appropriate level of erosion, sediment and drainage control.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low

5 Impact assessment and mitigation

Potential impact	Phase	Pre-mitigated significance			Mitigation measures	Residual significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
					• Development of site specific erosion and sediment control plans for all other petroleum activities. • During construction: — Soil testing to identify problem soils and amelioration if required — Stripping and stockpiling of topsoil for reuse for later rehabilitation — Stockpiling and mulching (where available) cleared vegetation or spreading over disturbed areas — Minimising the period that soil is left exposed to erosion through progressive ground cover revegetation — Installation and maintenance of drainage, erosion and sediment control devices appropriate to the erosion and sediment risk of the activity. • During operation: — Spreading of stockpiled topsoil across disturbed areas — Progressive revegetation — Stabilisation of batters — Establishment of permanent drainage. Santos GLNG will implement the Constraints protocol to high value soil resources where practical or obtain necessary approvals prior to works commencing in areas such as those identified as SCA and GQAL. The ESCMP will be implemented to provide for the conservation and management of soil resources. Pest and weed species will be managed in accordance with the PWMP, which includes measures such as: • Identification of pest and weed species and areas of infestation • Avoidance of traversing and placing infrastructure in areas of known infestation • Prevention of the spread of pest and weed species by implementing appropriate work practices and promotion of risk		

5 Impact assessment and mitigation

Potential impact	Phase	Pre-mitigated significance			Mitigation measures	Residual significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
					awareness Control of identified pest and weeds through containment, reduction or eradication as required by legislation.		
Degradation of soil resources	Construction	Moderate	Low	Low	Degradation of soil resources and the management of top soil will be managed in accordance with the Rehabilitation management plan, Constraints protocol, DAMP and ESCMP, which include measures such as: - Minimising the area of disturbance - Restricting vehicle movement on wet soil - Re-vegetating disturbance areas as soon as practicable - Pre-stripping and stockpiling topsoil for use as growth media for rehabilitation of areas of disturbance during development, construction and operation phases of the GFD Project. - Installation of appropriate erosion and sediment control measures. - Ameliorating sodic soils with gypsum and/or lime or addition of organic mulch to sodic soils to improve soil structure, infiltration and soil aeration.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low
Restricted access to productive (agricultural or forestry) land	Construction	Moderate	Moderate	Moderate	Temporary impacts on cropping, grazing or forestry land will be managed in accordance with the Rehabilitation management plan and Constraints protocol, which include measures such as: Remediate and rehabilitate.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low
Authorised release to soil	Construction	Moderate	Moderate	Moderate	Management of coal seam water including releases to soil are covered in the Draft EM plan which details treatment based on its proposed use to meet the water quality objectives. The LRMP includes mitigation measures for each application scenario including measures such as: - Prescribed water quality and monitoring requirements where applicable - Site selection assessment process and environmental values and	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low

5 Impact assessment and mitigation

Potential impact	Phase	Pre-mitigated significance			Mitigation measures	Residual significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
					characteristics to be considered • Application controls • Site operation controls where applicable • Monitoring and response requirements.		
Uncontrolled release to soil	Construction	Moderate	Moderate	Moderate	Fuel and chemicals will be managed and monitored in accordance with practices specified in the CFMP, which aligns to AS 1940. Spill response equipment and materials are provided at facilities, with key operations equipment and on operations and maintenance personal service trucks. The Contingency plan for environmental incidents details response to manage all levels of incidents, including appropriate emergency response equipment, its use and reporting and recording of releases in the incident register. Contaminated soil will be disposed of in accordance with relevant regulatory obligations.	Low	Low
	Operations		Low	Low		Low	Low
	Decommissioning		Low	Low		Low	Low
Sterilisation of coal reserves	Construction	Moderate	Moderate	Moderate	The DAMP will be implemented to provide a process for decommissioning and abandonment of facilities prior to implementation of the Rehabilitation Management Plan. The decommissioning and removal of surplus assets and facilities will allow for the restoration of historic land uses and limit sterilisation of land and deeper resources.	Low	Low
	Operations		Moderate	Moderate		Low	Low
	Decommissioning		Low	Low		Low	Low
Damage to fossils	Construction	Low	High	Moderate	Where fossils are identified they are managed in accordance with the Draft EM plan and appropriate legislation.	Low	Negligible
	Operations		Low	Low		Low	Negligible
	Decommissioning		Low	Low		Low	Negligible

5 Impact assessment and mitigation

5.5 Residual impacts

With the implementation of the mitigation and management measures outlined in Table 5-7, the residual impacts on the environmental values of the GFD Project area have been assessed as low to moderate.

5.6 Monitoring

Strategies for implementing a monitoring program throughout the duration of the GFD Project have been identified. Monitoring programs have been integrated into the management plans and provide a basis to measure the effectiveness of management strategies and enable review and update of processes to optimize environmental outcomes. These programs will be updated if required to align with GFD Project activities following field development planning. All monitoring will be carried out at a frequency to ensure compliance. The following existing monitoring plans and guiding documents will inform the development of development-specific monitoring programs within the GFD Project area:

- ESCMP
- Draft EM Plan.

Monitoring in relation to land resources will be undertaken in response to the following principal land risks, erosion and surface runoff, irrigation activities and land subsidence.

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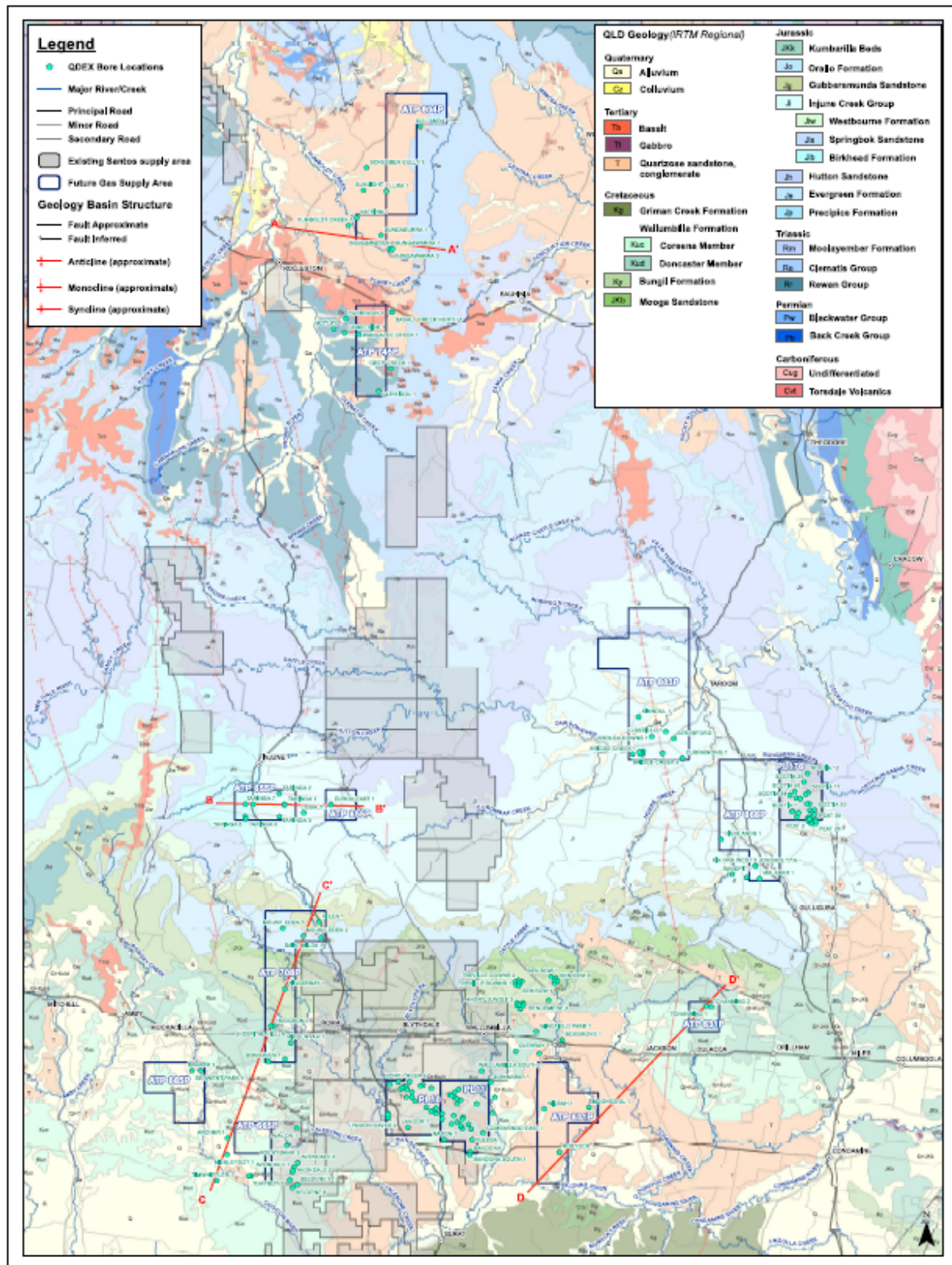
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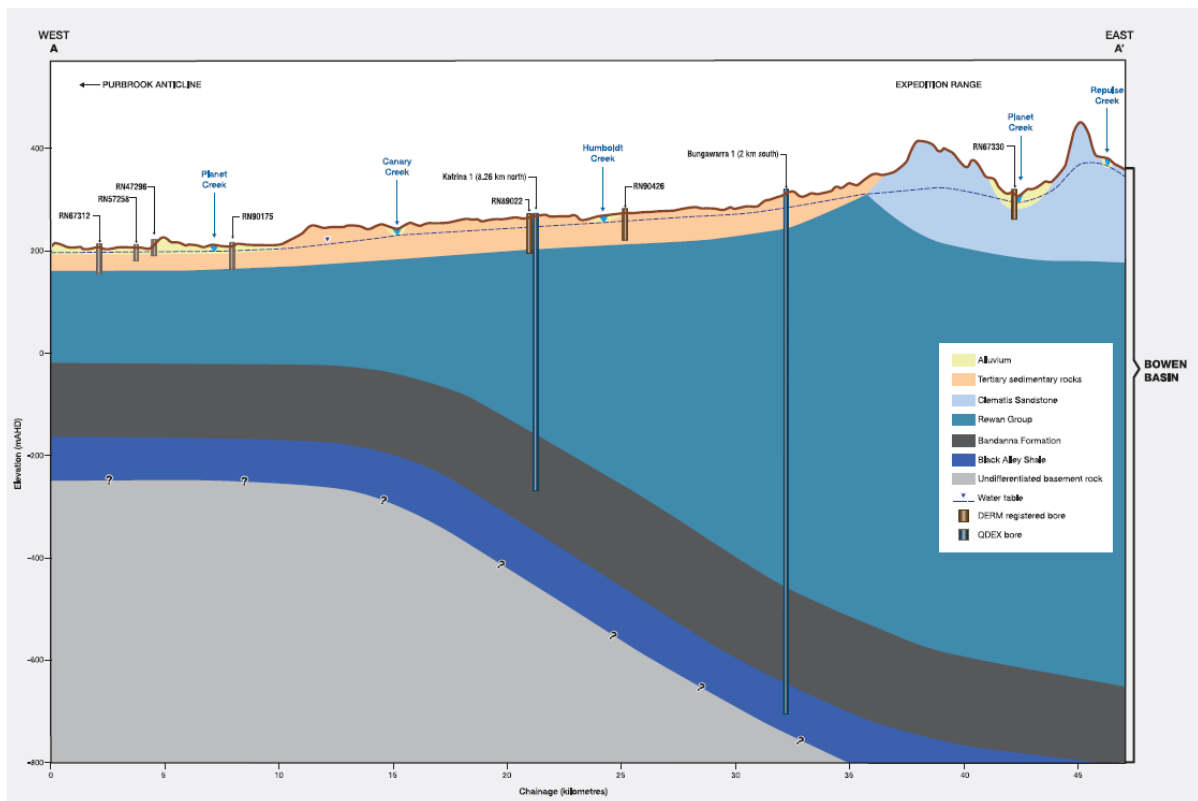
Appendix A – Geological cross-sections

