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Queensland Curtis Liquefied Natural Gas Project
Coal Seam Gas Field – Soils study

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Geology and regolith
Jurassic and Cretaceous sedimentary rocks are the oldest rocks in the Coal Seam Gas field. They underlie one-half of the Coal Seam Gas field but deep weathering during the Tertiary period with intervening phases of erosion and deposition has had a pronounced effect on altering these rocks and reshaping the landscape.

Strongly altered rocks that have been subjected to this prolonged period of deep weathering cover approximately 22% of the Coal Seam Gas field. These areas represent remnant fragments of a once extensive Tertiary land surface.

In addition, there is a wide expanse of unconsolidated sediments, covering more than 38% of the Coal Seam Gas field. These sediments are the products of numerous erosion and deposition phases, both during and following the Tertiary period.

Those Jurassic and Cretaceous sedimentary rocks that have been subjected to little weathering underlie only 22% of the area whilst recent alluvium is on approximately 10% of the Coal Seam Gas field.

Ground stability
The Coal Seam Gas field is very stable in geological terms with only six fault lines mapped west of the Leichhardt Highway around North Dulacca and three other minor fault lines over the remaining area.

Seismic activity is not reported as being significant in Queensland Department of Mines and Energy geological reports covering the Coal Seam Gas field.

Groundwater quality
Wellhead drilling will intersect groundwater aquifers in the Gubberamunda Sandstone, Mooga Sandstone, part of the younger Wallumbilla Formation and the Injune Creek Group.

Salinity can vary from low to medium and is lowest in the sandstone rocks whereas supplies from the Injune Creek Group are described as “brackish” but small in quantity.

Saline groundwater that is extracted during the drilling process will be stored either within a self-contained drilling rig or temporarily stored in drill pits.

Where drill pits are used, these will be dewatered and backfilled as soon as possible on completion of the drilling. Dewatering can involve irrigation of excess water onto nearby land as well as spreading any fine material that settled in the drill pit onto this land. The excess water and fine material may have elevated salinity and should only be dispersed locally if there is no impact.

Landform
As a result of extensive reshaping during, and at the close of, the Tertiary period, the current landscape is predominantly of low relief with gentle slopes. Level to gently undulating plains now cover 50% of the Coal Seam Gas field with undulating plains and rises occupying almost 22%.

Low hills and rises occur on a further 22% and plateaus are restricted (4% of the area) to small locations north of Miles and in the south-eastern corner. Hills and mountains occur in only one very small area south-west of Guluguba.

Special areas

From a geological and topographical perspective there are no areas of high conservation value.

The relatively small and isolated areas of dissected plateaus, hills and mountains represent "sensitive landscapes" due to their steep topography contributing to a significant erosion risk. However, other factors such as soil type and land use also determine erosion risk and are detailed in the report.

Suitability of local materials for construction purposes

All local hard rock sources for use in construction are sedimentary rocks, mainly sandstone, siltstone and mudstone though the much smaller pockets of conglomerate may also be an important source wherever it outcrops or occurs close to the ground surface. The most appropriate areas for extraction will be where bedrock occurs closest to the surface and are mainly located on the low hills, hills, mountains and dissected plateaus.

The suitability of particular sites for extraction will depend upon access, ease of extraction and ground stability. Ground stability is not a significant issue within the Coal Seam Gas field though quarry sites should probably be avoided along known fault lines.

If unconsolidated material containing clay is to be sourced for fill, road base or other use, the source material will need to be tested first to ensure the material is not dispersive and thus highly erodible. Unconsolidated material on plateau surfaces is unlikely to be dispersive.

The best sources for sand and gravel within the Coal Seam Gas field will be along major streams. Soil may also be extracted from these areas but again will need to be tested first for clay dispersion.

Soils

Soils associated with these landscapes vary from shallow sandy soils associated with outcropping sedimentary rocks to deep clay soils on level to gently undulating plains.

This wide range of soils within the Coal Seam Gas field has been amalgamated into a series of soil management groups. Each soil management group consists of soil types that have similar profile features as well as similar chemical and physical properties and thus require similar management inputs to ensure sustainable use and to minimise environmental impact.

Twelve soil management groups have been identified within the Coal Seam Gas field and are described in detail in the report. The soil management groups are:

- *Shallow sands and sandy loams* on both little weathered and deeply weathered rock;
- *Shallow loams and clay loams* on both little weathered and deeply weathered rock;
- *Deep sands and sandy loams* on recent alluvium;
- *Sandy or loamy gradational soils* on deeply weathered rock;
- *Loamy texture contrast soils (non dispersive)* on little weathered rock;
- *Loamy texture contrast soils (dispersive)* on both little and deeply weathered rock, unconsolidated sediments and recent alluvium;
- *Sandy texture contrast soils (dispersive)* on both little and deeply weathered rock, unconsolidated sediments and recent alluvium;
- *Brown cracking clays* on little weathered rock;
- *Grey-brown cracking clays* on little weathered rock an on unconsolidated sediments;
- *Grey-brown non-cracking clays* on little weathered rock;
- *Dark cracking clays* on both little and deeply weathered rock, unconsolidated sediments and recent alluvium; and
- *Melonhole clays* on unconsolidated sediments.

Names for the soil management groups have been chosen to portray their distinguishing characteristics. An equivalent taxonomic description from the Australian Soil Classification is also provided for each soil management group in the report.

The geology, landform and soil combinations largely determine the current land use patterns and land management practices for the area.

Good Quality Agricultural Land

According to the Queensland Department of Natural Resources and Water, just over 39% of the Coal Seam Gas field has some cropping potential and belongs in either Agricultural Land Class A or B.

Land with any cropping potential is generally designated as Good Quality Agricultural Land for the purpose of protecting agricultural productivity under State Planning Policy 1/92. Thus, approximately 183,910 ha within the Coal Seam Gas field have been designated Good Quality Agricultural Land.

Most of this GQAL is in the centre of the Coal Seam Gas field roughly bounded by Miles, Brigalow, Kogan and Condamine though substantial areas also occur along the Moonie Highway in the south-east and to the west of Wandoan and Guluguba.

The highest value cropping land is allocated to Agricultural Land Class A which comprises almost 21% of the Coal Seam Gas field. This land consists of most of the *Brown cracking clays*, *Grey-brown cracking clays*, *Grey-brown non-cracking clays*, *Dark cracking clays* and land containing *Loamy texture contrast soils (non dispersive)*.

Just over 18% have been allocated to Agricultural Land Class B which has limited crop potential. Limited cropping land comprises the *Melonhole clays*, small areas of the other clay soils, the *Deep sands and sandy loams* and small areas of *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)*.

All other soil management groups are not suited to cropping and are predominantly used for grazing.

Existing erosion

Only minor sheet and rill erosion are evident between erosion control structures in the cropping land and minor sheet erosion is the main form of erosion evident in grazing and forestry land.

The few instances of rill, gully and tunnel erosion that are evident throughout the Coal Seam Gas field are predominantly due to nearby road works.

Roadside gully and tunnel erosion were most commonly associated with *Loamy texture contrast soils (dispersive)* and *Sandy texture contrast soils (dispersive)* but was also observed with *Grey-brown non-cracking clays* south-west of Wandoan, especially where these soils were adjacent to outcrops of sedimentary rock.

Acid sulfate soils

Suitable conditions for formation of iron sulfides are not known within the Coal Seam Gas field and it is extremely unlikely that acid sulphate soils are present.

Potential constraints and impacts

A number of constraints to construction and production activities associated with the proposal and potential impacts on the geology and soils have been identified:

- topography;
- depth to bedrock;
- stoniness and rock outcrop;
- erosion hazard;
- soil fertility;
- “topsoil” depth;
- salinity;
- dust generation; and
- loss of GQAL.

The severity of each constraint or impact has been assessed using information obtained from the desktop analysis, field investigation and laboratory analyses of selected soil samples. A 5-category rating system has been used for the assessment:

Nil	No constraint or impact due to the feature.
Minor	A slight constraint or impact that is readily overcome or controlled with standard management practices and mitigation measures.
Moderate	A substantial constraint or impact but is overcome or controlled with a combination of standard and special practices and mitigation measures.
Severe	A substantial constraint or impact that may be overcome or controlled only with special practices and mitigation measures.
Extreme	A substantial constraint or impact that cannot usually be overcome or controlled even with special practices and mitigation measures.

Constraints and impacts that are rated as moderate or worse are considered to be significant as mitigation or control requires special attention and may be extremely difficult.

Severity of each constraint or impact

Only 1.6% of the Coal Seam Gas field has a moderate to severe topography restriction. This land comprises dissected plateaus between Tara and the Moonie Highway and hills and mountains west of the Leichhardt Highway between North Dulacca and Guluguba.

Shallow sands and sandy loams and *Shallow loams and clay loams* have very shallow depth to bedrock creating an extreme constraint wherever they occur. However, they are usually associated with much deeper soils and the only area where all the land has a severe to extreme constraint is on the dissected plateaus between Tara and the Moonie Highway.

The *Shallow sands and sandy loams* and *Shallow loams and clay loams* also have a severe to extreme stoniness and rock outcrop constraint rating but this constraint is either non existent or minor in all other soil management groups.

More than 87% of the Coal Seam Gas field has an erosion hazard rating despite the generally gently undulating landscape. The hazard is mainly due to the predominance of dispersive texture contrast soils which have high to very high inherent erodibility.

Almost 32% of the Coal Seam Gas field has a severe to extreme erosion hazard. This land consists of low hills, rises and undulating plains with dispersive texture contrast soils as the main soil management group or has steeper terrain with a combination of *Shallow sands and sandy loams*, *Shallow loams and clay loams* and dispersive texture contrast soils.

Grey-brown cracking clays may also have dispersive subsoil and a severe erosion hazard. Though not mapped as the main soil management group anywhere within the Coal Seam Gas field, land west of Wandoan contains these soils in association with *Grey-brown cracking clays*. Overall, this land has been assigned a minor to moderate erosion hazard.

All soil management groups have a low to very low level of at least one major nutrient and thus have a soil fertility constraint of some degree. The constraint is severe or moderate to severe on approximately 60% of the Coal Seam Gas field. The main soils on this land are either *Shallow sands and sandy loams*, *Shallow loams and clay loams* or those profiles of *Sandy texture contrast soils (dispersive)* that aren't developed on recent alluvium. Profiles of *Sandy texture contrast soils (dispersive)* that overlie recent alluvium have a higher fertility status and thus lesser constraint rating.

The *Dark cracking clays* and *Melonhole clays* have medium to heavy clay textures in their surface layers and are usually not used as planting media. *Grey-brown cracking clays*, *Grey-brown non-cracking clays* and *Brown cracking clays* may also have these textures. Altogether, these mapping units represent 28.5% of the Coal Seam Gas field.

Thin, suitable "topsoil" is a severe constraint to revegetation and rehabilitation on almost 7% of the Coal Seam Gas field where *Loamy texture contrast soils (dispersive)*, *Shallow sands and sandy loams* and *Shallow loams and clay loams* are the main soil management groups. Stripping thin "topsoil" may not only include unsuitable subsoil in the planting media but also leave highly erodible subsoil exposed within the stripped areas.

Approximately 47% of the Coal Seam Gas field consists of differing soil combinations that result in quite variable "topsoil" thickness and detailed site inspection will be required in these areas to determine the depth of usable "topsoil".

Salinity at the soil surface is not a significant issue within the Coal Seam Gas field but almost 34% of the area has a moderate to severe constraint due to subsoil salinity. This is land with *Grey-brown cracking clays*, *Sandy texture contrast soils (dispersive)* or *Loamy texture contrast soils (dispersive)* as the main soil management groups. *Sandy texture contrast soils (dispersive)* also occur in association with *Shallow sands and sandy loams* or with *Shallow loams and clay loams* on a further 32.5% of the Coal Seam Gas field. Though the shallow soils have no subsoil salinity, the *Sandy texture contrast soils (dispersive)* create a severe constraint.

Dust generation is a moderate to severe impact on 74.5% of the Coal Seam Gas field. Land dominated by *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* represents 40% of the area and has a capacity to generate severe bulldust. *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* are also associated with other soils of lesser capacity to generate dust on a further 34.5%.

The proposed wellhead density of 1 every 750 m and associated gravel access tracks will create an obstruction on 3-6% of individual cultivation paddocks during the construction phase. During the gas production phase, the proportion being obstructed would reduce to 1%, if partial restoration is performed.

Based on the development scenario provided for this assessment, both construction and gas production activities have a capacity to create significant impact on cropping by:

- reducing the actual area that can be cropped;
- impeding optimal farm layout for efficient crop production;
- interrupting essential physical run-off control measures that are designed to minimise erosion;

- modifying overland flow patterns – particularly via concentration of runoff, changes in runoff times of concentration and increased velocity along access tracks and around wellheads; and
- introducing weed species into the cultivation during both construction and ongoing maintenance activities.

Associated with the actual loss in production area will be impacts on farming and grazing practises on contiguous areas.

However, gas well construction will occur progressively and not all cropping land will be affected at the same time. Location of the wells and other infrastructure will be determined during land holder consultation. These strategies will help to reduce the impact.

Issues for individual soil management groups
Overall issues for each individual soil management group are summarised in the report.

Shallow sands and sandy loams and *Shallow loams and clay loams* have the largest number of moderate, severe or extreme constraints and impacts. In contrast, the *Sandy or loamy gradational soils* and the various clay soils have the fewest, or least severe, constraints and impacts.

Erosion hazard, soil fertility and dust generation are rated as moderate to extreme on the *Loamy texture contrast soils (dispersive)* and *Sandy texture contrast soils (dispersive)*. If the erosion hazard is not appropriately managed, resultant erosion and sedimentation can have a pronounced impact on the environment and the moderate to severe soil fertility constraint associated with these soils means that the appropriate management procedures must involve correct revegetation measures.

The potential loss of substantial areas of highly productive cropping land, mainly on the clay soil management groups, is also an extremely important impact for the region.

Mitigation and rehabilitation efforts

A range of mitigation measures are available for the constraints and impacts identified during this study.

Removing by-products of drilling
Saline subsoil and saline groundwater may be intersected during drilling and chemicals that may be used have a high salinity.

Though most large rigs are self-contained with in-built drilling mud tanks, drill pits may be used to store by-products. Excess water and fine material collected from the drill pit as production commences will approximate the salinity of seawater. The fine material should not be spread onto nearby land unless it can be applied over a large enough area to ensure the resultant salinity on the soil surface will not exceed 0.1 dS/m, which is equivalent to a low to very low salinity rating for all soil types.

Timing of major disturbance
An erosion hazard has been identified on more than 87% of the Coal Seam Gas field and the four-month, November to February, period produces almost ⅔ of the average total erosive potential of rainfall for an entire 12 months.

Thus, avoiding major earth works programmes between November and February can substantially reduce the risk of erosion. However, if earthworks must be undertaken during this period, it is essential that all standard erosion control measures be adopted and special measures be implemented on sloping areas with dispersive texture contrast soils.

<u>Dissected terrain</u>
There is a moderate to severe topography constraint on approximately 1.6% of the Coal Seam Gas field comprising hills and mountains between North Dulacca and Guluguba and dissected plateaus south of the Moonie Highway.
The dissected topography (combined with dispersive texture contrast soils south of the Moonie Highway), very shallow soils with abundant stone and rock outcrop and low fertility of the topsoil will make it extremely difficult to control erosion during construction and rehabilitate any disturbed areas. There is a high risk of pipelines being exposed and undermined after a few large rainfall events.

It would be preferable to exclude this land from development but appropriate mitigation measures are recommended in the report if it must be included.

<u>Adopting erosion control measures</u>
Because of an erosion hazard across more than 87% of the Coal Seam Gas field, erosion control measures should be implemented with all works that disturb the land surface where slopes exceed 1%. Where this land contains dispersive texture contrast soils, special precautions will be required in addition to the standard measures.

Eleven standard measures and seven special measures are recommended and briefly described in the report.

Erosion by overland flow will be a particular issue in the highest value cropping land where the farming system often involves cropping patterns, sequences and physical structures specifically designed to reduce runoff velocity and amount and to spread rather than concentrate flow.

<u>Stripping and re-using topsoil</u>
"Topsoil" should be stripped prior to excavating pipeline trenches and evaporation ponds or creating hardstand areas. The stripped material should be stockpiled for reuse during revegetation and rehabilitation of these areas.