Appendix A – Geological cross-sections

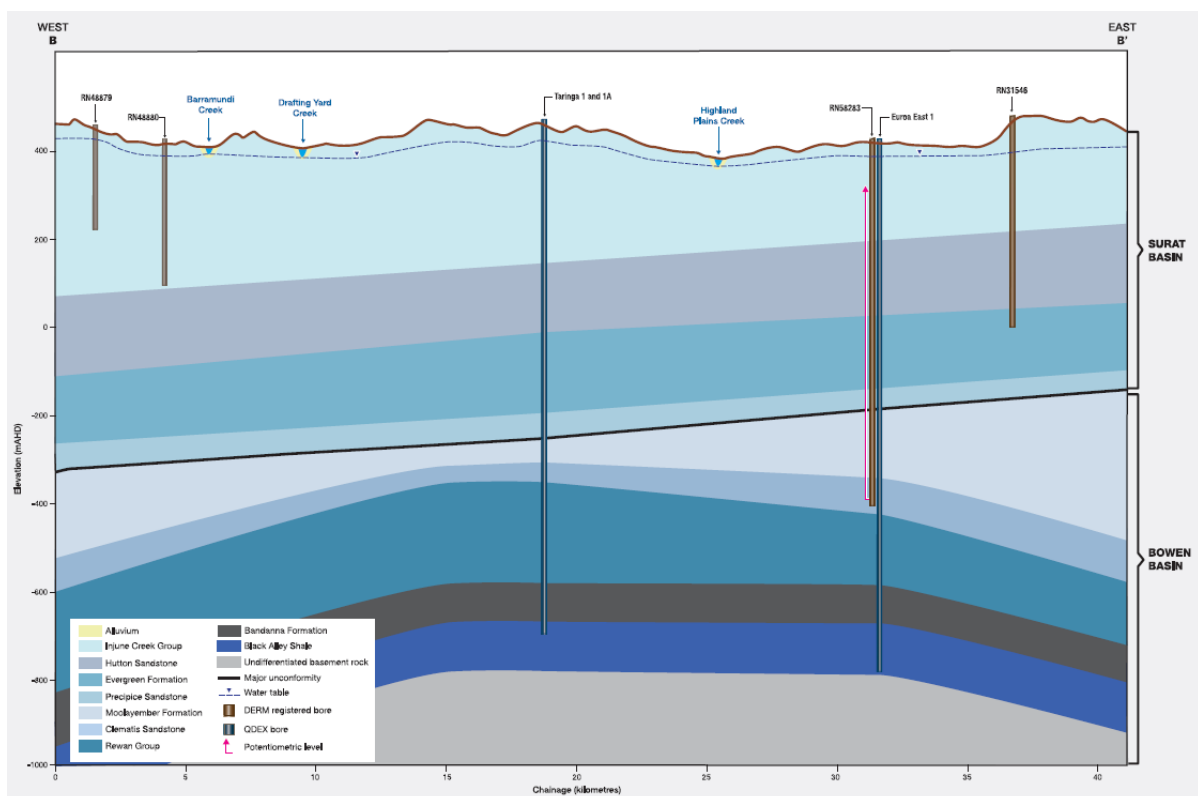


Geological cross-sections overview

Appendix A – Geological cross-sections

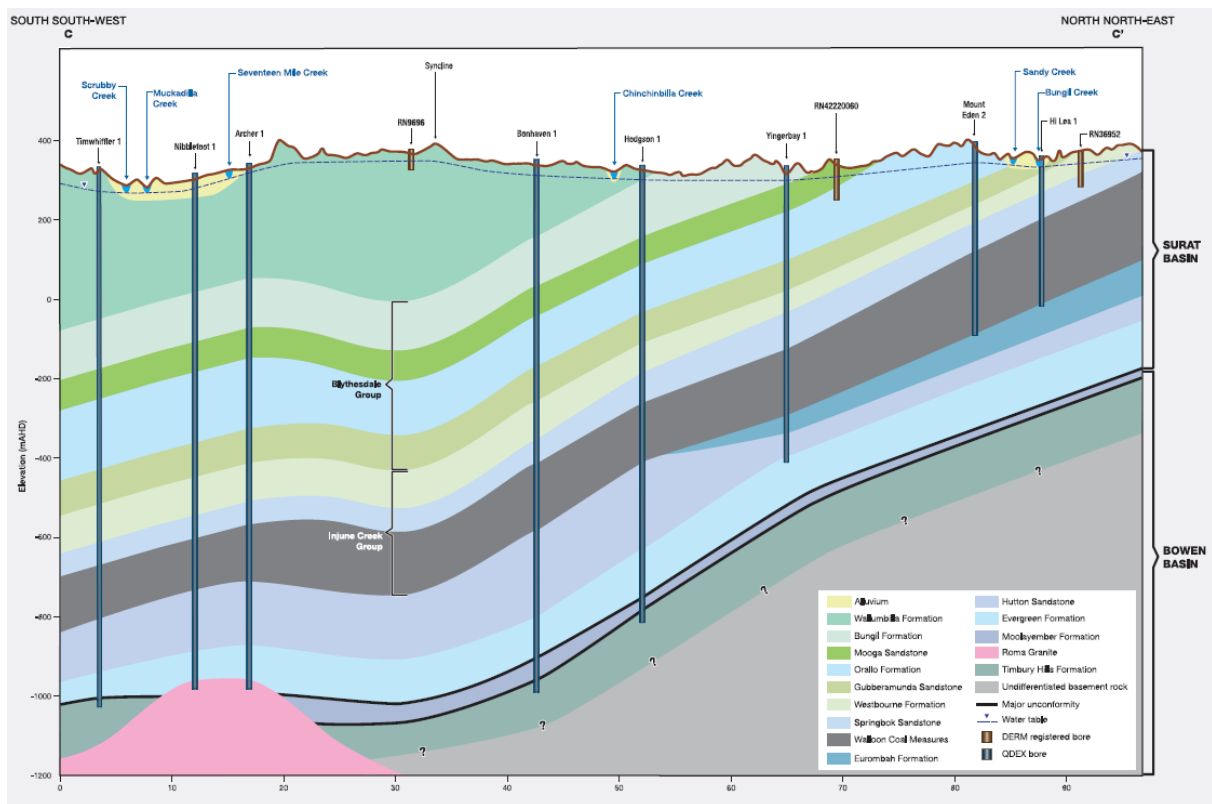


Geological cross-section A

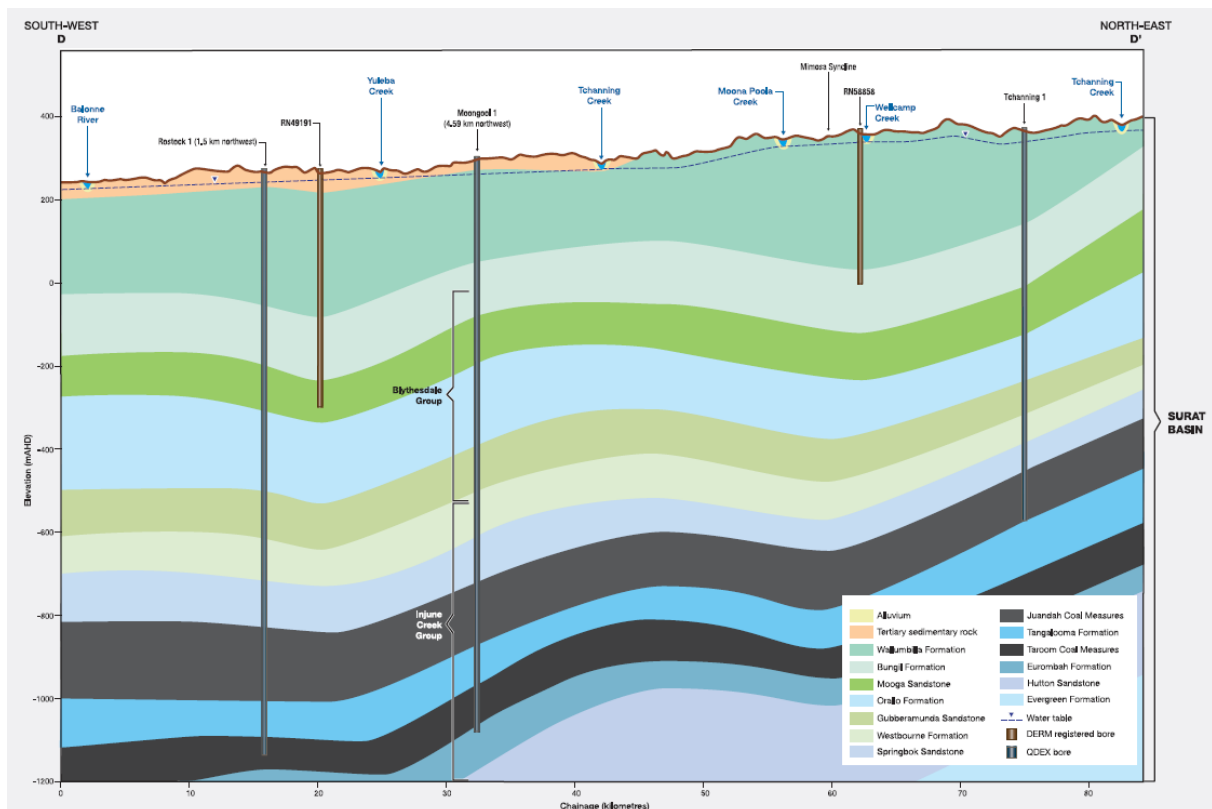


Geological cross-section B

Appendix A – Geological cross-sections



Geological cross-section C



Geological cross-section D

Appendix B – Interpretation of soil data

Appendix B – Interpretation of soil data

LABORATORY TEST METHODS

TEST SIGNIFICANCE AND TYPICAL VALUES

Particle Size Analysis

Particle size analysis measures the size of the soil particles in terms of grainsize fractions, and expresses the proportions of these fractions as a percentage of the sample. The grainsize fractions are:

- clay (<0.002 mm)
- silt (0.002 mm to 0.02 mm)
- fine sand (0.02 mm to 0.2 mm)
- medium and coarse sand (0.2 mm to 2 mm)

Particles greater than 2 mm, that is gravel and coarser material, are not included in the analysis.

Dispersion Percentage

Dispersion percentage is a measure of soil dispersibility representing the proportion of clay plus fine silt (<0.005 mm approximately) in a soil which is dispersible and is expressed as a percentage. The following rankings of dispersion percentage are applicable:

0 % to 30 %	low
30 % to 50 %	moderate
50 % to 65 %	high
65 % to 100 %	very high

Emerson Aggregate Test

Emerson aggregate test measures the susceptibility to dispersion of the soil in water. Dispersion describes the tendency for the clay fraction of a soil to go into colloidal suspension in water. The test indicates the credibility and structural stability of the soil and its susceptibility to surface sealing under irrigation and rainfall. Soils are divided into eight classes on the basis of the coherence of soil aggregates in water. The eight classes and their properties are:

- Class 1 - very dispersible soils with high tunnel erosion susceptibility.
- Class 2 - moderately dispersible soils with some degree of tunnel erosion susceptibility.
- Class 3 - slightly or non-dispersible soils which are generally stable and suitable for soil conservation earthworks.
- Class 4-6 - more highly aggregated materials which are less likely to hold water. Special compactive efforts are required in the construction of earthworks.
- Class 7-8 - highly aggregated materials exhibiting low dispersion characteristics.

Appendix B – Interpretation of soil data

The following subdivisions within Emerson classes may be applied:

- (1): slight milkiness, immediately adjacent to the aggregate
- (2): obvious milkiness, less than 50 % of the aggregate affected
- (3): obvious milkiness, more than 50 % of the aggregate affected
- (4): total dispersion, leaving only sand grains.