Recommended stripping depths are provided in the report, based on thickness of the soil surface and subsurface layers. Medium to heavy clay textures and dispersive clay are usually not suitable for use as planting media. Where there is insufficient stripping on-site, suitable "topsoil" will have to be imported from elsewhere. Where there is insufficient material for stripping on-site, suitable "topsoil" will have to be imported from elsewhere. Medium to heavy clay textures predominate in the surface layers of the clay soils and are generally not suitable for plant species commonly used in revegetation. A modified selection of plant species will have to be used on these soils.

Material that is suitable for stripping and stockpiling has low to very low fertility and all stockpiled material should be ameliorated with NPK fertilisers and would benefit from incorporation of composted organics.

Measures need to be taken to ensure dispersive and/or heavy clay subsoil are not stripped and mixed with suitable "topsoil" and stockpiles should be constructed on the contour, protected from run-on water with diversion banks or similar device upslope, and formed with run-off control devices immediately down slope.

The duration of stockpiling should be minimised to reduce nutrient rundown and colonisation by weeds. Stockpiling should not commence until immediately before bulk earthworks start and rehabilitation of disturbed areas should proceed as soon as works are completed.

However, stockpiles that are to be kept until reuse during decommissioning should be sown with an appropriate plant mix and managed to ensure adequate ground cover is maintained. This will minimise erosion and leaching of nutrients from the soil material and will provide a seed source when the material is eventually used. Such stockpiles can be landscaped into low mounds to improve visual amenity and reduce dust, noise and wind.

High value cropping land
Cropping land within the Coal Seam Gas field is extremely important to the region and the State. The proposal will create a significant impact on all cropping land but the severest impact in terms of loss of production and loss of land value will be on areas designated as Agricultural Land Class A.

The impact will last the full term of the project, estimated at 25 to 30 years but gas well construction will occur over time.

Location of the wells and other infrastructure will be determined during land holder consultation. To avoid significantly diminishing productivity of the cropping land, drill sites and access tracks should not be located within areas of cultivation. They should be placed on areas that will not be cultivated such as along paddock boundaries. Where the only option is placement within a cultivation area, the wellheads should be positioned to cause the least obstruction to the normal working pattern and to overland flow of stormwater within the paddock. Access tracks should be located along internal headlands or along contour banks.

Removal of hardstand and gravel material and any associated operational materials and the re-establishment of initial topography and drainage will be required as well as remediating any soil fertility or structural impacts.

Though location and siting of infrastructure can significantly mitigate the impact, there will inevitably be increased operational costs for both farming and grazing, particularly field operations.

Areas with severe subsoil salinity
The *Sandy texture contrast soils (dispersive)* have moderate to extreme subsoil salinity and salt levels in subsoil of the *Grey-brown cracking clays* are very high to extreme. Very high to extreme levels of salt can also corrode concrete and steel foundations and steel pipe.

More intensive salinity sampling is recommended wherever major earthworks involving concrete and steel are to be located on these soils. The sampling should be aimed at clarifying the depth at which salt levels reach problematic levels.

Medium to high salt levels can retard plant growth and care should be exercised when excavating or dealing with subsoil from the *Loamy texture contrast soils (dispersive)*, *Loamy texture contrast soils (non-dispersive)* and *Brown cracking clays* as well as from the *Sandy texture contrast soils (dispersive)* and *Grey-brown cracking clays*. Excavated subsoil should be buried deep or capped with at least 300 mm of suitable "topsoil" following construction activities. This will allow plants that are being established to achieve a reasonable root layer before encountering the saline material.

If saline subsoil is to be stockpiled for a short period, the stockpile should be bunded to prevent water running onto the pile from further upslope and to detain run-off water within the stockpiled area.

Minimising impact at minor watercourse crossings
Crossings for access tracks and pipelines on minor watercourses require special attention because many of the streams will have dispersive texture contrast soils or clay soils on their banks and bank slopes can be very steep, creating a severe to extreme erosion hazard.

Tracks should only cross watercourses at points where:

- the turbulence of stream flow is least;
- there is no active undercutting of the banks; and
- sediments are not dumped within the stream bed.

At stream crossing points, there should be as little disturbance to the stream bank as possible. Unless absolutely necessary, vegetation on the stream bank should not be disturbed and any cleared vegetation should not be placed in the watercourse. Following disturbance, these crossing points should be restabilised as soon as possible by refilling and slightly compacting, capping with at least 200 mm of suitable "topsoil" and revegetating the site.

Borrow pits
Unlike most other excavations, borrow pits are not fully rehabilitated when they are no longer required. Borrow pits may impact on the environment both during and after their active use through:

- accelerated soil erosion on disturbed cut faces and in the floor of the pit; and
- leaching of soluble salts from exposed soil material onto surrounding land and into local waterways; and
- loss of productive rural land and interruptions to its efficient use, especially in high value cropping land.

Environmental impact can be controlled by:

- adopting appropriate erosion control measures;
- careful location of pits in dissected terrain and outside cultivations areas within the high value cropping land; and
- bunding any pits that expose saline subsoil.

Apart from careful site selection, implementation of run-off control devices is essential to prevent water running over the cut faces from further upslope and to detain run-off water within the disturbed area.

The final cut faces should be left as close to vertical as possible to minimise erosion due to raindrop splash.

Evaporation ponds
Storage/evaporation ponds need to be adequately sealed to prevent leakage of the saline wastewater into the ground below. They should be preferably located where:

- soils have an appropriate clay base for sealing the pond;
- outside cultivation areas within the highly productive cropping land; and
- required cut and fill operations are minimal.

If a clay base of sufficient depth is not available at a preferred site, the pond will need to be covered with either compacted, imported clay or an artificial liner. If cut and fill operations are required on sloping land there is a high risk of exposing in the cut sections:

- permeable layers of soil or weathered rock in shallower profiles; and
- dispersive clay subsoil in deeper profiles.

In both situations, the pond will need to be lined as described above.

1. Introduction

1.1 Background

BG Group and Queensland Gas Company are proposing a Queensland Curtis Liquefied Natural Gas Project (QC LNG) for southern and central Queensland. The project involves developing existing gas fields in the Surat Basin and constructing a 380 km gas transmission pipeline (and other associated pipelines) to an export terminal near Gladstone in Central Queensland. The development will also entail construction of a Liquefied Natural Gas (LNG) plant near Gladstone.

The QC LNG project has been declared a "significant project" and, as such, requires an Environmental Impact Statement (EIS).

The QC LNG project involves expansion of QGC's existing coal seam gas (CSG) operations in the Surat Basin, to provide gas for the LNG plant and domestic gas markets. Over the minimum 20-year life of the project, this expansion is expected to comprise development of:

- a total of 6,000 wells to supply gas to two of three LNG trains;
- associated surface equipment, gas and water gathering systems and gas processing and compression infrastructure; and
- management, storage and potential beneficial use of associated water.

The proponents have commissioned Land Resource Assessment and Management Pty Ltd (LRAM) to conduct a soils study as part of the EIS for the CSG field (tenement areas).

This report describes the work undertaken during that soils study and presents the study results.

1.2 Study objectives

The study is to assess the environmental issues and impacts associated with development of the tenement areas in relation to soils.

Specific objectives of the study were to:

- describe and map the geological framework within the CSG field (nominated tenement areas);
- describe the soils and map their distribution within the CSG field;
- identify geology and soil related constraints to development;
- assess geology and soil related impacts that the development may have on the environment;
- recommend appropriate mitigation measures to minimise any significant potential impacts; and
- provide environmental protection objectives and monitoring requirements for each environmental parameter that may be affected by the development.

1.3 Study area

Initially, LRAM was requested to investigate the following twenty tenements:

- EPPs 574, 632, 647, 648, 651, 676; and
- PLs 179, 180, 201, 211, 212, 228, 229, 247, 257, 259, 261, 262, 263, 269.

As the original study was being finalised two additional tenements were added to the area:

- EPP 768; and
- PL 171.

The two additional tenements include substantial areas of soils that have only a minor presence within the original study area. Therefore, they will be referred to in this report as the “addendum study area” wherever this area needs to be distinguished from the original study area. To assist with this distinction, all associated mapping also shows both the original and addendum study areas.

The terms “CSG field” or “entire study area” will be used throughout this report to refer to all twenty-two tenements.

Figure 1 shows that all investigated tenements extend from west of Dalby to west of Wandoan and cover approximately 427,980 ha (≈ 4,280 sq km) within the original study area and approximately 40,700 ha (≈ 407 sq km) in the addendum study area.

2. Study methodology

The study was undertaken in four stages.

2.1 Desktop analysis

2.1.1 Collation of available geological data

Desktop analysis involved collating all available land resource information and using this information to delineate major units of geology, landform and soils within the CSG field.

All digital mapping data used for this study was provided by the proponent under license agreement with the appropriate data custodian. Descriptions for the mapping units were obtained from associated datasets or from published reports.

Geological data was extracted from the 1:250,000 Geological Series which provides mapping and explanatory notes for continental Australia based on 1:250,000 topographic map sheets. Digital mapping for the Chinchilla, Dalby, Roma and Taroom map sheets was combined and then cropped to fit the CSG field. Summary descriptions of the various geological formations were created to develop a unified coverage for the tenements.

2.1.2 Collation of available land resource data

Land systems have also been mapped and described across the CSG field, except south-east of Kogan. A land system represents a unique landscape pattern that contains a distinctive combination of geology, landform, soil and vegetation features. This pattern is usually repeated across the landscape but may occur in only one location. As land systems are based on distinctive geology and soil patterns, they can be used to develop both separate geology and soil map layers.

Four separate land systems maps occur within the tenements. Only one of these maps is available as digital data but the Queensland Department of Primary Industries (DPI) produced an amalgamated digital version of the other three for the former shires of Murilla, Tara and Chinchilla. This amalgamated version mapped Land Resource Areas (LRAs). An LRA is essentially a group of similar land systems.

The only land resource mapping available south-east of Kogan is an LRA map.

Geological information in the associated land systems reports also contains descriptions of the geological weathering that has occurred to create the existing landscape. Whereas the geology mapping 1:250,000 map sheets concentrates on delineating underlying formations of solid bedrock, the land systems information can be used to attain a more accurate description of the weathering history and resultant layer of unconsolidated materials above the bedrock (regolith).

Digital LRA and land system mapping was combined to produce a unified land resource mapping layer and cropped to fit the CSG field.

A series of common legends was created for the combined land resource mapping layer describing the weathering history, resultant regolith cover and landform and the major soils that developed on this landscape.

Though geology and landform are fairly uniform for each land system, soils can vary substantially within the defined pattern. However, the accompanying report separates each land system into individual land units with very little soil variation occurring within a unit. The soil content and relative proportion of each unit is described in the report.

The soil type within each land unit has been placed into a soil management group. Each soil management group consists of soil types that have similar profile features as well as similar chemical and physical attributes and thus require similar management inputs to ensure sustainable use and to minimise environmental impact.

All soil types occurring within each land system or LRA have been placed into soil management groups so that the main group could be identified and described. The main soil management group was then recorded. Only one soil management group was recorded where it represents at least 70% of the mapping unit. Two soil management groups were recorded, separated with"/", where no one group accounts for 70% of the mapping unit.

Unfortunately, land resource descriptions for the amalgamated LRA mapping of Murilla, Tara and Chinchilla shires were simplified with the original land systems information for land units being lost in the process.

Therefore, the original land system and land unit descriptions were used, where available, to create the common mapping legends for weathering-regolith cover, landform and soil management groups.

2.1.3 Review of collated data

Preliminary maps of geological formations, weathering and regolith cover and soil management groups were created using the combined mapping layers and common mapping legends for these layers.

The preliminary maps and associated data were then reviewed to identify and prioritise specific locations for field investigation.

Prioritisation was achieved by identifying particular soils which may have the following constraints:

- high soil erodibility;
- very low soil fertility;
- shallow soil depth;
- severe stoniness and presence of rock outcrop;
- saline subsoil;
- severe gilgai microrelief; and
- potential to generate dust.

In addition, the high-value cropping land was prioritised for inspection to ensure there is adequate description of their features and extent.

2.2 Field investigation

Field inspection was designed to view as many geology-regolith-soil combinations as possible and to record specific site information for those soils assigned a high priority during desktop analysis.

2.2.1 Ground observations

Approximately 495 km of accessible roads and tracks within the entire study area were traversed.

Apart from general notes on landscape features collected during these traverses, soil profile features were recorded at 66 sites.

Actual ground observation sites were chosen using a free survey technique so that the priority soils were adequately represented. This means that the most appropriate location for a particular site was chosen whilst in the field on the basis of local landscape features.

At 45 sites, detailed soil profile descriptions were undertaken to a depth of at least 1 m or to bedrock, whichever came first. Soil profiles were exposed with a hand held auger drilling a 75 mm diameter hole. The remaining 21 sites represent check sites where only sufficient information was collected to reliably determine soil type and its constraints.

Landscape position, vegetation, ground surface features and substrate material (where evident) were also recorded at each site to assist in soil classification and mapping.

All site descriptions used standard terminology of the Australian Soil and Land Survey Field Handbook (McDonald *et al* 1990). Site location was recorded with a hand-held GPS receiver which has an accuracy of ± 5-10 m. All ground observation sites are listed in Attachment A along with their GPS location.

2.2.2 Soil sampling for laboratory analysis

In total, 44 soil samples from the original study area were submitted for laboratory analysis. These samples were collected from 24 profiles described as part of the detailed site inspections.

Samples collected at each site were taken from the surface layer or from part of the subsoil.

General fertility of the surface layer was tested on 23 samples using the following tests:

- Soil pH;
- Electrical conductivity (EC), as a measure of salinity;
- Exchangeable cations (Calcium, Magnesium, Sodium, Potassium and Aluminium);
- Cation exchange capacity (CEC);
- Total nitrogen (Total N); and
- Available phosphorus (Olsen P).

Subsoil erodibility was analysed on 21 samples using:

- Soil pH;
- Electrical conductivity (EC), as a measure of salinity;
- Exchangeable cations (Calcium, Magnesium, Sodium, Potassium and Aluminium);
- Cation exchange capacity (CEC);
- ESP (Exchangeable sodium as a % of CEC); and
- Exchangeable calcium : Exchangeable magnesium (Ca:Mg) ratio.

Texture was recorded for each sample during site inspection.

Analytical methods for all tests were performed according to the relevant Australian laboratory handbook (Rayment and Higginson 1992). Full results are presented in Attachment B.

No additional soil sampling for laboratory analysis was undertaken for the addendum study area.

2.3 Data analysis

2.3.1 Soil classification and mapping

Soil profile descriptions and analytical data were used to confirm and refine the preliminary soil classification and common mapping legends created during desktop analysis.

General notes collected during field investigation were used to adjust boundaries to geology, regolith cover and soil mapping units, where necessary.

A series of maps was then produced to portray underlying geology, weathering history and overlying regolith, landform and soil management groups.

The accuracy and reliability of the various resource maps is governed by the original scale of the maps used for compilation. Geological mapping was undertaken at a scale of 1:250,000. The original land system and LRA maps were also produced at this scale, except for the north-western corner within 45 km of Wandoan. This part was mapped by CSIRO at approximately 1:500,000 scale. However, limited field inspection indicated that the CSIRO mapping is quite accurate and can probably be used at a scale of 1:250, 000.

Thus, all geology and land resource mapping was originally produced as part of reconnaissance level surveys (Reid 1988) and, whilst appropriate for regional overview, will not necessarily describe the landscape accurately for individual properties or sites.

Mapping scale also affects the positional accuracy of boundaries between mapping units. At 1:250,000 scale, the accuracy of mapping unit boundaries is a minimum ± 500-750 m.

<u>2.3.2 Constraint and impact analysis</u>

The geological and topographic mapping was assessed for the:

- suitability for location of borrow pits for gravel; and
- consequences of excavating and removing soil from any borrow pits.

No data were available for assessing the potential for any heavy metals to be released from sorbed geological materials.

Each soil mapping unit was assessed for the following constraints and environmental impacts:

- depth to bedrock;
- soil erodibility;
- soil fertility;
- soil depth;
- stoniness and presence of rock outcrop;
- saline subsoil;
- gilgai microrelief; and
- potential to generate dust.

Several data sources were used together to make these assessments, including:

- geological descriptions from the 1:250,000 Explanatory Notes;
- descriptions of soil features from the land system and LRA reports;
- field observations during this study;
- soil analytical data from sampling undertaken during this study; and
- soil analytical data from the land system and LRA reports.

Queensland Department of Natural Resources and Water (NRW) assessments of agricultural land quality were included in the datasets provided with the digital mapping. This information was used to locate high-value cropping land (both potential and existing) within the tenements.