Reactive Soils

The cation exchange capacity (CEC) to clay ratio (CCR) is used as an index of clay mineralogy on the basis of the relationship between CEC and clay content and clay activity. It is used in place of the standard X-ray diffraction measurement of clay mineralogy which is expensive and is not a routine laboratory test. It is sometimes also referred to as the clay activity ratio, CAR (Wilson and Baker 1990). The CEC / clay ratio is expressed as cmol (+)/ kg clay and it is determined by dividing the soil's CEC (cmol(+)/kg) by the clay content (%) of the <2mm particle size fraction (Shaw et al. 1998).

The formula is:

$$\text{CCR} = \text{CEC [cmol(+) kg soil]} \div \text{Clay \%}$$

Sodicity

The exchangeable sodium percentage (ESP) is determined by measuring the concentration of all the exchangeable cations in the soil and expressing the amount of exchangeable sodium as a proportion of the sum of all exchangeable cations (known as the cation exchange capacity (CEC)). Three categories of sodicity corresponding to different ESPs are shown:

Sodicity Rating	ESP's proposed for Australian Soils (Northcote and Skene 1972)
Non-sodic	0-6
Marginally sodic to sodic	6-14
Strongly sodic	>14

Salinity

Salinity is measured as electrical conductivity on a 1:5 soil:water suspension to give EC (1:5). The effects of salinity levels expressed as EC at 25°C (dS/cm), on plants are:

- 0 - 1 very low salinity, effects on plants mostly negligible.
- 1 - 2 low salinity, only yields of very sensitive crops are restricted.
- > 2 saline soils, yields of many crops restricted.

Appendix B – Interpretation of soil data

pH

The pH is a measure of acidity and alkalinity. For 1:5 soil:water suspensions, soils having pH values less than 4.5 are regarded as strongly acid, 4.5 to 5.0 moderately acidic, and values greater than 7.0 are regarded as alkaline. Most plants grow best in slightly acidic soils.

Phosphorus

Phosphorus is an important soil component indicating a main limiting growth factor. The phosphorus that is available to the plant is only a small fraction of the total amount of phosphorus in the soil. Extractable phosphorus was determined by the Bray No. 2 test.

Available phosphorus at 5 ppm is considered the deficiency limit whereas levels greater than 25 ppm are very high.

Phosphorus Sorption

Phosphorus sorption relates to the ability of a soil to remove phosphorus from solution and assimilate it within the soil matrix. Sorption index ratings are:

0 – 3	low
3 – 4.5	moderate
4.5 – 6	high
>6	very high

Nitrogen

Nitrogen is another important component of soil indicating a main limiting growth factor. The total amount of nitrogen in the soil was determined by the Kjeldahl method, which is essentially a wet-oxidation procedure.

The total nitrogen of soils ranges from less than 0.2 percent in subsoils to greater than 2.5 percent in peats. The surface layer of most cultivated soils contains between 0.06 to 0.5% N. As a guide, the following figures for total nitrogen may be used:

- less than 0.1 % N low
- 0.1 % to 0.2 % N medium
- more than 0.2 % N high

Cation Exchange Capacity and Exchangeable Cations

The concentration of cations is expressed as milli-equivalents (me)/100 g or mmol/kg. This takes account of their different valencies and atomic weights. The total quantities of cations that a soil can hold is called the cation exchange capacity (CEC), also expressed as me/100 g.

The five most abundant cations in soils are calcium (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), sodium (Na⁺) and in strongly acid soils, aluminum (Al³⁺). The cations manganese

Appendix B – Interpretation of soil data

(Mn²⁺), iron (Fe²⁺), copper (Cu²⁺) and zinc (Zn²⁺) are usually in amounts that do not contribute significantly to the cation complement. The following rankings are applicable:

Cation (me/100g)	Ranking				
	Very low	Low	Moderate	High	Very High
CEC	<5	5-10	0-15	15-35	>35
Na	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
K	<0.2	0.2-0.4	0.4-0.7	0.7-2.0	>2.0
Ca	<2	2.0-5.0	5-10	10-20	>20
Mg	<0.3	0.3-1.0	1.0-3.0	3.0-8.0	>8.0

Soils or substrates having values of exchangeable sodium percentage (ESP) exceeding 5 me% are described as sodic, and greater than 15 me% as strongly sodic. The clay particles in such soils are liable to disperse on wetting, causing structure to deteriorate and surface sealing to occur.

Organic Carbon

Organic Carbon content can be directly related to the levels of soil organic matter and is based on the (Walkley – Black) chromic acid method. Percentage organic matter can be obtained by multiplying percentage organic carbon by 1.72. This factor is based on the assumption that organic matter in the soil has a constant carbon composition of 58 percent.

The following rankings of organic carbon are applicable:

- 0 %to 0.5% very low
- 0.5 % to 1.5% low
- 1.5 %to 2.5% moderate
- 2.5 % to 5.0% high

Appendix C – Revised universal soil loss equation

Appendix 3 Applying the Revised Universal Soil Loss Equation

REVISED UNIVERSAL SOIL LOSS EQUATION

While assessment of runoff is commonplace in the urban planning process, estimating possible soil loss is not. Nonetheless, estimates of soil loss have four important applications to soil and water management. These are to:

- o assess the erosion risk at a site;
- o identify suitable measures to overcome the erosion risk;
- o estimate the required capacity of sediment retarding basins; and
- o compare the effectiveness of various erosion control measures.

Therefore, by estimating likely soil loss levels, land planners can gear erosion and sediment control measures to each part of any development site. Consequently, they can mitigate possible soil erosion and consequent sediment pollution to downslope lands and waterways.

The Revised Universal Soil Loss Equation (RUSLE) is designed to predict the long term, average, annual soil loss from sheet and rill flow at nominated sites under specified management conditions. The predicted losses are empirically derived and it is anticipated that the monitoring and comparison of actual soil loss onsite measured against that calculated will lead to a substantiation of the equation. Further validations of this methodology on construction sites are still being investigated. The original application is described by Wischmeier & Smith (1978) and revised by Renard, Foster, Weesies and Porter (1991) and Renard, Foster, Weesies, McCool and Yoder (1997). It has been adapted to urban sites by Goldman *et al.*, (1986) and modified for Australian conditions in a computer program called SOILOSS (Rosewell, 1993b). The equation is represented by:

$$A = R K L S P C \quad \text{Equation (1)}$$

where, A = computed soil loss (tonnes/ha/yr)¹⁰²

- R = rainfall erosivity factor
- K = soil erodibility factor
- LS = slope length/gradient factor
- P = erosion control practice factor
- C = *ground cover and management factor.*

Because the RUSLE takes into consideration all major components likely to affect sheet erosion, it is the most widely used (and abused) soil loss equation available. While it does have great practical value, its limitations should be recognised and understood.

The main limitations of the RUSLE are that:

- o It only predicts sediment entrained in the erosion process and does not predict sediment yields into particular sediment basins¹⁰³;
- o It predicts average annual soil loss and not that for a particular storm event;
- o It is effective for erosion through sheet and rill flow only on short slopes (<300m) and not for concentrated flow or long slopes; and
- o It does not adequately take into account soil dispersibility in assessment of the K-factor.

In the urban context, it can be assumed that soil loss derived from the RUSLE is equal to the sediment flux into a sediment retardation basin located on, or immediately next to a site, and the volume of sediment entering within a year is:

Despite these matters, the RUSLE has its benefits and should be applied at all urban development sites, even at a cursory level.

¹⁰² In the urban context, it can be assumed that soil loss derived from the RUSLE is equal to the sediment flux into a sediment retardation basin located on, or immediately next to a site, and the volume of sediment entering within a year is:

$$\text{Volume (m}^3\text{)} = \frac{\text{mass of dry delivered sediment}}{\text{density of saturated sediment}}$$

¹⁰³ In most situations, not all the sediment entrained on eroding lands is transported away from the site. However, at most construction sites where sediment trapping devices are very close to areas of erosion and the fine particles are flocculated, it can be assumed that most sediment entrained can be trapped.

RAINFALL EROSION FACTOR - R

The rainfall erosivity factor, R , is a measure of the ability of rainfall to cause erosion. It is the product of two components: total energy (E) and maximum 30-minute intensity for each storm (I_{30}). So, the total of EI for a year is equal to the R -factor.

Rosewell & Turner (1992) have identified a strong correlation between the R -factor and the 2-year ARI, 6-hour storm event. Data here has been based on this phenomenon. Where this still does not give sufficient detail, the R -factor can be obtained from Equation 2.

$$R = 164.74(1.1177)^S S^{0.6444} \text{ Equation (2)}$$

where S is the 2-year ARI, 6-hour ARI rainfall event (mm) (Rosewell & Turner, 1992).

Isoerodent maps showing lines of equal erosivity were published for Queensland (Rosenthal & White, 1980), Western Australia (McFarlane *et al.* 1986), New South Wales (Rosewell & Turner 1992), South Australia (Yu & Rosewell, 1966b), and Victoria (Sheridan & Rosewell, 2003). In addition, a relationship between the R -factor and 2-year, 6-hour rainfall intensity has been developed for many sites in Australia (Rosewell & Turner 1992, Rosewell 1993a). Such a relationship has been used to estimate rainfall erosivity for all states and territories based on rainfall intensity data published in Pilgrim (1998), Rosewell (1993b & 1997), and Sheridan & Rosewell (2003). High resolution, Australia-wide maps of R -factor are in the *Australian Natural Resources Atlas*.

The quality of the estimated R -factor depends on the quality of the limited pluviograph data. To overcome the problem with limited pluviograph data and to estimate the seasonal distribution of rainfall erosivity, a model using daily rainfall data has been tested for both temperate and tropical regions of Australia (Yu & Rosewell 1996a and 1996b, Yu 1998).

Also, regional relationships of model parameters were developed to allow prediction of the R -factor and its monthly distribution from daily rainfall anywhere in Australia (Yu, 1998).

Based on average rainfall data, the high R -factor for Cairns (16,950) is particularly relevant because 77% of it occurs in the four-month monsoon season between December and March. Conversely, Adelaide has a very low R -factor (330) with a much more non seasonal rainfall that is very much lower in total.

Where there is any significant seasonality to the R -factor, monthly or fortnightly data should be used to identify those times of the year when lands with very high erosion hazards should:

- o either not be developed, or
- o have special erosion control measures put in place to compensate.

Fortnightly EI data are available for some locations in New South Wales (Rosewell & Turner, 1992) and monthly data in Queensland (Rosenthal & White, 1980). Monthly estimates are available for some locations in South Australia (Yu & Rosewell, 1996b) and Western Australia (McFarlane *et al.*, 1986). A method for estimating half monthly values of erosivity from monthly data is provided by Renard *et al.* (1997).

Noting that data on the R -factor in the RUSLE are derived from average annual rainfall information is important. Consequently, it does not account for seasonality or hydrology, especially antecedent conditions affecting peak flow and total runoff. Other methods are available to help where more detailed data are required (Chapter 7)

In some areas in eastern Australia, rainfall erosivity does not vary much throughout the year. Such areas usually have quite low R -factors, so erosion hazards are relatively low.