2.4 Reporting

Reporting was aimed at clearly identifying the:

- environment values of the area;
- potential impacts of the proposal on those values; and
- recommended management measures to minimise adverse impacts.

A series of thematic maps displaying the distribution of various land resources, their constraints to infrastructure and the likely environmental impact following development were included as figures in the report.

For convenience, report figures were produced at a scale of 1:750,000 but they are based on GIS data layers which are appropriate to use at a scale of 1:250,000.

All GIS mapping layers created during the study, their associated datasets and relevant Metadata files describing the layers were included on CD/DVD media with digital copies of the report.

Quality control of the original GIS mapping could not be undertaken as part of this study and the following discrepancies may occur in the compiled data:

- small gaps between original survey areas in which there is no land resource data at all;
- incorrect copying of original land system boundaries when DPI compiled the LRA map; and
- incorrect data entry in any of the original datasets.

3. Environmental values of the area

3.1 Geology, regolith and landform

3.1.1 Available mapping used

Available information on the underlying formations of bedrock and unconsolidated sediments has been collated from the 1:250,000 geological mapping of Australia. Mapping from the Chinchilla (Exon *et al* 1969), Dalby (Exon *et al* 1968), Roma (Milligan *et al* 1971) and Taroom (Forbes *et al* 1967) map sheets has been used in the compilation. Descriptions of the various formations have been obtained from explanatory notes published for each map sheet - Chinchilla (Reiser 1971), Dalby (Mond 1973), Roma (Exon 1971) and Taroom (Forbes 1968).

Descriptions and mapping of weathering history and resultant regolith cover over the bedrock have been obtained from published land system surveys for the Dawson-Fitzroy (Speck *et al* 1968), Miles (Dawson 1972b), Jandowae (Dawson 1972a) and Millmerran-Moonie-Tara (Mullins 1980) areas. Land system mapping does not cover most of the CSG field between Kogan and the Moonie Highway (to the south-east) and additional weathering and regolith information for this area was obtained from an LRA survey of the central Darling Downs (Harris *et al* 1999).

Landform information was also obtained from the land system and LRA datasets and verified with 1:250,000 topographic maps for Chinchilla, Dalby, Roma and Taroom.

3.1.2 Field investigation

Field investigation has confirmed that the available mapping and description of landform components, geological formations and regolith cover was adequate for the regional comparison and assessment purposes of this study.

3.1.3 Geological formations

The geological formations found within the CSG field are briefly described in Table 1. Their distribution is shown in Figure 2.

The area is underlain by sedimentary rocks, varying in age from approximately 1.8 to 205 million years.

The oldest sedimentary rocks form the Injune Creek Group which was deposited during the Jurassic period, approximately 141 to 205 million years ago (mya). The rocks consist of sandstone, siltstone, mudstone, coal and conglomerate and have formed from sediments deposited in a freshwater environment.

A later sequence of sedimentary rocks were laid down on top of the Injune Creek Group during the Jurassic but continuing into the lower part of the Cretaceous period, approximately 65 to 141 mya. The sequence began with deposition of Gubberamunda Sandstone, followed by the Orallo Formation, Mooga Sandstone, Bungil Formation and Kumbarilla Beds. Rocks within this sequence are very similar to those in the Injune Creek Group though several formations are recognised as being deposited in a deltaic or marine environment.

Later in the Cretaceous Period, mudstone and siltstone of the Wallumbilla Formation were formed in the western part of the original study area. These rocks were also deposited in a shallow marine environment.

However, a prolonged period of deep weathering followed during the Tertiary period (approximately 1.8 to 65 mya) which substantially altered the original appearance and composition of these earlier rocks. Deep weathering was interspersed with significant phases of erosion and re-deposition forming some new (unnamed) formations of sandstone, mudstone and conglomerate in various stages of consolidation but also creating large areas of unconsolidated sand, soil and gravel. These unconsolidated sediments were in turn deeply weathered.

A gently undulating Tertiary land surface developed with generally deep soils overlying deeply weathered and strongly altered rocks and unconsolidated sediments.

More pronounced erosion and re-deposition towards the end of the Tertiary stripped much of the gently undulating land surface away. This stripping process exposed some of the deeply weathered rock and also re-exposed areas of little-weathered sedimentary rocks. However, the eroded material also buried wide expanses of rock under unconsolidated deposits of sand, soil and gravel.

Finally, as the present drainage system established itself during the Quaternary period (from 1.8 mya to present), ongoing erosion and deposition dumped recent alluvium of sand, silt, mud and gravel on flood plains along the waterways.

Table 1. Geology of the Coal Seam Gas field

Age [1]	Brief description [2]	Area	
		(ha)	(%)
Quaternary (up to 1.8 mya)	Alluvium: sand, silt, mud, gravel	57,830	12.3
Tertiary-Quaternary	Poorly consolidated sandstone, mudstone, conglomerate	7,175	1.5
Tertiary (≈ 1.8-65 mya)	Sandstone, mudstone, conglomerate	17,270	3.7
Cainozoic (up to 65 mya)	Very poorly sorted sand, soil and gravel	146,175	31.2
Cretaceous (≈ 65-141 mya)	Wallumbilla Formation: Mudstone and siltstone with calcareous concretions	7,715	1.7
Jurassic-Cretaceous [3] (≈ 65-205 mya)	Bungil Formation, Gubberamunda Sandstone, Kumbarilla Beds, Mooga Sandstone, Orallo Formation: Siltstone, mudstone; sandstone, minor conglomerate, siltstone, coal	208,715	44.5
Jurassic (≈ 141-205)	Injune Creek Group: Sandstone, siltstone, mudstone, coal, conglomerate	23,800	5.1
	Total	**468,680**	**100.0**

Notes:

1. Age is given as millions of years ago (mya).
2. The brief description is summarised for all map sheets.
3. Several formations are described as glauconitic, meaning they have been deposited in a marine environment.

The result of this evolutionary process is that Jurassic and Cretaceous sedimentary rocks underlie 51% of the resultant landscape seen today. Wide expanses of unconsolidated sand, soil and gravel cover more than 31% of the CSG field.

The remaining area consists of recent alluvium along waterways (≈ 12%) and small areas of Tertiary age sedimentary rocks (≈ 5%).

3.1.4 Weathering and regolith cover

The land system and LRA reports provide a comprehensive description of the geomorphic history of the area, especially during and following the Tertiary period.

The climate is believed to have been warm and wet during the Tertiary, resulting in deep weathering and erosion of the existing land surface and re-deposition of eroded materials. The landscape was worn down and labile rocks (with clay-forming minerals) were significantly altered though quartzose rocks were little changed due to the predominance of quartz (Maher 1996).

The strong alteration of most rock minerals resulted in release and mobilisation of iron and silica. The mobilised minerals were leached downwards to eventually concentrate in thick layers of ferruginised (iron-rich) and silicified (silica-rich) sediments. Over time, these layers formed laterite and silcrete bands.

Areas of softer, labile rocks were most eroded and re-deposition of the eroded material formed the gently undulating plains of unconsolidated sediments. The quartzose rocks were more resistant and remained in-situ, though worn down, to form slightly raised hard rock areas above the sediments.

As mentioned previously, the entire Tertiary land surface was removed throughout much of the area and the eroded material buried wide expanses of rock under unconsolidated deposits of sand, soil and gravel. However, the stripping process also re-exposed areas of little-weathered sedimentary rocks.

Land systems are separated on the basis of whether they are developed on recent alluvium, on little-weathered rock, on strongly weathered rock or on unconsolidated sediments deposited during the Tertiary stripping process. Thus, land system mapping is used to show the degree of weathering and regolith cover in Figure 2 and reveals a much different geomorphic landscape than the layer based solely on rock type.

Rocks that have been subjected to a prolonged period of deep weathering during the Tertiary period cover almost 22% of the CSG field. These areas represent remnant fragments of the Tertiary land surface. The resultant cover of unconsolidated sediments occupies more than 38% of the CSG field. Though these deeply weathered rocks and unconsolidated sediments extend throughout much of the original study area, only a few isolated patches occur within the addendum study area.

Thus, the deep weathering and reshaping of the landscape that occurred during the Tertiary period has had a pronounced effect on landscape development within the original study area but limited effect within the addendum study area.

Sedimentary rocks that have been subjected to little weathering underlie 30% of the CSG field. They occur in the south-east corner below Tara and Kogan and in the north-west corner above North Dulacca. Recent alluvium is mapped on approximately 10% of the CSG field and is confined to either side of the Condamine River and other major streams.

3.1.5 Ground stability

Figure 2 shows that the CSG field is very stable in geological terms with only a few fault lines within its boundaries.

There is a minor fault south of the Warrego Highway near Miles and a similar one between Kogan and Condamine. Another two minor faults are also found in the northwest corner west of Wandoan and five short fault lines have been mapped west of the Leichhardt Highway around North Dulacca.

Seismic activity is not reported as being significant in Queensland Department of Mines and Energy geological reports covering the CSG field.

3.1.6 Groundwater quality

Wellhead drilling will intersect a few groundwater aquifers. The only rock formations with known groundwater reserves are Gubberamunda Sandstone, Mooga Sandstone, part of the younger Wallumbilla Formation and the Injune Creek Group (Exon 1971, Mond 1973and Reiser 1971).

Salinity can vary from low to medium but is generally < 1,200 mg/L. Salinity is lowest in the sandstone rocks and Gubberamunda Sandstone produces the greatest flows. Groundwater supplies from the Injune Creek Group are small and the quality is described as “brackish” (Exon 1971).

Some groundwater will be extracted during the drilling process and stored either within a self-contained drilling rig or temporarily stored in drill pits.

Where drill pits are used, these will be dewatered and backfilled as soon as possible on completion of the drilling. Dewatering can involve irrigation of excess water onto nearby land as well as spreading any fine material that settled in the drill pit onto this land. The excess water and fine material may have elevated salinity and should only be dispersed locally if there is no impact (see section 5.1.1).

3.1.7 Landform

The existing landform within the CSG field is summarised in Table 2 using standard terminology of the Australian Soil and Land Survey Field Handbook (McDonald *et al* 1990).

Figure 3 displays the distribution of various landform components and shows that the existing landscape is of generally low relief.

Level to gently undulating plains with a relative relief of less than 9 m cover 50% of the CSG field. They mainly occur south of the Warrego Highway and slopes are commonly less than 3% though they may include a few low hills with steeper slopes.

Rises and undulating plains with greater slope (generally between 3 and 10%) are scattered over almost 22% of the area. Relief on the undulating plains is less than 9 m but is up to 30 m on the rises.

Low hills and rises also occur throughout the CSG field. They occupy a further 22% of the area where relief is between 9 and 90 m and slopes are predominantly greater than 3%.

Plateaus are restricted to small areas north of Miles and in the south-eastern corner of the CSG field. They cover almost 5 % of the area. The plateau surfaces are mainly level to gently undulating but the scarps and side slopes can be quite steep. Dissected plateaus have been severely eroded and are dominated by side slopes and scarps with very little of the surface remaining.

Hills and mountains with a relief of at least 90 m occur in only one very small area near the Leichhardt Highway, south-west of Guluguba.

Table 2. Landform components

Landform component	Area	
	(ha)	(%)
Hills and mountains	3,835	0.8
Dissected plateaus	3,550	0.8
Plateaus	19,400	4.1
Plateaus and low hills	1,370	0.3
Low hills and rises	104,065	22.2
Rises and undulating plains	101,430	21.6
Level to gently undulating plains	228,100	48.7
Level to gently undulating plains with Low hills	6,930	1.5
Total	**468,680**	**100.0**

3.1.8 Special areas

From a geological and topographical perspective there are no areas of high conservation value.

The relatively small and isolated areas of dissected plateaus, hills and mountains represent "sensitive landscapes" only by way of their steep topography contributing to a significant erosion risk. However, other factors including soil type and land use practices also determine erosion risk and this issue is discussed in detail in section 4.6.

3.1.9 Suitability of local materials for construction purposes

All local hard rock sources for use in construction are sedimentary rocks; mainly sandstone, siltstone and mudstone though the much smaller pockets of conglomerate may also be an important source wherever it outcrops or occurs close to the ground surface. The most appropriate areas for extraction will be where bedrock occurs closest to the surface. These areas are described in section 4.4 and will be mainly located on the low hills, hills, mountains and dissected plateaus.

The suitability of particular sites for extraction will depend upon access, ease of extraction and ground stability. As noted in section 3.1.4, ground stability is not a significant issue within the CSG field though quarry sites should probably be avoided along known fault lines.

If unconsolidated material containing clay is to be sourced for fill, road base or other use, the source material will need to be tested first to ensure the material is not dispersive and thus highly erodible. This issue is discussed in detail in section 4.6. Unconsolidated material on plateau surfaces is unlikely to be dispersive. Plateaus are located mainly east of Tara and near North Dulacca.

The best sources for sand and gravel within the CSG field will be along major streams. Soil may also be extracted from these areas but will need to be tested first for clay dispersion.

3.2 Soils

3.2.1 Available mapping used

The only soil mapping across the entire study area is the Atlas of Australian Soils, which was undertaken as a national soil mapping exercise and was published at a scale of 1:2 Million.

However, land system and LRA mapping is available for the area and contains soil information including a description of the relative proportion of different soils within each mapping unit. Land system surveys for the Dawson-Fitzroy (Speck *et al* 1968), Miles (Dawson 1972b), Jandowae (Dawson 1972a) and Millmerran-Moonie-Tara (Mullins 1980) areas and LRA mapping (Harris *et al* 1999) for the area between Kogan and the Moonie Highway (to the south-east) have been used to compile a soil map for the CSG field.

3.2.2 Field investigation

Field investigation has confirmed that the available land system mapping is quite accurate and reliable for the regional comparison and assessment purposes of this study.

However, the actual soil content within some individual mapping units has been altered following field observations and laboratory analyses to more accurately reflect which soils are dominant. Alterations have been made mainly to the distribution of clay soils with and without melonhole gilgai microrelief and to the presence of non dispersive texture contrast soils.

3.2.3 Identification of soil management groups

The range of soils within the CSG field has been amalgamated into a series of soil management groups. Each soil management group consists of soil types that have similar profile features as well as similar chemical and physical properties and thus require similar management inputs to ensure sustainable use and to minimise environmental impact.

Land system and LRA mapping does not allow individual soils to be delineated within each mapping unit. Rather, each land system or LRA represents a mixture of several soil types. Individual soil types within each land system or LRA have been allocated into a series of soil management groups.

3.2.4 Standard terminology

All descriptions of soil management groups in this report use standard terminology of the Australian Soil and Land Survey Field Handbook (McDonald *et al* 1990). Descriptions of field pH measurements (such as medium acid) are from Interpreting Soil Analyses – for Agricultural Land Use in Queensland (Baker and Eldershaw 1993).

The report describes the numerous soil layers that may occur through a soil profile as being either:

- surface layers which extend down from the ground surface and are generally darkened (compared to any underlying layers) due to the accumulation of organic matter;
- subsurface layers which occur below, and are very similar to, the surface layer in texture and structure but are usually paler in colour (due to much less organic matter); or
- subsoil, which refers to any layer below the subsurface layer (or below the surface layer if there is no subsurface layer) which has much higher clay content, brighter colours or markedly different structure.

The term “topsoil” is generally avoided in soil survey reports because its common usage covers a wide range of soil material that may be sourced from any part of the soil profile, though usually not clay. The term has also been applied to any natural soil (and artificial planting) material that is used for topdressing.

3.2.5 Description of soil management groups

Table 3 summarises the soil management groups identified within the CSG field. Their distribution is shown in Figure 4.

Table 3 also provides a correlation of each soil management group with the equivalent taxonomic unit from the Australian Soil Classification (Isbell 1996) to facilitate comparison with other soil reports.

The soil management groups have been given descriptive names that reflect their key soil profile features. The descriptive names are based on the following system:

- Soils referred to as sands and sandy loams have uniform texture consisting of sand, loamy sand or sandy loam throughout their profile.
- Similarly, loams and clay loams have uniform texture consisting of loam, sandy clay loam or clay loam throughout their profile.
- Texture contrast soils are soils with either sandy or loamy textured surface and subsurface layers that change abruptly (over ≤5 cm) into much heavier textured (usually clay) subsoil.
- Gradational soils have either a sandy or loamy textured surface layer and clay content gradually increases with depth to a heavier texture deep in the subsoil.
- Cracking clays are soils with a uniform clayey texture (light clay, medium clay and heavy clay) throughout their profile and shrink and swell with changing moisture content. As a result they develop vertical cracks from the subsoil up towards the surface as they dry.
- Melonhole clays are cracking clays that also develop a prominent (at least 30 cm deep) melonhole gilgai microrelief on the ground surface.
- Non-cracking clays also have a uniform clayey texture throughout their profile but do not shrink and swell with changing moisture content.

- Texture contrast soils (dispersive) have subsoil that readily disperses in water making them highly erodible and relatively impermeable to water movement.
- The subsoil of texture contrast soils (non dispersive) does not readily disperse in water and is more permeable and less prone to tunnel and gully erosion.
- In texture contrast and gradational soils, the qualifiers “sandy” and “loamy” refer to the texture of the surface and subsurface layers. The surface and subsurface layers in Sandy texture contrast soils have sand, loamy sand, sandy loam or light sandy clay loam texture whereas these layers have sandy clay loam, loam or clay loam texture in Loamy texture contrast soils.

In Figure 4, only one soil management group is shown where it represents at least 70% of the mapping unit. Where no one group accounts for 70% of the mapping unit, the two major soil management groups are shown but separated with “/”. In this case, the first soil mentioned name represents the most widespread or main soil management group.

Shallow sands and sandy loams

Shallow sands and sandy loams are the main soil management group on almost 20% of the CSG field and occur in combination with other soil management groups on a further 2%. They may occur throughout the CSG field, occasionally on little-weathered sedimentary rocks but are primarily found on deeply weathered material where they occupy hills, low hills, rises and plateau scarps.

The *Shallow sands and sandy loams* have a thin, brown, grey or black, surface layer of loamy sand to sandy loam texture that either directly overlies weathered rock or grades into a paler subsurface layer of similar texture which then overlies rock. The paler subsurface is often bleached sporadically (blotches of white or almost white) or conspicuously (entirely white or almost white).

The ground surface is hard setting when dry and both the surface layer and subsurface layer (if present) have massive structure[1].

Field pH can vary from slightly acid to very strongly acid through the profile.

The ground surface and soil profile contain abundant medium and large pebbles. Larger cobbles, stones and boulders may be present and bedrock may outcrop on up to 50% of the surface.

Total soil profile depth varies from less than 100 mm up to 300 mm.

Shallow loams and clay loams

This soil management group occupies the same landform components as the *Shallow sands and sandy loams* but is much less extensive. *Shallow loams and clay loams* are the main soil management group on only 1% of the CSG field but also occur in combination with other soil management groups on a further 4%.

The *Shallow loams and clay loams* have almost identical profile features to the *Shallow sands and sandy loams* apart from a heavier texture in the surface and subsurface layers.

They are also very stony with much rock outcrop and total soil profile depth varies from less than 100 mm up to 300 mm.

[1] Strong structure refers to soil material consisting of >⅔ natural soil aggregates (peds).
Moderate structure refers to soil material consisting of ⅓ to ⅔ peds.
Weak structure refers to soil material with <⅓ peds.
Massive structure refers to coherent soil material with no peds.
Single grain structure refers to a loose, incoherent mass with no peds.

Deep sands and sandy loams

Deep sands and sandy loams are the main soil management group on less than 4% of the CSG field. They occupy levees and channel benches in the level to gently undulating floodplains that flank major streams. Their most widespread occurrence is along the Condamine River between Condamine and Miles. Where mapped as the main soil management group, they are closely associated with *Loamy texture contrast soils (dispersive)* but may occur as a minor soil component of most floodplains.

The *Deep sands and sandy loams* have a very thick, dark brown to grey, surface layer of sand to sandy loam texture that overlies subsoil of similar texture but with a brighter, red or yellowish brown, colour. Buried layers, representing earlier deposition events, of loamy or clayey texture may occur below 400 mm depth.

The ground surface is soft to firm when dry. Where texture is loamy sand or sand, structure is generally single grain but sandy loam textures usually have massive structure.

Field pH may vary from medium acid to neutral in all layers.

There is few, if any, gravel on the surface or through the profile.

Total soil profile depth, including the buried layers is more than 1 m.

Sandy or loamy gradational soils

Sandy or loamy gradational soils are the main soil management group on the plateau remnants that have developed on deeply weathered material. They are closely associated with *Sandy texture contrast soils (dispersive)* in these areas. They mostly occur north and north-west of North Dulacca, covering approximately 1.5% of the CSG field. However, the *Sandy or loamy gradational soils* may also occupy small plateau remnants that are scattered throughout the CSG field but are too small to map separately.

The *Sandy or loamy gradational soils* have a very thick, brown surface layer of sandy loam to clay loam, sandy texture that gradually merges into red or yellow subsoil of sandy light clay to medium clay texture. The deep subsoil may become strongly mottled with coarse blotches of red, yellow and light grey.

The ground surface is firm to hard setting when dry and structure is massive throughout the profile.

Few, if any, gravel are present on the ground surface. The surface layer and upper subsoil are also gravel free but there may be a few, small to large, pebbles through the deep subsoil.

Field pH may vary from medium acid to very strongly acid in all layers.

Weathered and strongly altered rock may be encountered below 600 m depth though many profiles are deeper than 1 m.

Loamy texture contrast soils (non dispersive)

Though not mapped as the main soil management group within the CSG field, the *Loamy texture contrast soils (non dispersive)*are a major landscape component south-west of Miles where the soils are closely associated with *Shallow loams and clay loams* on low hills and rises and with *Dark cracking clays* on rises and undulating plains. The low hills and rises are developed on deeply weathered material whereas the rises and undulating plains overlie unconsolidated sediments. Together these units occupy almost 3% of the CSG field. *Loamy texture contrast soils (non dispersive)* also form a minor component of flood plains on recent alluvium where they are associated with *Deep sands and sandy loams*.

The *Loamy texture contrast soils (non dispersive)* have a thin, grey or brown, surface layer of clay loam texture that abruptly overlies brown medium clay subsoil. There may be a very thin, sporadically bleached subsurface layer between the surface layer and clay subsoil.

The ground surface is firm to hard setting when dry and the surface layer is weakly structured with natural soil aggregates (referred to as peds) of fine size (≤ 10 mm diameter). The clay subsoil is strongly structured but ped size is much coarser (≥ 20 mm diameter).

Few, if any, gravel are present on the ground surface or through the soil profile.

Field pH may vary from medium acid to strongly acid in the surface layer but increases through the clay subsoil to become neutral to strongly alkaline at depth.

The soils are generally quite deep with weathered rock not present before 1 m.

Loamy texture contrast soils (dispersive)

Loamy texture contrast soils (dispersive) are a widespread soil management group throughout the entire study area, occurring on little-weathered rock, deeply weathered material, unconsolidated sediments and on recent alluvium. They are found primarily on rises and plains but may also be on low hills. In many places these soils occur in close association with similar *Sandy texture contrast soils (dispersive)* where the two soil management groups cannot be separated. In these places, the area of each soil management group has been estimated by simply halving their total area. Using this method, the *Loamy texture contrast soils (dispersive)* are estimated to be the main soil management group on 15% of the CSG field.

The *Loamy texture contrast soils (dispersive)* have a thin, brown or dark grey, surface layer of loam, sandy clay loam or clay loam texture that abruptly overlies brown, grey or mottled, brown and grey, sandy light clay to medium clay subsoil. There is often a very thin, sporadically or conspicuously bleached subsurface layer between the surface layer and clay subsoil.

The ground surface is hard setting when dry and the surface layer is massive to weakly structured with a few peds of fine size (≤ 10 mm diameter). The clay subsoil is moderately to strongly structured but ped size is coarse (≥ 20 mm diameter).

A few, small to large, pebbles may be present on the ground surface and through the soil profile.

Field pH varies from strongly acid to neutral in the surface and subsurface layers, then either remains strongly acid in the clay subsoil or increases to become strongly alkaline at depth. Small nodules of calcium carbonate are may be common deep in the alkaline clay subsoil.

The soils are moderately deep to deep with weathered rock being encountered below 600 mm depth though soil profiles on the recent alluvium are deeper than 1 m.

Sandy texture contrast soils (dispersive)

This is the most widespread soil management group throughout the CSG field, occurring on all types of terrain except dissected plateaus. As mentioned previously, these soils often occur in close association with the *Loamy texture contrast soils (dispersive)* and in these places the area of each soil management group has been determined by simply halving their total area. Using this method, the *Sandy texture contrast soils (dispersive)* are estimated to be the main group on 30% of CSG field and are the second most common group on a further 12%.

The *Sandy texture contrast soils (dispersive)* have similar profile features to the *Loamy texture contrast soils (dispersive)* apart from having a:

- mainly thick (rather than thin) surface layer of sand, loamy sand or sandy loam texture;
- sporadically to conspicuously bleached subsurface layer of similar texture that is almost always present; and
- subsoil that is generally mottled grey, brown or yellow and has a sandy feel to its clay textures.

These soils are also moderately deep to deep with weathered rock being encountered below 600 mm depth though soil profiles on the recent alluvium are deeper than 1 m.

Brown cracking clays

Brown cracking clays occupy level to gently undulating plains developed on little-weathered sedimentary rocks between Miles and North Dulacca but are mapped as the main soil management group on only 0.1% of the CSG field.

The *Brown cracking clays* have a thin, dark brown surface layer of light clay to light medium clay texture that overlies brown or reddish brown medium clay to medium heavy clay subsoil.

The ground surface is self-mulching when dry and the soils shrink and swell with changing moisture content, developing vertical cracks from the subsoil up towards the surface as they dry. Structure in the surface layer is strong with peds of very fine size (≤ 5 mm diameter). The clay subsoil is also strongly structured but ped size is much coarser (≥ 20 mm diameter).

Field pH is neutral to mildly alkaline in the surface layer then increasing to moderately to strongly alkaline through much of the subsoil before becoming increasingly acid very deep in the subsoil. Soft segregations of calcium carbonate are abundant in the mildly alkaline subsoil.

There is few, if any, gravel on the surface or through the profile.

Total soil profile depth, is more than 1 m.

Grey-brown cracking clays

This soil management group occupies rises and undulating plains developed on little-weathered sedimentary rocks. It is mapped as the main soil management group on 7% of the CSG field, primarily within the addendum study area west of Wandoan and Guluguba.

The *Grey-brown cracking clays* are also shrink and swell soils that develop vertical cracks from the subsoil up towards the surface as they dry. They have a thin, brown or dark grey surface layer of light clay to medium clay texture that overlies brown, dark grey or reddish brown, medium clay to heavy clay subsoil that often becomes brown to yellowish brown with depth.

The ground surface is self-mulching when dry and the surface layer is strongly structured with peds of very fine size (≤ 5 mm diameter). The clay subsoil is moderately to strongly structured and ped size is much coarser (≥ 20 mm diameter).

Field pH is neutral to mildly alkaline in the surface layer then often increases to be mildly alkaline in the upper part of the subsoil before becoming very strongly acid to extremely acid deep in the subsoil. A few calcium carbonate nodules are often found in the mildly alkaline subsoil.

A few, small to large, pebbles may occur on the surface and through the profile.

Total soil profile depth, is more than 1 m.

Grey-brown non-cracking clays

The *Grey-brown non-cracking clays* are a minor soil management group associated with *Grey-brown cracking clays* on 6.5% of the CSG field. They occur on rises, low hills and undulating plains developed on little-weathered sedimentary rocks, primarily within the addendum study area west of Wandoan and Guluguba.

Despite the uniform clay texture throughout their profile, the *Grey-brown non-cracking clays* do not shrink and swell or develop vertical cracks as they dry. They have a thick, brown or black, surface layer of light clay to medium clay texture that overlies greyish brown to reddish brown subsoil of similar texture.

The ground surface is soft to firm when dry and the surface layer is moderately to strongly structured with peds of very fine size (≤ 5 mm diameter). The clay subsoil is similarly structured but ped size is much coarser (≥ 10 mm diameter).

Tunnel and gully erosion have been observed in several profiles, especially where these soils are adjacent to outcrops of sedimentary rocks (usually on hills and low hills)

Field pH is medium acid to mildly alkaline in the surface layer but increases with depth to become moderately alkaline to strongly alkaline deep in the subsoil where a few calcium carbonate nodules and soft segregations are often found.

Cobbles, stones and small to large pebbles are common on the surface and through shallower profiles but deeper profiles have very few, if any, gravel.

Weathered rock may be encountered below 300 mm depth but many profiles may be at least 1 m deep.

Dark cracking clays

Dark cracking clays occupy rises and plains developed on little-weathered sedimentary rocks, unconsolidated sediments and recent alluvium. They are mapped as the main soil management group on 18.5% of the CSG field, being widespread between Miles, Condamine, Kogan and Brigalow. Substantial areas also occur in the south-east and north-west corners of the CSG field.

The *Dark cracking clays* are shrink and swell soils that develop vertical cracks from the subsoil up towards the surface as they dry. They have a thin, black or dark grey, surface layer of sandy light clay to medium heavy clay texture that overlies light medium clay to heavy clay subsoil of similar colour. At depth, subsoil colour may become paler grey or brown.

The ground surface is generally self-mulching when dry but on areas of recent alluvium a surface crust may form. The surface layer is weakly to strongly structured with peds of very fine to medium size (≤ 5-10 mm diameter). The upper part of the subsoil is strongly structured with coarse peds (≥ 20 mm diameter) but structure often declines with depth to become weak or moderate.

Field pH is generally mildly alkaline to strongly alkaline in the surface layer though some profiles may be medium acid to strongly acid at the surface. Subsoil pH is moderately alkaline to strongly alkaline on the recent alluvium and little-weathered sedimentary rocks and calcium carbonate nodules and soft segregations are commonly present. On the unconsolidated sediments, subsoil pH is moderately alkaline to strongly alkaline in the upper subsoil but decreases with depth to become strongly acid in the lower subsoil.

Very few, small to large, pebbles may occur on the surface.

Total soil profile depth is more than 1 m on the recent alluvium and unconsolidated sediments but weathered rock may be encountered below 600 mm on the little-weathered sedimentary rocks.

Melonhole clays

Melonhole clays occupy level to gently undulating plains developed on unconsolidated sediments, mostly south of the Warrego Highway. They have been mapped as the main soil management group on 3% of the CSG field, but are closely associated with *Dark cracking clays* on a further 2%.

The *Melonhole clays* are also shrink and swell soils that develop prominent melonhole gilgai microrelief. With this form of microrelief the land surface comprises an almost continuous pattern of irregularly shaped and randomly spaced mounds and depressions in which the bottom of the depressions is at least 300 mm below the top of mounds. Soil features in the depressions can be quite different from the mounds.

Melonhole clays have a very thin, grey or brown, surface layer of light medium clay to heavy clay texture that overlies grey medium clay to heavy clay subsoil.

The ground surface on the mounds is generally self-mulching when dry but in the depressions may be weakly self-mulching, hard setting or have a crust. The surface layer on the mound is strongly structured with peds of very fine size (≤ 5 mm diameter) but in the depression the surface layer varies from massive (in hard setting soils) to moderately or strongly structured. Ped size in the surface layer of the depressions is usually coarser than on the mounds (5-50 mm diameter). The clay subsoil beneath both mounds and depressions is moderately to strongly structured and ped size is very coarse (≥ 20 mm diameter).

Field pH is quite variable. The surface layer is principally slightly acid to neutral but the clay subsoil may be either moderately alkaline or very strongly acid. A few calcium carbonate nodules are often found in the alkaline subsoil.

Very few, if any, gravel occur on the surface and through the profile.

Total soil profile depth, is more than 1 m.

3.3 Acid sulphate soils

Acid Sulfate Soils (ASS) refers to soil profiles, soil layers and sediments that contain iron sulfides, the most common of these being pyrite. When disturbed, ASS can have highly negative effects on the immediate and surrounding environment.

ASS characteristically occur in estuaries, tidal mangroves, wetlands, floodplains, lakes and other areas at elevations less than 5 metres above sea level. ASS can also be found at higher elevations inland, where pyrite forming conditions are present. Pyrite can form where there is an abundance of iron in the sediment, organic matter, saline water and anaerobic conditions.

These conditions are only met inland where there are organically enriched deposits at the edges of saline lakes and waterways.

Such conditions are not known within the CSG field and it is extremely unlikely that acid sulphate soils are present.