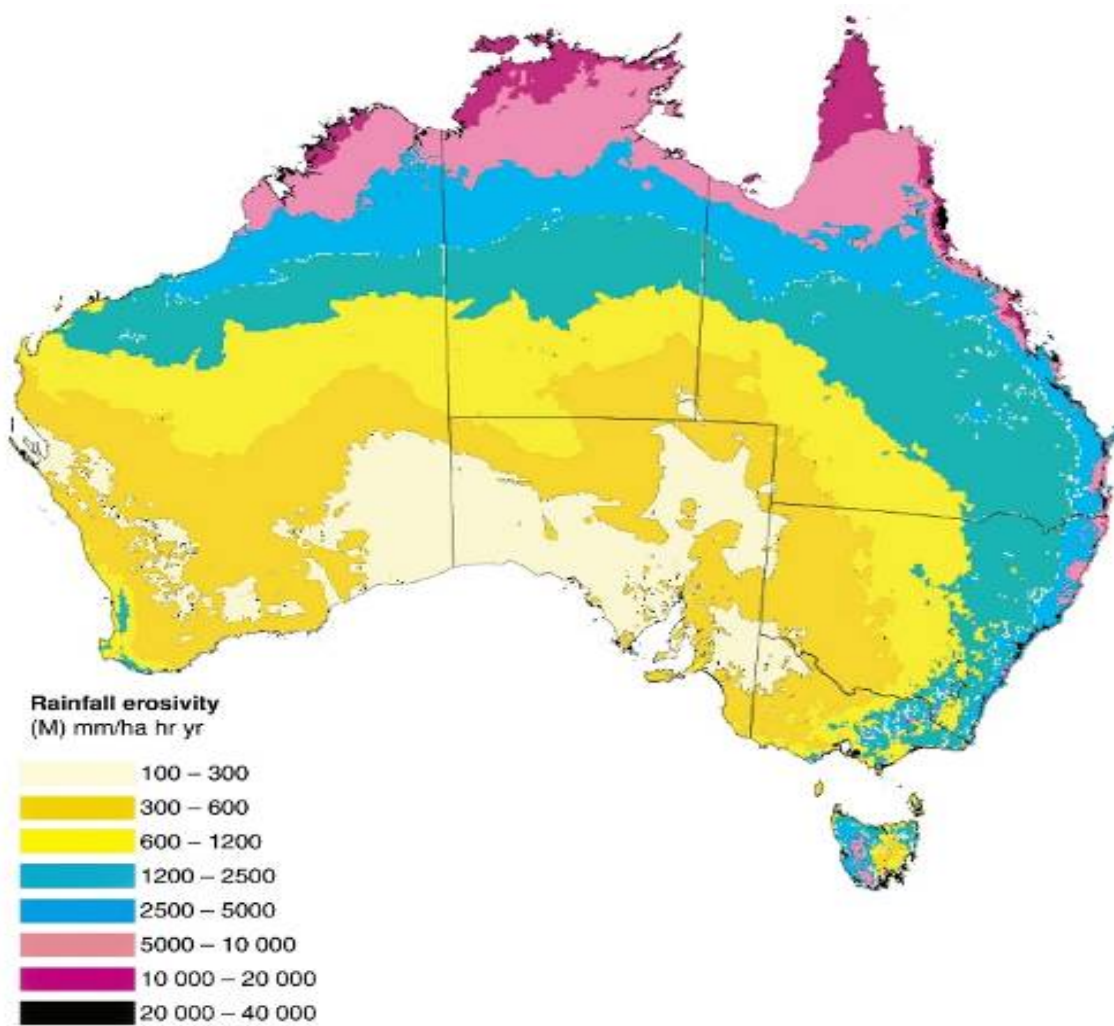


Figure A3-1 R-factors for Australia¹⁰⁴

However, local rainfall statistics in other areas show marked seasonal trends and some of these have quite high *R*-factors. In these areas, development and construction works programs should take advantage of the statistical information and encourage works on lands with high erosion hazards to be undertaken in "drier" months. This risk-based approach recognizes that unseasonable rainfall events might occur at unexpected times, both from one year to another and seasonally.

Rosewell & Turner (1992) provide data for 29 sites in NSW on the "annual exceedence probability" (AEP) for rainfall erosivity.

The annual exceedence probability is the probability of exceedence of a given *R*-factor in any one year. 2 above illustrates the effect of rainfall variation at a site at Richmond, NSW. It shows computed average annual soil loss for different slopes using:

- the *R*-factor for the site (1,772); and
- the 50%, 20% and 5% AEP for rainfall erosivities (1,397, 2,247 and 3,536, respectively) instead of the *R*-factor.

¹⁰⁴ Australian Natural Resources Atlas, 2001

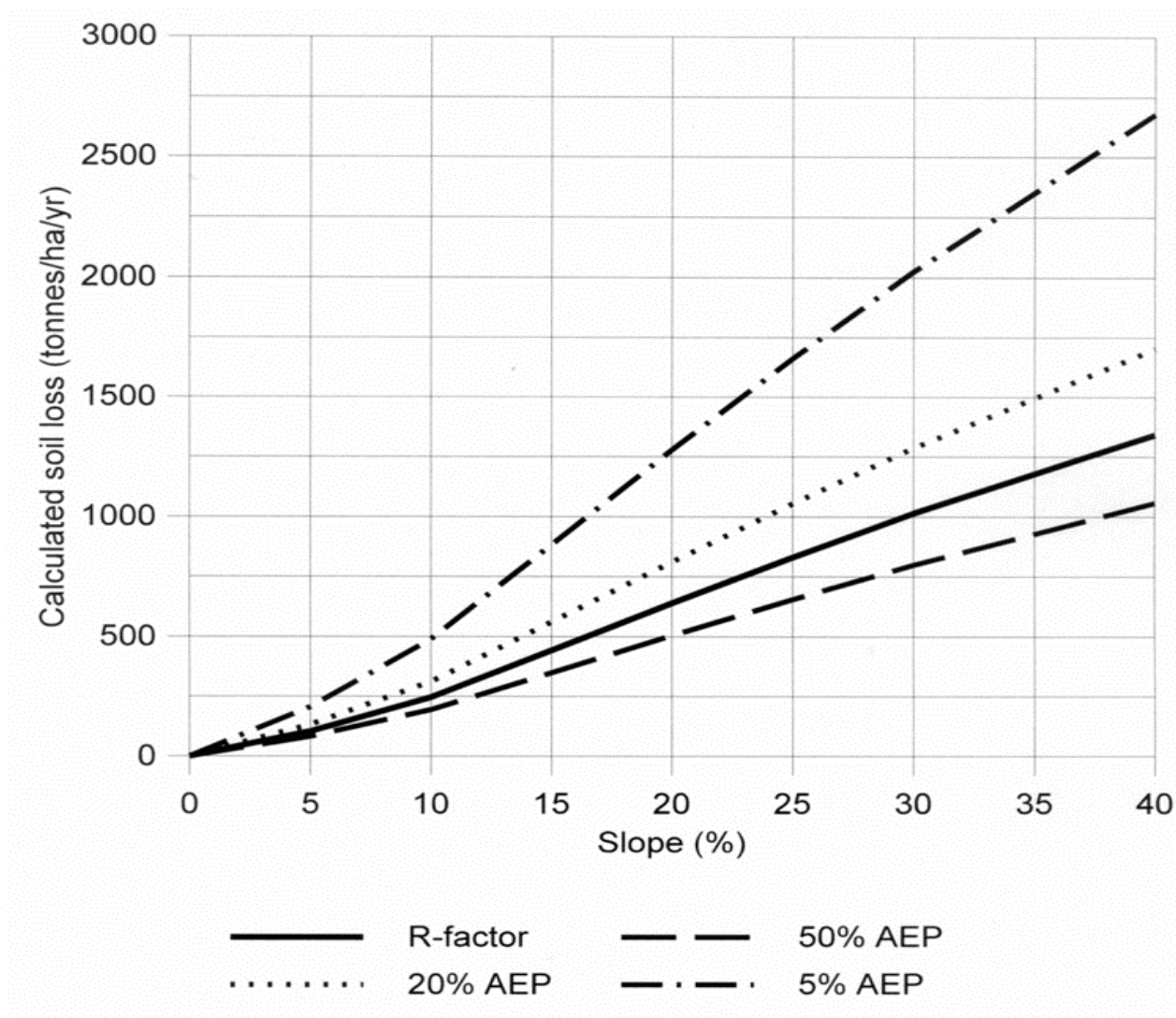


Figure A3-2 Average Annual Soil Losses Calculated for an Example Site in NSW¹⁰⁵

The site has a *K*-factor of 0.038, a *P*-factor of 1.3, a *C*-factor of 1.0 and slope length is 80m. Most importantly, the data shows that the calculated average annual soil loss based on:

- the 5% AEP rainfall erosivity is higher than data based on the *R*-factor by 1.99;
- the 20% AEP is higher by 1.27; and
- the 50% AEP is lower by 0.79.

Note that the variations illustrated are not constant from one location to another. For example, a similar analysis closer to the coast, shows the 5% AEP higher by 3.28, the 20% AEP higher by 1.52 and the 50% AEP lower by 0.68.