Table 3. Soil management groups

Soil management group [1]	Major terrain unit [2]	Brief description	ASC Suborder [3]	Area [4] (ha)	Area [4] (%)
Shallow sands and sandy loams	Little-weathered sedimentary rocks	Shallow and gravelly soils with thin, brown, grey or black, loamy sand to sandy loam that either directly overlies weathered rock or grades into a paler subsurface layer of similar texture which then overlies rock; weathered rock at <100 to 300 mm depth	Clastic Rudosols, Leptic Tenosols and Bleached-Leptic Tenosols	5,205	1.1
	Deeply weathered material			87,035	18.6
Shallow loams and clay loams	Deeply weathered material	Shallow and gravelly soils with thin, brown, grey or black, sandy clay loam, loam or clay loam that either directly overlies weathered rock or grades into a paler subsurface layer of similar texture which then overlies rock; weathered rock at <100 to 300 mm depth	Clastic Rudosols, Leptic Tenosols and Bleached-Leptic Tenosols	5,845	1.3
Deep sands and sandy loams	Recent alluvium	Deep soils with very thick, dark brown to grey, sand to sandy loam that overlies subsoil of similar texture but with a brighter, red or yellowish brown, colour; buried layers may occur below 400 mm depth	Stratic Rudosols, Red-Orthic Tenosols and Brown-Orthic Tenosols	17,040	3.6
Sandy or loamy gradational soils	Deeply weathered material	Moderately deep to deep soils with very thick, brown, sandy loam to clay loam, sandy grading into red or yellow subsoil of sandy light clay to medium clay that may be strongly mottled at depth; weathered rock below 600 mm depth	Red Kandosols and Yellow Kandosols	6,000	1.3
Loamy texture contrast soils [5] (non dispersive)	Little-weathered sedimentary rocks	Deep soils with thin, grey or brown, clay loam abruptly overlying brown medium clay subsoil. There may be a very thin, sporadically bleached subsurface layer; weathered rock below 1 m depth	Brown Chromosols	0	0.0
Loamy texture contrast soils (dispersive)	Little-weathered sedimentary rocks	Moderately deep to deep soils with thin, brown or dark grey, loam, sandy clay loam or clay loam often overlying bleached subsurface of similar texture which abruptly overlies brown, grey or mottled, brown and grey, sandy light clay to medium clay subsoil; weathered rock below 600 mm depth	Brown and Grey Sodosols, Brown and Grey Kurosols	34,830	7.4
	Deeply weathered material and unconsolidated sediments			32,615	7.0
	Recent alluvium			3,810	0.8
Sandy texture contrast soils (dispersive)	Little-weathered sedimentary rocks	Moderately deep to deep soils with thick, brown or dark grey, sand, loamy sand or sandy loam usually overlying a bleached subsurface of similar texture which abruptly overlies mottled brown, grey or yellow, sandy light clay to sandy medium clay subsoil; weathered rock below 600 mm depth	Brown, Grey and Yellow Sodosols, Brown, Grey and Yellow Kurosols	52,705	11.2
	Deeply weathered material and unconsolidated sediments			84,880	18.1
	Recent alluvium			4,830	1.0
Brown cracking clays	Little-weathered sedimentary rocks	Deep soils with thin, dark brown, light clay to light medium clay overlying brown or reddish brown, medium clay to medium heavy clay subsoil; weathered rock below 1 m depth	Brown Vertosols	460	0.1
Grey-brown cracking clays	Little-weathered sedimentary rocks	Deep soils with thin, brown or dark grey, light clay to medium clay texture overlying brown, dark grey or reddish brown, medium clay	Brown Vertosols and Grey Vertosols	32,905	7.0
	Unconsolidated sediments			80	<0.1

Soil management group [1]	Major terrain unit [2]	Brief description	ASC Suborder [3]	Area [4] (ha)	Area [4] (%)
		to heavy clay subsoil becoming brown to yellowish brown with depth; weathered rock below 1 m depth			
Grey-brown non-cracking clays [6]	Little-weathered sedimentary rocks	Shallow to deep soils with thick, brown or black, light clay to medium clay overlying greyish brown to reddish brown subsoil of similar texture; weathered rock below 300 mm depth	Grey Dermosols and Brown Dermosols	0	0.0
Dark cracking clays	Little-weathered sedimentary rocks	Moderately deep to deep soils with thin, black or dark grey, sandy light clay to medium heavy clay overlying light medium clay to heavy clay subsoil of similar colour, often becoming paler grey or brown with depth; weathered rock below 600 mm depth	Black Vertosols and Grey Vertosols	16,650	3.6
	Deeply weathered material and unconsolidated sediments			50,000	10.7
	Recent alluvium			19,895	4.2
Melonhole clays	Unconsolidated sediments	Deep soils with melonhole gilgai and very thin, grey or brown, light medium clay to heavy clay overlying grey, medium clay to heavy clay subsoil; weathered rock below 1 m depth	Grey Vertosols	13,895	3.0
			Total	**468,680**	**100.0**

Notes:

1. A soil management group represents several soils that have similar profile features, chemical properties and physical properties and thus require similar management inputs to ensure sustainable use and to minimise environmental impact.
2. A terrain unit is based on weathering history of the underlying rocks and resultant regolith cover. A major terrain unit is one in which the soil management group is the most widespread and is therefore listed first.
3. ASC Suborder represents the soil taxonomic classification (to its second or suborder level) using the Australian Soil Classification (Isbell 1996).
4. The *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* could not be separated in many mapping units and the individual area of each has been estimated in these units as being one-half of the total area of the mapping unit.
5. *Loamy texture contrast soils (non dispersive)* are not the main soil management group in any terrain unit but are a major soil group closely associated with other soil management groups on 12,680 ha south-west of Miles.
6. *Grey-brown non cracking clays* are not the main soil management group in any terrain unit but are a major soil group closely associated with *Grey-brown cracking clays* on 29,915 ha west of Wandoan.

3.4 Good Quality Agricultural Land

Agriculture, either in the form of crop production or cattle and sheep grazing, is the dominant land use across the entire study area.

The differing soil profile features, chemical properties and physical properties between soil management groups results in a varying capacity to support crop and pasture production within this area.

The agricultural productivity of the CSG field has been assessed by DPI and was, in fact, the main reason for undertaking the various land system and LRA surveys. The DPI assessments used a land capability classification scheme to place land into one of 8 classes depending upon the severity of any known limitations to sustainable production.

The Queensland Government introduced a State Planning Policy in 1992 (SPP 1/92) to protect Good Quality Agricultural Land (GQAL). In support of this policy, four classes of agricultural land were defined for Queensland:

Class A	Crop land
Class B	Limited crop land
Class C	Pasture land
Class D	Non-agricultural land.

NRW has used the DPI land capability classifications to assign an Agricultural Land Class to all mapping units within the CSG field. Table 4 presents the results of this allocation.

According to NRW, all clay soils are considered to have some cropping potential (either Class A or Class B). The *Loamy texture contrast soils (non dispersive)* are considered to represent cropping land as well and the *Deep sands and sandy loams* have limited cropping potential (Class B). Relatively small areas of *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* on either recent alluvium or on little-weathered rock also have limited cropping potential.

All other soil management groups are classified as being pasture land except for a very small area of *Sandy texture contrast soils (dispersive)* near the junction of the Moonie Highway and Surat Development Road. This area is classified as non agricultural land and is considered unsuitable for any agricultural use.

Generally, crop land (both Class A and Class B) is designated as GQAL for the purpose of protecting agricultural productivity under State Planning Policy 1/92.

Table 5 gives the relative area of GQAL and other Agricultural Land Classes within the entire study area.

Just over 39% of the CSG field is considered to be GQAL with 60.5% being pasture land and less than 0.5% representing non agricultural land. The distribution of these land classes is shown in Figure 5.

Figure 5 shows that most GQAL is in the centre of the CSG field roughly bounded by Miles, Brigalow, Kogan and Condamine though substantial areas also occur along the Moonie Highway in the south-east and to the west of Wandoan and Guluguba.

Table 4. Agricultural land classes

Soil management group [1]	Major terrain unit [2]	Agricultural Land Class [3]
Shallow sands and sandy loams	Little-weathered sedimentary rocks	Class C
	Deeply weathered material	Class C
Shallow loams and clay loams	Deeply weathered material	Class C
Deep sands and sandy loams	Recent alluvium	Class B
Sandy or loamy gradational soils	Deeply weathered material	Class C
Loamy texture contrast soils (non dispersive)	Little-weathered sedimentary rocks	Class A
Loamy texture contrast soils (dispersive)	Little-weathered sedimentary rocks	Class C
	Deeply weathered material and unconsolidated sediments	Class C
	Recent alluvium	Class B or C
Sandy texture contrast soils (dispersive)	Little-weathered sedimentary rocks	Class B or C or D
	Deeply weathered material and unconsolidated sediments	Class C
	Recent alluvium	Class B or C
Brown cracking clays	Little-weathered sedimentary rocks	Class B
Grey-brown cracking clays	Little-weathered sedimentary rocks	Class A
	Unconsolidated sediments	Class A
Grey-brown non-cracking clays	Little-weathered sedimentary rocks	Class A
Dark cracking clays	Little-weathered sedimentary rocks	Class A
	Deeply weathered material and unconsolidated sediments	Class A
	Recent alluvium	Class A or B
Melonhole clays	Unconsolidated sediments	Class B

Notes:

1. A soil management group represents several soils that have similar profile features, chemical properties and physical properties and thus require similar management inputs to ensure sustainable use and to minimise environmental impact.
2. A terrain unit is based on weathering history of the underlying rocks and resultant regolith cover. A major terrain unit is one in which the soil management group is the most widespread and is therefore listed first.
3. The *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* could not be separated in many mapping units and the individual area of each has been estimated in these units as being one-half of the total area of the mapping unit.

Table 5. Area of GQAL and other land

Agricultural Land Class	Status	Area (ha)	(%)
Class A	GQAL	96,965	20.7
Class B	GQAL	86,945	18.5
Class C	Pasture land	283,485	60.5
Class D	Non agricultural land	1,285	0.3
	Total	**468,680**	**100.0**

3.5 Existing erosion

Soil erosion is governed by the inherent erodibility of the soil profile, the topography of the site, volume and intensity of the incident rainfall and the land use practices which determine the amount of vegetative cover and condition of the ground surface.

Approximately 75% of the CSG field consists of level to gently undulating plains, undulating rises and plains and plateaus with level to gently undulating surfaces. The remaining 25% consists mainly of low hills and rises.

Land use practices have been, and still are, predominantly grazing on most of the area with dryland (rain grown) and some irrigated cropping principally on the clay soils of the level to gently undulating plains. Timber getting from native forests has also been an important practice, especially north of Miles.

3.5.1 Grazing and forestry lands

Whilst many of the soils are highly erodible (see section 4.6), the grazing and forestry practices and mainly gentle slopes have created only minor erosion within their respective areas.

Minor sheet erosion is evident on the sloping *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* through the:

- accumulation of small debris lines containing grass, leaf and twig litter that run across the slope and indicate overland sheet flow of water;
- loss of some of the darkened surface layer from bare areas between grass tussocks; and
- raising of grass tussocks onto low pedestals that indicates some loss of the soil surface layer.

More severe sheet erosion is evident on the steeper grazing land with *Shallow sands and sandy loams* or *Shallow loams and clay loams.*

It is difficult to find any evidence of sheet erosion on the *Loamy texture contrast soils (non dispersive)*, *Sandy or loamy gradational soils*, *Deep sands and sandy loams* and on the various clay soil management groups.

Rill, gully and tunnel erosion were observed in the grazing and forestry lands but all instances were associated with either nearby road works or pipeline construction. Roadside gully and tunnel erosion were most commonly associated with *Loamy texture contrast soils (dispersive)* and *Sandy texture contrast soils (dispersive)* but was also observed with *Grey-brown non-cracking clays* in the addendum study area, especially where these soils were adjacent to outcrops of sedimentary rock.

3.5.2 Cropping land

Cropping within the CSG field is restricted mainly to the *Dark cracking clays*, *Brown cracking clays* and part of the *Melonhole clays*. However, some minor areas of the recent alluvium that are cropped include *Sandy texture contrast soils (dispersive)*, *Loamy texture contrast soils (dispersive)*, *Loamy texture contrast soils (non dispersive)* and *Deep sands and sandy loams*.

Where these soil management groups occur on sloping land, run-off control structures and appropriate land management practices have generally been adopted that effectively minimise any ongoing erosion.

As a result, only minor soil movement due to sheet and rill erosion between run-off control structures is evident on cropping land.

However, as for the grazing and forestry lands, rill, gully and tunnel erosion were observed occasionally and all instances were due to nearby road works.

4. Potential constraints and impacts

This section describes the issues and constraints for constructing infrastructure associated with the proposal and also assesses the potential impacts of the proposed activities on the geology and soils.

4.1 Relevant activities

The upstream component of the proposal involves the following construction activities that may be affected by, or impact upon, the environment:

- creating hardstand areas approximately 100 m by 100 m in size as drilling pads at well sites, though partial restoration of each drilling site to about 10 m x 10 m may be possible after the wellhead becomes operational;
- progressively drilling up to 6,000 wells across the entire study area to extract the coal seam gas, located approximately 750 m apart to optimise production;
- building an estimated 27 field compression stations which comprise compression facilities, a vent for pressure management, power generation facilities and a water management system, including an on-site evaporation pond;
- building an estimated 9 central processing plants which comprise compression facilities, gas dehydration and regeneration units, a flare, power generation, metering facilities, offices, control room and car park;
- laying underground gas gathering pipelines made of high density polyethylene pipe or steel pipe between the extraction wells, field compression stations and central processing plants which will involve trench excavation to a maximum 1.5 m depth;
- erecting accommodation camps and administration facilities;
- building an anticipated 2,000 km of lightly formed and gravelled access tracks (i.e. typically 4 m wide x 150 mm thick) to connect wellheads with other facilities; and
- excavation of borrow pits for accessing local construction materials.

Well life is considered to be 25 years and each well field will be depleted and rehabilitated in 25-30 years after initial construction. Ongoing production and maintenance activities during that period will also be constrained by, and have an impact on, the geology and soils.

All relevant construction, production and maintenance activities have been considered when assessing each prospective constraint and potential impact.

4.2 Data and rating system used

Information used to assess the constraints and impacts has been obtained from available soil information reviewed during the desktop analysis and from data collected during field investigation. This has been supported by laboratory analyses of selected soil samples collected during field investigation when assessing erosion, soil fertility and salinity.

The assessment involves rating the severity of each constraint or impact into one of five categories:

Nil — No constraint or impact due to the feature.

Minor — A slight constraint or impact that is readily overcome or controlled with standard management practices and mitigation measures.

Moderate — A substantial constraint or impact but is overcome or controlled with a combination of standard and special practices and mitigation measures.

Severe — A substantial constraint or impact that may be overcome or controlled only with special practices and mitigation measures.

Extreme — A substantial constraint or impact that cannot usually be overcome or controlled even with special practices and mitigation measures.

Constraints and impacts that are rated as moderate or worse are described as being “significant” throughout this report as mitigation or control requires special attention and may be extremely difficult.

4.3 Topography

Steep slopes and deeply dissected terrain can:

- limit access of specialist heavy machinery;
- impede excavation; and
- require special measures to build access tracks with appropriate grade.

Slope degree and length also have a strong influence on potential erosion but this aspect of topography is considered under the issue of erosion hazard (see section 4.6).

Landform descriptions from the Land system and LRA reports have been used to develop a decision matrix, shown in Table 6, which rates the severity of topography as a constraint to access, building tracks and excavation.

Figure 6 shows where the topography is a constraint across the entire study area.

Approximately 76% of the CSG field has no topography constraint and an additional 22% has only a minor constraint to any development activities.

Only dissected plateaus between Tara and the Moonie Highway (0.8%) and hills and mountains west of the Leichhardt Highway between North Dulacca and Guluguba (0.8%) have a moderate to severe restriction.

Table 6. Decision matrix for rating topography

Landform component	Relief [1] and modal slopes [2]	Constraint rating
Rolling to steep hills and mountains	Relief ≥ 90 m; slopes >10%	Severe
Dissected plateaus	Relief unknown; slopes >10%	Moderate
Undulating to rolling low hills and rises	Relief 30-90 m; slopes 3-30%	Minor
Rises and undulating plains	Relief 9-30 m; slopes 3-10%	Nil
Level to gently undulating plains	Relief <9 m; slopes 1-3%	Nil

Notes:

1. Relief refers to the difference in elevation between the highest and lowest levels of the landform component.
2. Modal slopes are the most common slopes within the landform component.

4.4 Depth to bedrock

Depth to bedrock will mainly affect the ability to:

- lay underground gas pipelines;
- excavate evaporation ponds; and
- excavate trenches for building foundations and associated services.

Soil depth is usually reported as depth to weathered rock which can be either soft or hard. However, for the purpose of this study all weathered rock has been assumed to be hard.

Table 7 presents the decision matrix used to rate the severity of depth to bedrock for infrastructure development that involves excavation.