Also, note that at the first site, there is a 20% probability that a single storm can yield a rainfall erosivity (erosion index) of 1,021 compared with the *R*-factor (long-term average annual sum of erosion index) of 1,772. Likewise, there is a 10% and 5% probability that it can yield rainfall erosivities of 1,453 and 2,258 respectively.

¹⁰⁵ Based on the usual *R*-factor, and the 50%, 20% and 5% AEP

SOIL ERODIBILITY FACTOR - K

The soil erodibility factor, *K*, is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Soil texture is the principle component affecting *K*, but soil structure, organic matter and profile permeability also contribute. In the RUSLE, it is a quantitative value experimentally determined.

K should be derived for each particular site and based on laboratory analysis, particularly at sensitive sites. The method for estimating the *K*-factor is described by Rosewell and Loch (2002). the SOILOSS program (Rosewell, 1993b) or can help deriving *K* from raw laboratory data¹⁰⁶. Generally, the *K*-factor ranges from 0.005 (very low) to 0.075 (very high).

Note that “**Texture grading**” is described in the following classes – only particles finer than 2mm are entered here:

- Coarse sand – 0.1 to 2.0mm diameter (100 to 2,000 microns)

Fine sand – 0.1 to 0.2mm (100 to 200 microns)

Very fine sand – 0.02 to 0.1mm diameter (20 to 100 microns)

Silt – 0.002 to 0.02mm diameter (2 to 20 microns)

Clay – < 0.002mm diameter (<2 microns).

“**Organic matter**” – to convert percentage organic carbon to percent organic matter, multiply by 1.72.

- “Soil structure” is described in the following grades:

1 – very fine granular where particles are mostly less than 1mm diameter

2 – fine granular where particles are mostly 1 to 2mm diameter

3 – medium or coarse granular where particles are mostly 2 to 10mm diameter

4 – blocky, platy or massive.

“**Profile permeability**” refers to the rate of infiltration of water (*K*_{sat}) into the whole soil profile as follows:

- 1 – rapid, greater than 130mm per hour (includes most Soil Hydrologic Group A (Table F2))

2 – moderate to rapid, 60 to 130mm per hour (includes some Soil Hydrologic Group B and some Group A)

3 – moderate, 20 to 60mm per hour (includes some Soil Hydrologic Group B)

4 – slow to moderate, 5 to 20mm per hour (includes some Soil Hydrologic Group B and some Group C)

5 – slow, 1 to 5mm per hour (includes some Soil Hydrologic Group C)

6 – very slow, <1mm per hour (includes all Soil Hydrologic Group D).

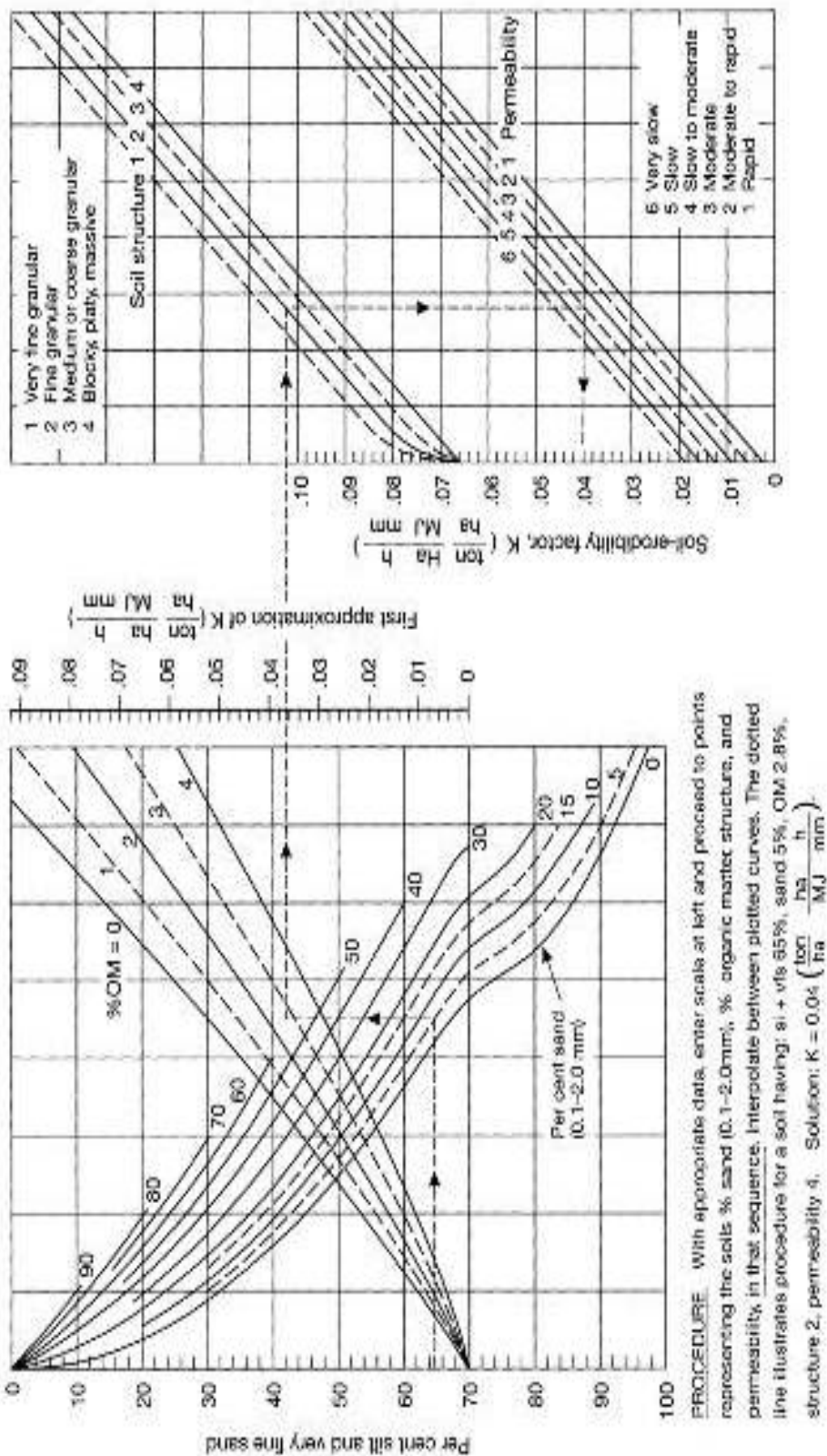
In addition, Rosewell (1993b) suggests that:

- Soils where the subsoil structure grade is moderate or strong or where the texture is coarser than silty clay are usually Class 3;
- Soils that have moderately permeable topsoils underlain by silty clays or silty clay loams with weak sub-angular or angular blocky structures are usually Class 4;
- Permeable surface soils overlying massive clays or silty clays are usually Class 5; and
- All soils with hardpans or other impervious layers near the surface (see [# Appendix 3 Practice Factor](#)) are usually Class 6.

“Gravel” describes those particles from 2 to 60mm diameter. Do not enter data here if the permeability class already includes an allowance for the effect of rock fragments. Rocks on the surface should be treated as surface cover and allowed for in the C-factor.

Probable conservative values for subsoil *K*-factors of many Maroochy soils are provided [# Appendix 3 K-factors](#). On highly variable units (e.g. alluvial) and/or on sensitive sites obtain *K* from data directly derived for the local soils and applied to the SOILOSS program

¹⁰⁶ Rosewell (1993b) is an excellent program for estimating the *K*-factor in Australia. However, the program was developed for use in agricultural situations and should not be used on other lands except to derive the *K*-factor.

Figure A3-3 Soil Erodibility Nomograph in SI Units¹⁰⁷¹⁰⁷ Foster et al., 1981

Arguably, the *K*-factor is the least accurate component of the RUSLE. It has special weaknesses on soils that are strongly stabilised by iron and on those that are highly dispersible¹⁰⁸. The problem of strongly stabilised soils can be addressed by ensuring that a chemical dispersion agent (e.g. Calgon) is not used before particle size analysis, i.e. dispersion is achieved only through mechanical means. However, there is very little data to show the effect of soil dispersion on the *K*-factor. Nevertheless, it is suggested that the *K*-factor be increased by 20% for all Emerson Aggregate Class 1 and 2 soils

SLOPE LENGTH/GRADIENT FACTOR – *LS*

The slope length–gradient factor, *LS*, describes the combined effect of slope length and slope gradient on soil loss. It is the ratio of soil loss per unit area at any particular site to the corresponding loss from a specific experimental plot of known length and gradient. Take typical upper values for slope length (metres) and gradient (percent) for the site in question and apply them to **Table 3-1**.

In the RUSLE, different *LS*-factors apply to low, moderate and high ratios of rill to interrill erosion:

- (a) low ratio applies to undisturbed grazing/pasture lands with good cover (e.g. many construction sites before works start) – Option 1;
- (b) moderate applies to moderately consolidated crop lands with little to moderate cover (the default used in SOILOSS) – Option 2; and
- (c) high applies to highly disturbed lands with little or no cover (e.g. most operational construction sites) – Option 3.