Table 7. Decision matrix for rating depth to bedrock constraint

Depth to rock		Constraint rating
(m)	Category	
< 0.3	Very shallow	Extreme
0.3-0.6	Shallow	Severe
0.6-0.9	Moderately deep	Moderate
0.9-1.2	Deep	Minor
>1.2	Very deep	Nil

Depth to hard rock across the entire study area and its related constraint to excavation activities are shown in Figure 7.

More than 51% of the CSG field has no constraint caused by shallow bedrock.

Bedrock can occur at very shallow depth wherever *Shallow sands and sandy loams* or *Shallow loams and clay loams* occur. These soil management groups are spread across almost 27% of the CSG field. They are mapped primarily south of Wandoan but, at the scale of mapping available, cannot often be separated from intervening areas of deeper soils. The resultant rating for the mapping units vary from nil (very deep soils) or minor (deep soils) to extreme. The extreme rating only applies to the very shallow soils which are usually located on hills, low hills and rises.

In some original land system reports, depth to bedrock for the *Shallow sands and sandy loams* and *Shallow loams and clay loams* is not split into shallow and very shallow categories. However for the purpose of this study, all areas containing *Shallow sands and sandy loams* or *Shallow loams and clay loams* are considered to have very shallow depth to bedrock and thus an extreme constraint.

Less than 0.5%, comprising dissected plateaus in the far south-west corner of the CSG field, has a severe to extreme depth to bedrock constraint. *Shallow sands and sandy loams* and *Shallow loams and clay loams* are the main soil management groups on this land.

Any excavation for trenches or foundations on the *Shallow sands and sandy loams* and *Shallow loams and clay loams* below 300 mm depth will require using heavy duty equipment that can cut through hard rock.

Bedrock can occur at shallow to moderate depth in a further 13% of the CSG field, primarily south of the Moonie Highway and in the north-east corner above North Dulacca. The main soil management groups within this land occur on little-weathered sedimentary rocks where soil depth varies from 300 mm to more than 1.2 m.

4.5 Stoniness and rock outcrop

Presence of cobbles, stones or boulders (with >60 mm diameter) and outcropping bedrock can:

- limit the suitability of an area for locating hardstand areas;
- lower the efficiency of excavation; and
- reduce the working life of excavation equipment.

Table 8 presents the decision matrix used to rate the severity of stoniness and rock outcrop to constraining the creation of hardstand areas and to excavation.

Table 8. Decision matrix for rating stoniness and rock outcrop

Stoniness [1] or rock outcrop [2] (%)	Constraint rating
>50	Extreme
25-50	Severe
10-25	Moderate
2-10	Minor
<2	Nil

Notes:

1. Stoniness refers to the presence of cobbles (60-200 mm diameter), stones (200-600 mm diameter) and boulders (>600 mm diameter).
2. Rock outcrop refers to the presence of bedrock outcropping at the surface.

The stoniness and rock outcrop constraint across the entire study area is shown in Figure 8.

Most soil management groups within the CSG field contain only a few, if any, small to large pebbles (up to 60 mm diameter) and would have minimal effect on construction activities.

However, abundant cobbles, stones and boulders may occur in the *Shallow sands and sandy loams* and *Shallow loams and clay loams* and bedrock may outcrop on up to 50% of the surface. These soils have been assigned a severe to extreme rating and are widespread throughout the CSG field south of Wandoan but mostly occur on rises, low hills, hills and mountains. Wherever these soils are the main soil management group a severe to extreme constraint has been assigned. In other units containing these soils the constraint will vary from nil to extreme.

Shallow profiles of the *Grey-brown non-cracking clays* may also contain abundant cobbles and stones and have been assigned a severe constraint. However, these soils principally occur within the addendum study area west of Wandoan where *Grey-brown cracking clays* are the main soil management group. The combined mapping unit covers 6.5% of the CSG field and has been assigned an overall nil to moderate stoniness and rock outcrop rating.

4.6 Erosion hazard

Environmental impact due to soil erosion can result from the following activities that are associated with the proposed development and will disturb the ground surface and ground cover, including:

- clearing vegetation for infrastructure;
- building access tracks;
- excavation for all infrastructure listed in section 4.1; and
- concentrating run-off water flow from disturbed areas.

Soil erosion is governed by the inherent erodibility of the soil profile, topography, volume and intensity of the incident rainfall and land use practices which determine the amount of vegetative cover and condition of the ground surface.

Though the rainfall regime for the CSG field is characterised by low average rainfall (compared with the coast), intensity can be very high due to occurrence of summer storms that move through the district with weather fronts and to the occasional incidence of low pressure systems which are remnants of tropical cyclones.

The erosion hazard associated with the proposal has been determined within the existing rainfall regime. Two factors have been primarily used to determine erosion hazard - soil erodibility and degree of slope. Though slope length, land use practices and vegetation cover also have an influence, these factors can be manipulated by management decisions and can thus be changed to reduce and manage the overall risk.

4.6.1 Soil erodibility indicators

The erodibility of soil is determined by the rate of infiltration at its surface, permeability of the soil profile and coherence of the soil particles. Coherence and permeability are related to structure, texture and chemical properties such as organic matter content. These properties often vary between the surface layer and subsoil. Thus, the overall potential of a soil profile to erode is a combination of the inherent erodibility for its surface layer (often referred to as topsoil erodibility) and the erodibility of any underlying subsoil.

Even coherent and structured soils can be highly erodible due to clay dispersion. Dispersion of clay particles can damage soil structure by destroying large, flocculated aggregates and filling the voids between these aggregates with much smaller dispersed material. Thus, the porosity and permeability of the soil declines and the erodibility increases as the small dispersed particles are easily moved in water that ponds and then seeps along the top of the dispersed material.

A direct measure of soil erodibility is very difficult to obtain and this attribute is usually estimated through identification of key soil features such as texture, surface condition, consistence, colour and structure. Laboratory analyses are also used to determine surrogate chemical properties for dispersion.

The erodibility of soil management groups within the CSG field has been assessed using key soil features and published chemical properties for the soils supported by sampling of the main groups to confirm their tendency to disperse.

Twenty three (23) surface layer samples and twenty one (21) subsoil samples were submitted for laboratory analysis. Full results are presented in Attachment B and relevant analytical results for soil erodibility are summarised in Table 9.

The Exchangeable Sodium Percentage (ESP) and Exchangeable Calcium : Exchangeable Magnesium (Ca:Mg) ratio are two chemical properties used as independent estimates of dispersion. They are determined from analysis of the relative proportion of exchangeable calcium, magnesium, sodium, potassium and aluminium.

ESP and Ca:Mg ratio are derived from chemical analyses and must be interpreted with care. When the actual exchangeable cation levels are very low, any small change in one value can cause a disproportionate change in the percentage or ratio calculation and thus significantly alter the dispersion rating.

Sodic soil (ESP 6-14) is usually considered as being dispersive and strongly sodic (ESP ≥ 15) soil is nearly always dispersive. Ca:Mg ratios of 0.5 or less commonly cause dispersion in Australian soils and ratios of less than 1 have been associated with dispersion in some soils with a relatively low ESP.

Table 9 shows that most surface layer samples vary from non sodic (ESP <5) to sodic though a few samples are strongly sodic. Ca:Mg ratios are generally >1, except in the *Shallow sands and sandy loams* and *Sandy or loamy gradational soils*. However, the actual level of exchangeable cations in these latter soil samples is low and both ESP and Ca:Mg ratio may not necessarily be reliable indicators.

Data in Table 9 also confirm the separation of dispersive and non dispersive texture contrast soils into different soil management groups, which was based initially on field observations and published soil information. The *Sandy texture contrast soils (dispersive)* have strongly sodic subsoil with very low Ca:Mg ratios. *Loamy texture contrast soils (dispersive)* with acid subsoil are similar though profiles with an alkaline subsoil are slightly more benign, having a sodic to strongly sodic subsoil but a Ca:Mg ratio >1.

The data also reveal that the various clay soils have sodic to strongly sodic subsoil but Ca:Mg ratios are primarily >1. However, Ca:Mg ratios can be very low in subsoil of the *Melonhole clays* and ESP is sodic to strongly sodic suggesting some tendency to disperse.

Interestingly, the subsoil sample for *Sandy or loamy gradational soils* is strongly sodic and has an extremely low Ca:Mg ratio but, once again, these figures may not be a reliable indication due to low level of exchangeable cations. Such soils are generally known to be non dispersive.

Table 9. Analytical results for soil erodibility

Soil group	Soil layer	pH	EC [1] (dS/m)	CEC [2] (meq%)	ESP [3] (%)	Ca:Mg [4]
Shallow sands and sandy loams	Surface layer	3.9	0.06	3	5	0.7
Deep sands and sandy loams	Surface layer	7.0	0.09	12	1	3.1
	Subsoil	6.9	0.03	8	5	1.5
Sandy or loamy gradational soils	Surface layer	4.2	0.04	3	5	0.3
	Subsoil	6.5	0.05	7	15	<0.1
Loamy TC soils (non dispersive)	Surface layer	5.7-6.0	0.04-0.31	5-15	4-6	1.3-1.9
	Subsoil	6.1-9.0	0.05-0.66	8-37	6-10	1.4-2.2
Loamy TC soils (dispersive) - acid subsoil	Surface layer	5.6-5.8	0.09-0.11	5-10	7-23	0.4-1.1
	Subsoil	4.2-5.5	0.15-0.77	5-33	12-37	0.1-0.3
Loamy TC soils (dispersive) - alkaline subsoil	Surface layer	5.4-6.6	0.06-0.09	7-15	1-5	1.8-4.5
	Subsoil	7.6-8.9	0.19-0.70	19-33	12-20	1.1-3.2
Sandy TC soils (dispersive)	Surface layer	4.9-6.3	0.04-0.30	2-8	3-40	0.9-2.0
	Subsoil	5.4-9.3	0.26-2.01	10-17	22-33	0.0-0.6
Grey-brown cracking clays	Surface layer	6.7	0.21	33	2	4.9
	Subsoil	4.4	1.53	30	14	2.9
Dark cracking clays	Surface layer	6.2-7.9	0.08-0.26	15-33	1-9	1.5-2.7
	Subsoil	8.4-8.7	0.55-0.60	34-38	10-11	1.4-1.6
Melonhole clays	Surface layer	5.7-6.3	0.13-0.34	15-25	4-15	0.9-3.3
	Subsoil	4.7-8.3	0.42-1.42	15-38	10-26	0.3-2.3

Notes:

1. EC represents Electrical Conductivity which is a measure of soil salinity.
2. CEC represents Cation Exchange Capacity and is a measure of the soil ability to retain positively charged nutrients (such as calcium, magnesium, potassium, ammonium) for use by plant roots, as well as sodium and aluminium; CEC is measured in milliequivalents per 100g soil (meq %).
3. ESP represents Exchangeable Sodium Percentage and is the percentage of CEC that is due to exchangeable sodium.
4. Ca:Mg is the ratio of exchangeable calcium to exchangeable magnesium.

4.6.2 Overall soil erodibility

Table 10 gives the inherent soil profile erodibility of the soil management groups based on all available evidence.

Soils with either incoherent to weakly coherent surface layers or lower permeability and some tendency to disperse in the subsoil have a higher erodibility rating than others.

Table 10. Inherent erodibility of the soil management groups

Soil group	Erodibility rating	Factors
Shallow sands and sandy loams	Moderate	Incoherent to weakly coherent sandy material which is quite permeable but can be easily detached by flowing water
Shallow loams and clay loams	Very low	Coherent loamy material which is also quite permeable
Deep sands and sandy loams	Moderate	Incoherent to weakly coherent sandy material which is quite permeable but can be easily detached by flowing water
Sandy or loamy gradational soils	Low to moderate	Sandy profiles have incoherent to weakly coherent surface layers but loamy profiles are coherent; both profiles are quite permeable
Loamy TC soils (non dispersive)	Moderate	Coherent, permeable surface layer overlying slowly permeable subsoil causing some water ponding and seepage along the top of the non dispersive subsoil
Loamy TC soils (dispersive) - acid subsoil	Very high	Coherent, permeable surface layer overlying very slowly permeable subsoil causing water to pond then seep along the top of the very dispersive subsoil
Loamy TC soils (dispersive) - alkaline subsoil	High	Coherent, permeable surface layer overlying very slowly permeable subsoil causing water to pond then seep along the top of the dispersive subsoil
Sandy TC soils (dispersive)	Very high	Incoherent but permeable surface layer overlying very slowly permeable subsoil causing water to pond then seep along the top of the very dispersive subsoil
Brown cracking clays	Low	Incoherent, self-mulching surface layer and very slowly permeable subsoil
Grey-brown cracking clays	Low	Incoherent, self-mulching surface layer and very slowly permeable subsoil
Grey-brown non-cracking clays	Very low to high	Coherent surface layer and moderately permeable subsoil that may be dispersive in places
Dark cracking clays	Low	Incoherent, self-mulching surface layer and very slowly permeable subsoil
Melonhole clays	Low to moderate	Incoherent, self-mulching or hard, slowly permeable surface layer and very slowly permeable subsoil which may have some dispersion

Though no soils analytical data are available, roadside tunnel and gully erosion has been observed in *Grey-brown non-cracking clays*. The subsoil at such sites has a typical sodic "feel" when being textured (handles like a bar of soap when wet). Therefore, the erodibility rating for the *Grey-brown non-cracking clays* has been rated as very low (non dispersive subsoil) to high (dispersive subsoil).

4.6.3 Slope degree

Generally, soil erosion is minimal on slopes of less than 1% unless dispersive soil material is exposed to running water. Tunnel and gully erosion can develop on exposed dispersive soil material, even on land with minimal slope. With increasing slope, the capacity for run-off increases and thus the potential for dislodging and moving soil particles also rises.

The land system and LRA reports provide very little slope information but do describe the landform for each mapping unit. These landform descriptions have been converted into standard landform categories defined in the Australian soil and land survey field handbook (McDonald *et al* 1990). The standard landform categories have typical slope ranges which have been used to estimate slope categories for the mapping units within the CSG field.

4.6.4 Erosion hazard rating

An erosion hazard rating has been determined to account for the high level of disturbance associated with most construction activities proposed for the CSG field. Table 11 summarises the decision matrix developed to assign an erosion hazard rating to soil management groups. Figure 9 shows the erosion hazard rating for the entire study area.

Only 13% of the CSG field is rated as having no erosion hazard. This land contains various cracking clays on level to gently undulating plains surrounding the Condamine River and along the Moonie Highway in the south-east.

The erosion hazard varies from nil to minor or from nil to moderate on approximately 11% of the CSG field. This land is either dominated by *Melonhole clays* or contains various combinations of cracking clays, *Deep sands and sandy loams*, *Sandy or loamy gradational soils* and dispersive texture contrast soils on level to gently plains. They are scattered throughout the entire study area.

The remaining land throughout the CSG field has at least a minor hazard rating and parts are rated extreme.

Almost 26.5% of the CSG field has a minor to moderate hazard rating due to the predominance of dispersive texture contrast soils on level to gently undulating plains or due to a combination of *Dark cracking clays* with *Loamy texture contrast soils (non dispersive)* on undulating rises and plains.

Almost 8% has a minor to severe hazard rating due to the combination of *Grey-brown non-cracking clays* with *Grey-brown cracking clays* on undulating plains and rises or the combination of dispersive texture contrast soils with less erodible soils on undulating plains, rises and occasional low hills.

Almost 2% of the CSG field has a moderate to severe or moderate to extreme erosion hazard. The moderate to severe rating has been assigned to low hills and rises with a combination of *Shallow loams and clay loams* and *Loamy texture contrast soils (non dispersive)* on low hills and rises. The moderate to extreme rating belongs to various combinations of *Shallow sands and sandy loams* and dispersive texture contrast soils occupying low hills, rises, undulating plains and plateau remnants.

Just under 32% of the CSG field has a severe to extreme erosion hazard. This land consists of low hills, rises and undulating plains with dispersive texture contrast soils as the predominant soil management group or has steeper terrain with a combination of *Shallow sands and sandy loams*, *Shallow loams and clay loams* and dispersive texture contrast soils.