No experimental data exist to support the *LS*-factor for undisturbed soils (Option 1) on slopes steeper than 60%. Further, only limited data are available for disturbed soils (Option 3) on slopes of less than 5m length and steeper than 84%. Because SOILOSS defaults to Option 2 and construction sites should be using Option 3, any *LS* data from

SOILOSS should be adjusted. Note that, generally, *LS* should be kept below 10.00 on construction sites.

Table 3-1 assumes that on Soil Loss Classes 3, 4, 5, 6 or 7 lands where more than 1,000m² of land are to be disturbed, slope lengths do not exceed 80m immediately before forecast rainfall or during shutdown periods. Longer slopes might be acceptable where the calculated average annual soil loss from the total area of land disturbance is maintained at low levels (e.g. <150m³ per year)

¹⁰⁸ Usually, soils that are strongly stabilised by iron are red and well aggregated (e.g. Krasnozems). Some of their clay fraction exists as very small aggregates in the silt and fine sand-size range, the most erodible size. Dispersible soils usually have high levels of exchangeable sodium on the clay fraction, and low levels of soluble salts in the soil (see Chapter).

Table A3-1 LS (Length Slope)-factors on construction sites using RUSLE

Slope ratio	Slope gradient (%)	Slope length (m)												
		5	10	20	30	40	50	60	70	80	90	100	150	200
100:1	1	0.09	0.11	0.13	0.15	0.16	0.17	0.18	0.19	0.19	0.20	0.20	0.23	0.24
50:1	2	0.14	0.18	0.24	0.28	0.31	0.34	0.36	0.39	0.41	0.43	0.44	0.52	0.58
33:1	3	0.17	0.24	0.34	0.41	0.47	0.52	0.57	0.61	0.65	0.69	0.72	0.87	1.00
25:1	4	0.21	0.30	0.44	0.54	0.63	0.71	0.78	0.85	0.91	0.97	1.03	1.26	1.47
20:1	5	0.24	0.36	0.54	0.68	0.80	0.91	1.01	1.10	1.19	1.27	1.35	1.70	2.00
16.6:1	6	0.28	0.42	0.64	0.81	0.97	1.11	1.24	1.36	1.47	1.58	1.68	2.14	2.54
12.5:1	8	0.34	0.53	0.83	1.08	1.31	1.51	1.70	1.88	2.05	2.21	2.37	3.07	3.70
10:1	10	0.42	0.68	1.09	1.44	1.75	2.04	2.31	2.56	2.81	3.04	3.27	4.06	4.94
8.3:1	12	0.52	0.85	1.39	1.85	2.27	2.66	3.02	3.37	3.70	4.02	4.33	5.77	7.07
7.1:1	14	0.62	1.02	1.69	2.26	2.79	3.28	3.74	4.18	4.61	5.02	5.42	7.27	8.95
6.3:1	16	0.71	1.19	1.98	2.67	3.31	3.90	4.46	5.00	5.52	6.02	6.51	8.78	10.86
5.5:1	18	0.80	1.35	2.27	3.07	3.82	4.51	5.17	5.81	6.42	7.02	7.59	10.30	12.78
5:1	20	0.89	1.50	2.55	3.47	4.32	5.12	5.88	6.61	7.32	8.01	8.68	11.92	14.84
4:1	25	1.09	1.88	3.23	4.43	5.54	6.59	7.60	8.57	9.51	10.43	11.32		
3.3:1	30	1.28	2.23	3.86	5.32	6.69	7.99	9.23	10.43	11.60	12.74	13.85		
2.5:1	40	1.61	2.83	4.98	6.92	8.74	10.48	12.15	13.77					
2:1	50	1.88	3.33	5.89	8.22	10.42	12.52	14.55						

EROSION CONTROL PRACTICE FACTOR – *P*

The erosion control practice factor, *P*, is the ratio of soil loss with a nominated surface condition ploughed up and down the slope. It is reduced by practices that reduce both the velocity of runoff and the tendency of runoff to flow directly downhill. At construction sites, it reflects the typical roughening or smoothing of the soil surface by machinery (Photo 3.1).

Table 3-2 (right) suggests appropriate values for *P* for construction sites. (Goldman et al 1986).

Table A3-2 Smooth and compact ground surface typical of an urban construction site raising the *P* factor as high as 1.3

Surface Condition	<i>P</i> -Factor
Compacted and smooth	1.3
Track-walked along the contour ¹⁰⁹	1.2
Track-walked up and down the slope ¹¹⁰	0.9
Punched straw ¹¹¹	0.9
Loose to 0.3m depth	0.8

Photograph A3-1 Compacted and smooth surface condition on a construction site.



¹⁰⁹ Track marks are orientated normal to the contours.

¹¹⁰ Track marks orientated parallel to the contour.

¹¹¹ Straw mulch has been punched into a loose ground surface with a disc harrow.

COVER FACTOR – C

The cover factor, *C*, is the ratio of soil loss from land under specified crop or mulch conditions to the corresponding loss from continuously tilled, bare soil. The *C*-factor is different from the runoff coefficient used in hydrologic calculations.

The most effective method of reducing the *C*-factor is maintenance, or formation of a good ground cover such as outlined in Chapter 7. The best practices referred to in Table 3-4) are those that reduce both the soil exposed to raindrop impact and the erosive effects of runoff. shows the effect of different land uses on calculated average annual soil loss where the *R*-factor is 2,500, the *K*-factor is 0.035, the gradient is 10% and the slope length is 100m. The *P* and *C*-factors were the defaults used in the SOILOSS program (Rosewell, 1993) for cultivation, forest and pasture.

Table 3-3 C-factors for Established Grass Cover

Practice	C-factor	Turbidity factor	Loss factor for phosphorus
Open-weave jute mesh	0.40	0.97	0.70
Wood fibre mulch	0.01	0.04	0.40
Straw mulch	0.06	0.20	0.20
Woven straw blanket	0.08	0.20	0.13

Table A3.4 Cover factor for Best Practices

Note that the *C*-factor provides gross information only. It does not give a true indication as to the fraction retained. Table 3-4 provides data on this matter based on University of Washington research. The table assumes proper installation and maintenance of the practice.