Table 11. Decision matrix for rating erosion hazard

Soil erodibility	Landform-slope categories [1]	Constraint rating
Very low to low	Steep to precipitous mountains, hills, dissected plateaus and plateau scarps	Extreme
Moderate	Rolling hills and low hills	
High to very high	Undulating low hills and rises	
Very low to low	Rolling mountains, hills and low hills	Severe
Moderate	Undulating low hills and rises	
High to very high	Undulating rises and plains	
Very low to low	Undulating low hills and rises	Moderate
Moderate	Undulating rises and plains	
High to very high	Level to gently undulating plains	
Very low to low	Undulating rises and plains	Minor
Moderate	Level to gently undulating plains and plateau surfaces	
High to very high	Level plains	
Very low to low	Level to gently undulating plains and plateau surfaces	Nil
Moderate	Level plains	

Notes:

1. Slope categories are from the second edition of the Australian soil and land survey field handbook (McDonald *et al* 1990):

Steep to precipitous	≥ 32%
Rolling	10-32%
Undulating	3-10%
Gently undulating	1-3%
Level	<1%

4.7 Soil fertility

Soil fertility is a prime determinant of the ability to successfully revegetate disturbed areas. Low soil fertility can result in:

- inadequate establishment of plant species used for revegetation;
- on-going exposure of bare land in poorly rehabilitated areas;
- increased soil erosion due to greater exposure of bare land; and
- damage to infrastructure through soil erosion.

Soil fertility is usually determined using laboratory analyses of the surface layer as plant roots for most species are concentrated in the top one to two hundred millimetres of soil.

Table 12 summarises the analytical results for samples collected as part of this study. Full results are presented in Attachment B.

Table 12. Soil fertility analytical results

Soil group	pH	EC [1] (dS/m)	CEC [2] (meq%)	Exch Ca [3] (meq%)	Exch K [3] (meq%)	Tot N [4] (%)	Avail P [5] (mg/kg)
Shallow sands and sandy loams	3.9	0.06	3	0.33	0.16	0.95	4
Deep sands and sandy loams	7.0	0.09	12	8.4	1.2	1.55	11
Sandy or loamy gradational soils	4.2	0.04	3	0.31	0.12	0.81	4
Loamy TC soils (non dispersive)	5.7-6.0	0.04-0.31	5-15	2.6-8.6	0.18-1.7	0.41-1.49	4-9
Loamy TC soils (dispersive) - on recent alluvium	5.4	0.06	7	4.6	0.55	0.95	25
Loamy TC soils (dispersive) - on other material	5.6-6.6	0.06-0.11	5-15	0.98-11.7	0.40-1.1	0.54-1.62	4-9
Sandy TC soils (dispersive) - on other material	4.9-6.3	0.04-0.30	2-8	1.1-4.5	0.10-0.54	0.41-0.54	3-8
Grey-brown cracking clays	6.7	0.21	33	25.0	1.9	2.70	32
Dark cracking clays	6.2-7.9	0.08-0.26	15-33	8.2-19.5	0.59-1.3	0.61-1.22	5-23
Melonhole clays	5.7-6.3	0.13-0.34	15-25	5.9-17.3	0.65-1.3	1.35-2.43	8-41

Notes:

1. EC represents Electrical Conductivity which is a measure of soil salinity.
2. CEC represents Cation Exchange Capacity and is a measure of the soil ability to retain positively charged nutrients (such as calcium, magnesium, potassium, ammonium) for use by plant roots, as well as sodium and aluminium; CEC is measured in milliequivalents per 100g soil (meq %).
3. Exch Ca and Exch K represent exchangeable calcium and exchangeable potassium respectively, and are measured in meq %.
4. Tot N represents Total nitrogen and is a measure of the total nitrogen reserves in the soil.
5. Avail P represents available phosphorus and is a measure of the amount of phosphorus, expressed in milligrams per kilogram of soil (mg/kg), that is readily available for plant use

Table 12 shows that the clay soils generally have higher capacity to retain positively charged nutrients (referred to as CEC) and thus higher calcium and potassium levels than most other soils. They also have quite high phosphorus levels.

For the other soils, those overlying recent alluvium generally have higher phosphorus levels than similar soils developed on little-weathered sedimentary rocks, deeply weathered material or unconsolidated sediments.

The data in Table 12 generally support information available in the land system and LRA reports. Soil fertility of each soil management group has been assessed using all available information but based solely on the three major nutrients - nitrogen, phosphorus and potassium.

Soil fertility levels are summarised for each soil management group in Table 13.

Total nitrogen reserves in each soil management group are generally quite variable and are strongly influenced by vegetation cover and land use history. This variability probably reflects the diverse range of sites that have been sampled to collate these ratings.

Available phosphorus is less variable than nitrogen and exchangeable potassium levels are the least variable. Levels of these nutrients have been shown to be closely related to source geology and history of weathering throughout Queensland, though land use history still has some effect.

Table 13. Soil fertility levels and constraint rating

Soil group	Tot N [1]	Avail P [2]	Exch K [3]	Constraint rating
Shallow sands and sandy loams	Low-very high	Very low	Low	Severe
Shallow loams and clay loams	Low-very high	Very low	Low	Severe
Deep sands and sandy loams	Low-very high	Low-medium	Medium-very high	Minor
Sandy or loamy gradational soils	Low-high	Very low	Low-high	Severe
Loamy TC soils (non dispersive)	High-very high	Very low-low	Low-very high	Moderate
Loamy TC soils (dispersive) - on recent alluvium	Low-very high	High	High	Minor
Loamy TC soils (dispersive) - on other material	High-very high	Very low-low	Medium-very high	Moderate
Sandy TC soils (dispersive) - on recent alluvium	Low	Very low-low	Medium-high	Moderate
Sandy TC soils (dispersive) - on other material	Very low-very high	Very low-low	Low-medium	Severe
Brown cracking clays	Low	Low	Very high	Moderate
Grey-brown cracking clays	Low-very high	Medium	High-very high	Minor
Grey-brown non-cracking clays	Low-very high	Medium	High-very high	Minor
Dark cracking clays	Low-very high	Low-very high	High-very high	Minor
Melonhole clays	Low-very high	Low-very high	High-very high	Minor

Notes:

1. Tot N represents Total nitrogen and is a measure of the total nitrogen reserves in the soil.
2. Avail P represents available phosphorus and is a measure of the amount of phosphorus that is readily available for plant use.
3. Exch K represents exchangeable potassium and is a measure of the amount of potassium that is readily available for plant use.

Based on nitrogen, phosphorus and potassium levels, a constraint rating has been determined for each soil management group that reflects the likelihood of having plant deficiencies in any of these major nutrients. The ratings are given in Table 13 for each soil management group and the fertility constraint across the entire study area is shown in Figure 10.

All soil management groups have a low to very low level of at least one of the major nutrients and so all have been given a soil fertility constraint of some degree.

Most of the CSG field (60%) has a severe or moderate to severe soil fertility constraint. This land is dominated by *Shallow sands and sandy loams*, *Shallow loams and clay loams* or *Sandy texture contrast soils (dispersive)* that aren't developed on recent alluvium.

Around 6.5% has a moderate constraint and is dominated either by *Brown cracking clays* (north-west of Miles), *Loamy texture contrast soils (dispersive)* which aren't overlying recent alluvium but are scattered throughout the entire study area or by *Sandy texture contrast soils (dispersive)* that are on recent alluvium flanking the major streams.

Approximately 30% of the CSG field has a minor soil fertility constraint. Land with a minor constraint is dominated by *Dark cracking clays*, *Grey-brown cracking clays*, *Melonhole clays* or *Deep sands and sandy loams* and *Loamy texture contrast soils (dispersive)* overlying recent alluvium. This is level to gently undulating land, mostly on either side of the Condamine River or along the Moonie Highway in the south-east corner.

Almost 3.5% of the CSG field has a minor to moderate constraint due to a combination of various cracking clays with dispersive texture contrast soils or the combination of *Loamy texture contrast soils (dispersive)* and *Sandy texture contrast soils (dispersive)* overlying recent alluvium.

A minor to severe soil fertility constraint has been assigned to 0.5% of the CSG field where *Grey-brown cracking clays* are closely associated with *Shallow loams and clay loams*.

4.8 Topsoil depth

This refers to the depth of soil material within a landscape that is suitable for use as "topsoil" during rehabilitation, especially revegetation, activities. Use of unsuitable material as "topsoil" during rehabilitation can decrease establishment and growth of ground cover and thus increase the erosion hazard through the presence of:

- coarse peds and clods that can't be worked to produce an adequate seedbed;
- highly erodible material; or
- material that is too saline for plant growth.

The Queensland Main Roads Department has issued specifications for identifying and classifying "topsoil" material that is suitable for use as planting media (Main Roads 2006).

These specifications have been adopted for rating topsoil depth as a constraint within the CSG field. According to the specifications, any soil material from sand to light clay in texture is suitable for use as planting media, though amelioration may be required. Amelioration can be undertaken to raise plant nutrients to adequate levels and to reduce acidity or any tendency to disperse.

Soils of medium to heavy clay texture are usually not used for revegetation as they are:

- too coarsely structured to maintain sufficient contact of moist soil with small seeds;
- only slowly permeable and can quickly saturate; and
- very hard when dry, thus restricting plant establishment.

Both surface and subsurface layers may be used as "topsoil" but fertility is usually lower below the surface layer and amelioration is usually required for subsurface layers to ensure successful revegetation.

Table 14 presents the decision matrix used to determine the severity of "topsoil depth" as a constraint to stripping for later use as planting media.

Table 14. Decision matrix for rating "topsoil" depth

"Topsoil" depth [1] (%)	Description	Constraint rating
Nil [2]	Not usable	Not usable
≤100	Very thin	Extreme
<100-300	Thin	Severe
100-300	Thick	Minor
≥300	Very thick	Nil

Notes:

1. "Topsoil" consists of any surface layer and subsurface layer with a texture of sand to light clay.
2. Nil refers to clay soils with a texture in the surface layer that is predominantly heavier than light clay.

Figure 11 shows "topsoil" depth across the entire study area.

Mapping units with the *Dark cracking clays* or *Melonhole clays* as the main soil management group are considered not usable due to their medium to heavy clay textures in the surface layer. These units represent 21.5% of the CSG field.

The *Grey-brown cracking clays*, *Grey-brown non-cracking clays* and *Brown cracking clays* have light to medium clay textures in their surface layers and may be partly usable. However, suitable "topsoil" is only very thin to thin in these soil management groups and it will be extremely difficult to remove very thin “topsoil” for use as planting media without including any unsuitable subsoil material below. These are the main soil management groups on 7% of the CSG field.

The *Loamy texture contrast soils (dispersive)* have thin “topsoil”, as do the *Shallow sands and sandy loams* and *Shallow loams and clay loams*. They are the main soil management groups on almost 7% of the CSG field. The constraint is rated as severe as stripping thin “topsoil” may not only include unsuitable subsoil in the planting media but also leave highly erodible subsoil exposed within the stripped areas.

Areas with thick to very thick “topsoil” cover almost 18% of the CSG field and have no or only minor constraint. These areas consist of mapping units with *Sandy texture contrast soils (dispersive)*, *Sandy or loamy gradational soils* or *Deep sands and sandy loams* as the main soil management groups.

The remainder of the CSG field (47%) consists of differing soil combinations that result in quite variable “topsoil” thickness and thus quite variable constraints. Detailed site inspection will be required in these areas to determine the depth of usable “topsoil”.

4.9 Salinity

Salinity refers to the concentration of soluble salts in the soil water. Soil sodicity refers to the relative abundance of sodium retained on clay surfaces where it can exchange with other ions in the soil water. High levels of soil sodicity primarily affect dispersion of clay particles, thus increasing soil erodibility and decreasing permeability. Therefore, the effects of soil sodicity are discussed section 4.6.

Elevated soil salinity within the root zone can retard plant growth. Very high to extreme levels of salt can also corrode concrete and steel foundations and steel pipe. With regard to the proposed development, soil salinity can:

- reduce revegetation efforts on disturbed areas;
- affect plant growth surrounding disturbed areas if saline water is released from excavations and thus increase erosion hazard; and
- corrode inappropriately designed foundations for infrastructure.

Available soil information and supporting data in Table 9 indicate that particular soil management groups have elevated levels of soluble salts in their profiles.

Salinity is generally low to very low in the surface layer of all soils except the *Melonhole clays* and *Loamy texture contrast soils (non dispersive)*. Surface layer salinity varies from low to medium in the *Melonhole clays* and is medium in the *Loamy texture contrast soils (non dispersive)*. One sample from the *Sandy texture contrast soils (dispersive)* also has medium salt levels but all other surface layer samples from this group are low to very low.

Salinity remains low to very low through the soil profile of *Shallow sands and sandy loams*, *Shallow loams and clay loams*, *Deep sands and sandy loams* and *Sandy or loamy gradational soils*.

Salinity generally increases in all other soil management groups and reaches the following levels deep in the subsoil:

- high in some profiles of the *Loamy texture contrast soils (non dispersive)*;
- low to high in the *Loamy texture contrast soils (dispersive)*;
- medium to extreme in the *Sandy texture contrast soils (dispersive)*;
- medium in the *Brown cracking clays*;
- low to medium in the *Grey-brown non-cracking clays*;
- very high to extreme in the *Grey-brown cracking clays*;
- low to medium in the *Dark cracking clays*; and
- medium to very high in the *Melonhole clays*.

Salinity at or near the surface is not a significant constraint within the CSG field. However, any construction activity that disturbs the saline subsoil and brings it to the surface or just below can impact upon rehabilitation and revegetation and result in soluble salts being leached from the soil material and moved into local waterways.

Subsoil salinity categories and their corresponding constraint to construction activities within the CSG field are presented in Table 15.

Table 15. Decision matrix for rating subsoil salinity

Subsoil salinity [1]	Constraint rating
Very high to extreme	Severe
Medium to high	Moderate
Low to medium	Minor
Low to very low	Nil

Notes:

1. Subsoil salinity categories are from the Queensland salinity management handbook (DNR 1997).

Figure 12 shows where subsoil salinity is a constraint across the entire study area. Approximately 16.5% of the CSG field has a severe constraint. This is land dominated by *Grey-brown cracking clays* and *Sandy texture contrast soils (dispersive)*.

Another 18% of the CSG field has a moderate to severe constraint and is land with a combination of *Loamy texture contrast soils (dispersive)* with *Grey-brown cracking clays* or with *Sandy texture contrast soils (dispersive)*.

Approximately 6.5% has a minor to severe constraint due to the combination of *Grey-brown cracking clays* with *Grey-brown non-cracking clays*.

Almost 26% has a combination of severe constraint on *Sandy texture contrast soils (dispersive)* and nil constraint on associated *Shallow sands and sandy loams* or with *Shallow loams and clay loams*. A further 0.6% also has a nil to severe constraint due to the combination of *Grey-brown cracking clays* and *Shallow loams and clay loams*.

This land that is either entirely or partly severely constrained occurs extensively throughout the CSG field.

Just over 14% of the CSG field has either no subsoil salinity constraint (dominated by *Shallow sands and sandy loams* and *Shallow loams and clay loams*) or a minor constraint (dominated by *Dark cracking clays*). The largest areas are between Brigalow and Condamine and along the Moonie Highway in the south-east corner.

The remainder of the CSG field is characterised by a minor to moderate constraint and consists of *Brown cracking clays*, *Dark cracking clays*, *Melonhole clays* and *Loamy texture contrast soils (dispersive)* in various combinations.

4.10 Dust generation

All soils have a capacity to create dust when the vegetative cover is removed and when they are subjected to vehicular traffic or disturbance by machinery. Dust can impact upon:

- occupational health and safety of workers;
- health and working conditions of agricultural workers within the surrounding areas;
- efficiency and working life of nearby machinery; and
- crop and pasture production where dust conditions are extreme.

Sands and soils with a clayey texture in the surface layer create the least dust whereas surface layers dominated by fine sand and silt can generate overwhelming clouds of “bulldust”.

The soil management groups within the CSG field have been rated according to their capacity to generate dust.

The rating system has been based solely on texture of the surface layer and, in particular, the presence of fine sand or silt.

The decision matrix developed to rate dust generation as a constraint is presented in Table 16 and the capacity to generate dust across the entire study area is shown in Figure 13.

Table 16. Decision matrix for rating dust generation

Surface layer texture	Constraint rating
Loamy (fine) sand, Sandy (fine) loam, Loam, Sandy (fine) clay loam	Severe
Sand, Sandy clay loam, Clay loam	Moderate
Clay	Minor

Areas mapped as containing at least 70% clay soils cover approximately 25.5% of the CSG field and have only a minor capacity for dust generation. This land is scattered throughout the study though mostly occurring south of the Warrego Highway between brigalow and Condamine.

A further 1% of the area has a minor to moderate capacity. This land contains *Shallow loams and clay loams* in combination with either *Shallow sands and sandy loams* or *Grey-brown cracking clays* in association with *Shallow loams and clay loams*.