See overleaf Table A3.5 Soil Stabilisation Matrix

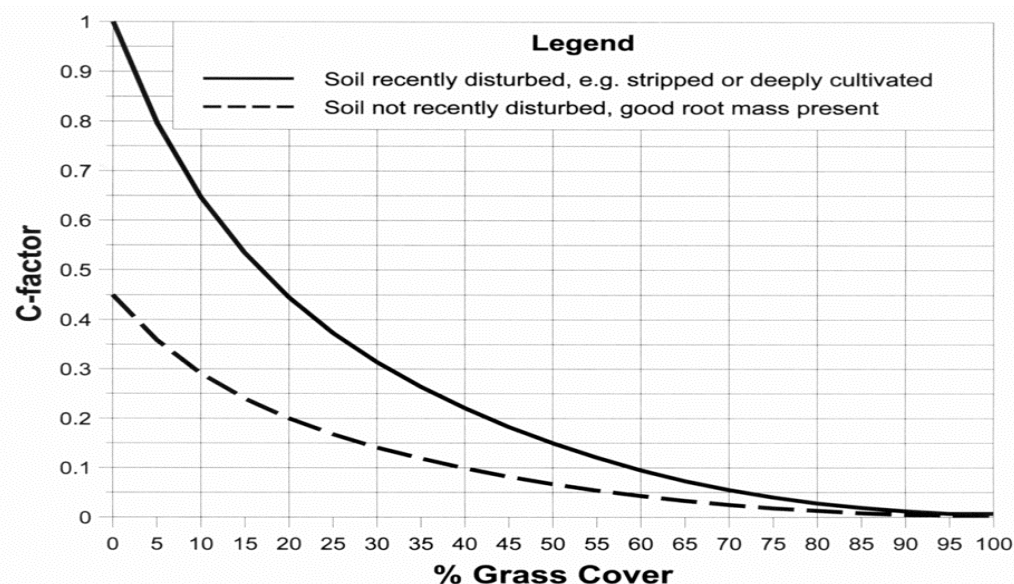


Table A3-5 Soil Stabilisation Matrix

Class	Type	Suitable for Vegetation Type ⁽¹⁾	Design Life (months)	Use in Concentrated Flow ⁽²⁾	Availability (days) ⁽³⁾	Relative Cost Bracket ⁽⁴⁾	Residual Impact ⁽⁵⁾	C-factor ⁽⁶⁾ <33%, <6m	C-factor <33%, 6-15m	C-factor <33%, >15m	C-factor 33-50%, <6m	C-factor 33-50%, 6-15m	C-factor 33-50%, >15m	Notes
BIODEGRADABLE MULCHES ⁽⁷⁾														
Straw (anchored)	4.5 tonnes per hectare	Grass	1 to 6	No	< 5days	Low	Moderate	0.17	0.17	0.20	0.20	0.20	0.20	1 Whether vegetation is required and its type if so, will affect the technique used. Biodegradable mulches, RECPs and hydraulic soil stabilisers can all be used on their own to provide short term protection. However, their effectiveness is less when used in isolation than when used with vegetative growth. Most techniques are used to help establish vegetative growth using sown grasses. Should the client specify shrubs (primarily planted as tubestocks), then thicker mulches, RECPs or biodegradable mulches should be used. Non biodegradable RECP's are used to reinforce grasses (turf) permanently. They are not suitable for use with individual shrubs. They can work synergistically with the established grass to increase its resistance to shear stress and, therefore, increase its resistance to erosion by concentrated flow.
Wood Chip	16 tonnes per hectare	Grass/Shrubs	1 to 6	No	< 5days	Low	Moderate	0.08	0.08	0.08	No data	No data	No data	2 Products might or might not be suitable for use in areas of concentrated flow. All products are suitable for sheet flow conditions, although some would be over designed in such cases.
Wood Chip	27 tonnes per hectare	Shrubs	1 to 6	No	< 5days	Low	Moderate	0.05	0.05	0.05	No data	No data	No data	3 Whether or not a product is readily available is critical to the selection process. Many RECP and hydraulic soil stabiliser techniques use products that might be "off the shelf" and available from several suppliers. Biodegradable mulches can be affected by seasonal variation, although they might also be available on site after initial clearing and grubbing. Temporary seeding might also be seasonal.
Wood Chip	56 tonnes per hectare	Shrubs	1 to 6	No	< 5days	Low	Moderate	0.02	0.02	0.02	0.02	0.02	0.02	4 For any given technique, cost can vary greatly depending on geographic location, size of project and installation requirements. In addition, costs can vary over time. Because of these factors, giving accurate installed costs is not possible. However, if a product is relatively inexpensive to purchase and install close to its point of manufacture, it will still be relatively inexpensive to purchase and install remote from it.
Hydromulching	1.5 tonnes mulch + 300 litres binder per hectare	Grass	1 to 3	No	< 5days	Low	Low	0.00	0.03	0.07	0.03	0.06	0.10	5 This criterion relates to the impact that a particular practice might have on construction activities once they are resumed on an area that was temporarily stabilised.
Bonded Fibre	5 tonnes fibre per hectare	Grass	1 to 6	No	< 5days	Low	Moderate	0.00	0.03	0.07	0.03	0.06	0.10	6 The performance of an erosion control technique is quantified by assigning it with a C-factor (Appendix A). The C-factor will vary from close to zero for full cover, to 1.0 for no cover on highly disturbed soils. The C-factor strongly affects the soil loss calculation (RUSLE) and users need to be careful in specifying its value, particularly when values <0.01 are quoted. Note that the C-factor does not apply to concentrated flow.
ROLLED EROSION CONTROL PRODUCTS (RECPs) ⁽⁷⁾														
Biodegradable	Jute mesh	Grass	6 to 12	Yes	< 5days	Low	Moderate	0.10	0.20	0.40	0.20	0.40	0.60	Values for the C-factor are given for various slopes gradients and lengths and show that it can change dramatically with them. The values given are compiled from existing data and from inference between products of a similar nature. They are given as a guide only and do not profess to be accurate in all respects. Overall, accurate C-factors are only available for manufactured products, primarily from the USA (RECP's in particular) where extensive independent testing has been undertaken. Unfortunately, very little data is available for the "lower cost" options such as biodegradable mulches, jute mesh and hydraulic soil stabilisers. Wherever possible, the manufactures should be contacted for their latest data on acceptable C-factors.
	Coconut fibre mesh (~400 gsm)	Grass	24	Yes	< 5days	Low	Moderate	0.10	0.20	0.40	0.20	0.40	0.60	For the RECP's in particular, the C-factors given here are for the product as installed with no vegetation. Note however that lower C-factors can be expected if vegetation is promoted with
	Coconut fibre mesh (~700 gsm or more)	Grass	48	Yes	< 5days	Medium	Moderate	0.10	0.10	0.20	0.10	0.15	0.20	
	Curled wood fibre	Grass	6 to 12	Yes	< 5days	Medium	Moderate	0.01	0.05	0.10	0.10	0.15	0.20	
	Jute matting (~350 gsm)	Grass	6 to 18	Yes	< 5days	Medium	Moderate	0.00	0.03	0.07	0.03	0.06	0.10	
	Jute matting (~600 gsm)	Shrubs	12 to 24	Yes	< 5days	Medium	Moderate	0.00	0.03	0.07	0.03	0.06	0.10	
	Coconut fibre matting (~450 gsm)	Grass	12 to 18	Yes	< 5days	Medium	Moderate	0.00	0.03	0.07	0.03	0.06	0.10	
	Coconut fibre matting (~900 gsm)	Shrubs	8 to 24	Yes	< 5days	Medium	Moderate	0.00	0.03	0.07	0.03	0.06	0.10	
Photodegradable	Mesh (< 5 mm openings)	Grass	1 to 6	Yes	< 5days	Low	Moderate	0.01	0.05	0.10	0.10	0.15	0.20	
Non Biodegradable	Plastic fibres with netting	Grass	> 48	Yes	< 5days	High	High	0.00	0.05	0.10	0.03	0.05	0.10	
	Composite with biodegradable	Grass/Shrubs	> 12	Yes	< 5days	High	High	0.00	0.03	0.07	0.03	0.06	0.10	
HYDRAULIC SOIL STABILISERS ⁽⁷⁾														
	Polymers/Polyacrylamide (rate depends on type)	Grass	1 to 6	No	< 5days	Low	Low	0.01	0.05	0.10	0.10	No data	No data	
	Bitumen emulsion (12,000 l/ha)	Grass	1 to 6	No	< 5days	Low	Low	0.01	0.05	0.10	0.10	No data	No data	
TEMPORARY SEEDING														
	Annual	NA	6 to 12	No	< 5days	Low	Low	0.05	0.05	0.10	0.10	No data	No data	
	Perennial	NA	6 to 12	No	< 5days	Low	Low	0.05	0.05	0.10	0.10	No data	No data	

SEDIMENT YIELDS

Sediment Delivery Ratio

The ratio of sediment yield at a given location to the sediment entrained in the erosion process is the sediment delivery ratio. The RUSLE can calculate the sediment entrained in the erosion process. Other factors influencing the sediment delivery ratio include:

the drainage area;

- the topography and channel density;
- the relief and length of the watershed;
- the presence of natural or built sediment traps;
- rainfall characteristics; and
- coefficient of runoff.

Once a value has been determined for the sediment delivery ratio, sediment yield can be determined.

Studies in the USA, mainly for rainfall events, have produced coefficients of $a = 89.6$ and $b = 0.56$. Some references show the value of $a = 11.8$, which is for K in metric units rather than the SI units quoted here. A comparison on agricultural soils in southern Queensland (Freebairn *et al.*, 1989) shows that MUSLE explained better than 80% of the variance in the measured sediment yield.

The Modified USLE

The Modified USLE (MUSLE) eliminates the need for a sediment delivery ratio in many situations. It is based on work by Williams (1975), who replaced the R -factor in the USLE with a term for runoff intensity to eliminate the need for a delivery ratio. This modified USLE (MUSLE) is shown in Equation 3.

$$Sy = a (V Qp)^b K LS C P \quad \text{Equation (3)}$$

where:

Sy is the sediment yield in tonnes

a and b are coefficients

V is the volume of runoff for the event in cubic metres

Qp is the peak runoff rate for the event in cubic metres per second

K, LS, P and C are normal USLE factors.

The equation is identical to the USLE except that:

- Sy is sediment yield instead of soil loss
- $(VQp)^b$ is a runoff factor for sediment transport instead of the USLE rainfall erosivity factor R .

Water Erosion Prediction Project

The Water Erosion Prediction Project (WEPP) has been a major program of several US agencies to develop soil erosion prediction technology that will advance, and possibly replace the USLE in a few years. It is a physically based model, based on algorithms that simulate physical processes such as infiltration, detachment, sediment transport, etc. This contrasts with the USLE, which is based largely on empirical relationships.

The WEPP model operates by running a continuous simulation of most of the components of the water cycle on a daily time step. It contains components that model hydrology, plant growth and residue production, and erosion.

WEPP predicts runoff volume from a rainfall event using a water balance submodel. Depending on soil and cover conditions, this runoff may entrain soil particles. It determines:

- the total runoff volume;
- average and maximum sediment yields (annual or storm-based);
- whether erosion is by rill and/or interrill erosion processes;
- where eroded sediment might be deposited;
- the particle size composition of the eroded sediment; and
- whether further sediment might be entrained.

Unfortunately, WEPP requires a large data input, much more than the USLE. Evaluation of WEPP at Gunnedah, New South Wales, (Yu & Rosewell, 2001) shows that it has a good potential to provide a quantitative basis for further development of erosion hazard.



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