However, 40% of the CSG field has a capacity to generate severe bulldust. This represents the entire area dominated by *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)*.

The remaining 33.5% has either a minor to severe or a moderate to severe constraint and is land with different combinations of *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* with other soils.

Land with some degree of severe constraint occurs extensively throughout the entire study area.

4.11 Loss of GQAL and other cropping land

There are approximately 183,910 ha of GQAL within the CSG field. Most of the GQAL is in the centre of the CSG field roughly bounded by Miles, Brigalow, Kogan and Condamine though substantial areas also occur along the Moonie Highway in the south-east and between Wandoan and North Dulacca.

Cropping patterns are evident in the satellite imagery displayed in Figure 14. The figure reveals that around 80-90% of the GQAL east and south of Miles is currently being cropped. Much of the adjacent land is also being cropped though not deemed GQAL by NRW.

The original study area forms part of the extremely important "Downs" agricultural zone that extends west from Toowoomba to Miles. The generally fertile clay soils and climate of this zone are capable of growing a wide variety of crops (Harris *et al* 1999).

Summer and winter grain cropping and cotton production are major agricultural land uses, especially on the clay soils. Cultivation for cropping and/or sown pasture is also carried out to some extent on many other soil management groups. A number of other important industries such as horticulture and floriculture have developed in the area due to the diversity of soils, proximity to markets and favourable climate (Harris *et al* 1999).

Despite its high productivity, the cropping land of this region is also prone to significant soil erosion and even clay soils on very gently sloping land have an erosion hazard (see section 4.6). Land managers have controlled erosion on sloping land by placing run-off control structures in their cultivation paddocks as well as changing cultivation practices to protect the ground surface and reduce raindrop splash and run-off between these structures.

Construction and ongoing production activities associated with this proposal have the capacity to impact on cropping by:

- reducing the actual area that can be cropped;
- impeding optimal farm layout for efficient crop production;
- interrupting essential physical run-off control measures that are designed to minimise erosion;
- modifying overland flow patterns – particularly via concentration of runoff, changes in runoff times of concentration and increased velocity along access tracks and around wellheads; and
- introducing weed species into the cultivation during both construction and ongoing maintenance activities.

Associated with the actual loss in production area will be impacts on farming and grazing practises on contiguous areas.

Based on a wellhead density of 1 every 750 m and wellhead clearing of 100 m by 100 m, it is calculated that wellheads within cropping land will create an obstruction of up to 1 ha in size every 36 ha during drilling. If partial restoration reduces the hardstand area to 10 m by 10 m for wellhead operation, a 100 square metre obstruction will be created for every 36 ha during production. In addition, gravelled access tracks of around 4 m width will be formed between each well. Table drains on either side of the access tracks will also be unusable for cropping. If wells are installed on a fixed 750 m grid, access tracks plus 1 m wide table drains could cover 1.8 ha of land for every 5 wells.

The size of individual cultivation paddocks varies within the CSG field but many are 70 to 100 ha. Under the proposal, each of these paddocks will contain 2 to 3 wellheads plus around 1 ha of gravel tracks. The total area taken out of crop production will be around 3-4 ha during drilling, representing 3-6% of the paddock. During the gas production phase, the total area removed from crop production in an individual paddock would reduce to 1%, if partial restoration is performed.

Thus, construction and production activities have substantial potential to:

- reduce the productive area and increase the costs of crop production;
- lower the value of the land itself;
- increase erosion and thus lower the value of cropping land as well as increase sedimentation of the nearby waterways; and
- be a continuing source of weed species for the production areas.

Loss of GQAL and other cropping land under this proposal represents a significant impact. However, gas well construction will occur over time and not all cropping land will be affected at the same time. Location of the wells and other infrastructure will be determined during land holder consultation. These strategies will help to reduce the impact.

There will be less effect on grazing land. Construction and production activities will reduce the area available for grazing and may impede stock management practices such as mustering. Some possible interruption to overland flow may also occur, especially due to construction of access tracks. However, overall constraints and impact should be minor.

4.12 Overall issues for each soil management group

The range of constraints and impacts identified for each soil management group is summarised in Table 17.

The table shows that constraints and impacts not only differ between soil management groups but can also vary within a particular group. Variation within a particular soil management group can be due to three reasons. Firstly, some soil features such as profile depth can vary sufficiently within one group to affect the severity of the constraint. Secondly, the constraint or impact is primarily determined by a landscape feature other than soil type, such as topography, and the soil management group occupies differing landscape elements. Thirdly, the constraint or impact may be a combination of soil features and landscape element, such as erosion hazard and soil fertility, and the soil management group has several combinations.

Table 17 shows that *Shallow sands and sandy loams* and *Shallow loams and clay loams* have the largest number of moderate, severe or extreme constraints and impacts. In contrast, the *Sandy or loamy gradational soils* and various clay soils have the fewest, or least severe, constraints and impacts. However, the potential loss of substantial areas of highly productive cropping land on the clay soils is an extremely important impact for the region.

Erosion hazard, soil fertility and dust generation are the only constraints and impacts associated with the dispersive texture contrast soils that are rated as moderate or worse. If the erosion hazard is not appropriately managed, resultant erosion and sedimentation can have a pronounced impact on the environment and the soil fertility constraint associated with these soils means that the appropriate management procedures must involve correct revegetation measures.

Table 17. Development issues for each soil management group

Soil group	Topography [1]	Depth to bedrock	Stoniness and rock outcrop	Erosion hazard [2]	Soil fertility [3]	Topsoil depth [4]	Salinity	Dust generation	Loss of GQAL [5]
Shallow sands and sandy loams	Nil-severe	Severe-extreme	Severe-extreme	Moderate-extreme	Severe	Thin	Nil	Minor	Nil
Shallow loams and clay loams	Nil-severe	Severe-extreme	Severe-extreme	Minor-extreme	Severe	Thin	Nil	Moderate	Nil
Deep sands and sandy loams	Nil	Nil	Nil	Nil	Minor	Very thick	Nil	Minor	Nil-severe
Sandy or loamy gradational soils	Nil	Nil-moderate	Nil	Moderate	Severe	Thick	Nil	Moderate	Nil
Loamy TC soils (non dispersive)	Nil	Nil	Nil	Moderate	Moderate	Thin	Moderate	Severe	Nil-severe
Loamy TC soils (dispersive)	Nil-minor	Nil-moderate	Nil	Minor-extreme	Minor-moderate	Thin	Moderate	Severe	Nil-severe
Sandy TC soils (dispersive)	Nil-moderate	Nil-moderate	Nil	Minor-extreme	Moderate-severe	Thick-very thick	Severe	Severe	Nil-severe
Brown cracking clays	Nil	Nil	Nil	Nil	Minor	Thin	Moderate	Minor	Severe
Grey-brown cracking clays	Nil	Nil-moderate	Nil	Nil-minor	Minor	Very thin	Severe	Minor	Nil-severe
Grey-brown non-cracking clays [6]	Nil	Nil-moderate	Severe	Minor-severe	Minor	Thin	Minor	Minor	Nil-severe
Dark cracking clays	Nil	Nil-moderate	Nil	Nil-minor	Minor	Not usable	Minor	Minor	Severe
Melonhole clays	Nil	Nil	Nil	Nil-minor	Minor	Not usable	Moderate	Minor	Nil-severe

Notes:

1. The topography constraint is based on landform and slope categories and will vary for individual soil management groups that occur across a wide range of landforms.
2. Erosion hazard rating is a product of soil erodibility and topography factors and thus varies within each soil management group according to landform characteristics.
3. Soil fertility varies for the dispersive texture contrast soils depending on geology; profiles overlying recent alluvium have higher fertility status and a lower constraint than all other profiles.
4. The *Grey-brown cracking clays*, *Grey-brown non-cracking clays* and *Brown cracking clays* have light to medium clay textures in their surface layers and may have partly usable “topsoil”.
5. Loss of GQAL is considered severe on all existing and potential cropping land but some soil management groups are only partly cropped or only partly represent GQAL.
6. *Grey-brown non cracking clays* are not the main soil management group in any terrain unit and hence their constraints are discounted to some extent by those assigned to the main soil management group.

5. Mitigation measures required

A range of mitigation measures are available for the constraints and impacts identified in section 4. In the main, measures recommended for the CSG field are already used for mitigation in similar construction and production activities. However, a few have been adapted from existing industry-acceptable inputs to address the special constraints and impacts associated with the QC LNG proposal.

5.1 Universal measures for the entire area

Several measures can be applied universally throughout the CSG field to ensure environmental impacts are minimised.

5.1.1 Removing by-products of drilling

Information supplied by Queensland Gas Company indicates that drilling involves a number of processes that result in by-products being dumped (some temporarily) on site.

Depending upon the type of drill rig in use, mud pits may or may not be required. Many of the larger drill rigs in use today are fully self-contained with in-built water and drilling mud tanks. Where rigs are not fully-self contained, drill pits or sumps (i.e. 3 lined pits approximately 7 m x 8 m x 1.5 m) are required for storing water for drilling, recirculation of water into the mud system and collection of drill cuttings.

Water is used for lubrication of cutting fluids and for washing and conditioning of the hole. This water is sourced externally and stored at site either in tanker trucks or in constructed drill pits/sumps. Where drill pits are used, they are constructed with upslope drainage to divert stormwater run-off around the pit.

Chemicals that are occasionally used in the drilling fluid are:

- Potassium chloride (KCl);
- "Tuff Trol", an organic polymer; and
- "Tuff CRP", a copolymer of acrylamide and sodium acrylate that is classified as not hazardous.

Salinity levels in the subsoil are at least medium in many soil groups and groundwater salinity varies from low to medium. Saline soil water and groundwater are potential by-products of drilling which may be temporarily stored in drill pits.

Each operational wellhead will only require about 100 square metres and the initial 100 m x 100 m drill sites can be partially restored once the wells commence production. Partial restoration will involve:

- dewatering, drying and backfilling of drill pits (where used);
- removal of surplus hardstand gravel material;
- partial ripping and respreading of topsoil on cleared areas not required during production to promote revegetation and stabilisation of the edges;
- ripping excess roads and tracks used during drilling unless otherwise requested by the landholder;
- removal of excess material off-site;
- respreading of stockpiled topsoil; and
- reseeding and fertilising as required and in accordance with landowner requirements.

Where drill pits are used, these will be dewatered and backfilled as soon as possible on completion of the drilling. However, fine material will be settled and the excess water in the pit disposed of by irrigation to pasture where:

- KCl concentration in the mud sump is less than 25,000 ppm; and
- Other Total Dissolved Salts including sodium chloride (NaCl) is less than 5,000 ppm; and
- the landholder agrees.

The only long-term impact upon land around the drill site will be the possible irrigation of excess water and disposal of fine material from a drill pit. The total salinity of the excess water and fine material may be up to 30,000 ppm TDS which is equivalent to an Electrical Conductivity (EC) of 40-50 dS/m.

In comparison, seawater has, on average, a salinity of about 35,000 ppm. Soils with an EC rating of more than 0.93 dS/m in sands and sandy loams, or with more than 1.87 dS/m in medium to heavy clays, are considered to be extremely saline for plant growth (DNR 1997).

Excess water and fine material from the drill pit should not be spread onto nearby land unless it can be applied over a large enough area to ensure the resultant salinity on the soil surface will not exceed 0.1 dS/m, which is equivalent to a low to very low salinity rating for all soil types.

5.1.2 Timing of major disturbance

An erosion hazard has been identified on 87% of the CSG field (see section 4.6) and as rainfall is highly seasonal in southern Queensland, careful timing of major earth works can be significant in reducing actual erosion.

The Queensland Main Roads Department has analysed long-term rainfall records to determine the monthly and annual erosive potential (termed erosivity) throughout the State (Main Roads 2002). Rainfall erosivity at Dalby between the four-month, November to February, period represents almost ⅔ of the average total erosivity for an entire 12 months.

Thus, avoiding major earth works programmes between November and February can substantially reduce the risk of erosion.

However, if earthworks must be undertaken during this period, it is essential that all standard control measures (section 5.1.3) be adopted and special measures be implemented on sloping areas with dispersive texture contrast soils (section 5.2.1).

5.1.3 Adopting standard erosion control measures

Because of the widespread erosion hazard, standard erosion control measures should be implemented with all works that disturb the land surface where slopes exceed 1%.

These measures include:

- minimising access and disturbance to only essential areas;
- bunding all bare earth areas to divert upslope stormwater run-off from around the site;
- incorporating run-off control devices to reduce slope length on access tracks and on other disturbed areas of bare ground;

  (Such devices include "whoa boys", berms, sediment fences, straw bale banks or geotextile socks of at least 300 mm diameter filled with coarse filter media).
- only undertaking any stripping and stockpiling of "topsoil" immediately before starting bulk earthworks;
- ensuring "stockpiles" are constructed on the contour, protected from run-on water with diversion banks or similar device upslope, and formed with run-off control devices immediately down slope;
- revegetating or rehabilitating disturbed areas as soon as works are completed;
- designing channels/drains and inlet and outlet works to convey water at least up to the design peak flow;
- incorporating check dams and/or sediment retention basins within major development sites (central processing plants, accommodation camps and administration centres) to slow peak discharge and reduce sediment load in water entering the local waterways.
- placing all water quality and quantity control structures above the riparian zone;
- designing sediment retention basins to adequately handle dispersive soil material in the dispersive texture contrast soils and to handle clayey subsoil material in all other areas; and
- installing energy dissipaters at drainage outlets, including the outlet to the local watercourses.

5.1.4 Stripping and re-using topsoil

"Topsoil" should be stripped prior to excavating pipeline trenches and evaporation ponds or creating hardstand areas. The stripped material should be stockpiled for reuse during revegetation and rehabilitation of these areas.

As described in section 4.8, not all surface layers within the CSG field are suitable for reuse as "topsoil". Surface layers with medium clay texture or heavier are unsuitable for reuse and any dispersive soil material is also unsuitable.

Table 18 lists recommended stripping depths for areas to be excavated or built over. Stripping these areas may provide insufficient "topsoil" material for later use, requiring additional areas outside the earth works footprint to be stripped. Less material should be stripped from these additional areas so that a minimum 100 mm of suitable "topsoil" material is left on-site to encourage revegetation and to minimise erosion.

The variation in recommended stripping depth means that detailed field checking should be undertaken before areas are stripped to determine the appropriate depth.

Where there is insufficient material for stripping on-site, suitable "topsoil" will have to be imported from elsewhere. Medium to heavy clay textures predominate in the surface layers of *Melonhole clays*, *Dark cracking clays* and partly in the *Grey-brown cracking clays*, *Grey-brown non-cracking clays* and *Brown cracking clays*. Medium to heavy clay textures are generally not usable for plant species commonly used in revegetation and a modified selection of plant species will have to be used on these soils.

Table 18. Recommended stripping depths

Soil group	Stripping depth [1] (mm)	
	Earth works footprint	Outside footprint
Shallow sands and sandy loams	50-300	0-200
Shallow loams and clay loams	50-300	0-200
Deep sands and sandy loams	150-400	50-300
Sandy or loamy gradational soils	300-500	200-400
Loamy TC soils (non dispersive)	100-300	0-200
Loamy TC soils (dispersive) - on recent alluvium	50-150	0
Loamy TC soils (dispersive) - on other material	100-300	0-200
Sandy TC soils (dispersive) -on recent alluvium	300-500	200-400
Sandy TC soils (dispersive) - on other material	100-500	0-400
Brown cracking clays [2]	50-150	0
Grey-brown cracking clays [2]	50-100	0
Grey-brown non-cracking clays [2]	50-100	0
Dark cracking clays	0	0
Melonhole clays	0	0

Notes:

1. The recommended stripping depth includes suitable soil material from the surface layer and from the underlying subsurface layer (if present).
2. The *Grey-brown cracking clays*, *Grey-brown non-cracking clays* and *Brown cracking clays* have light to medium clay textures in their surface layers and may be only partly usable.

Material that is suitable for stripping and stockpiling has low to very low fertility (see section 4.7) and will require soil ameliorants to ensure successful growth of plants. The minimum requirement would be amelioration with an NPK fertiliser but using a product that also contains calcium would be preferable. Organic matter levels vary low to high in the surface layers (see Attachment B) but organic matter content can be lowered during stockpiling. All stockpiled material would benefit from incorporation of composted organics with a nitrogen drawdown index (NDI) > 0.5. Use of this organic amendment will increase soil water holding, soil drainage (leaching) and nutrient retention and help stabilise the topsoil to resist erosion and promote healthy plant growth. If controlled or slow release fertilisers are applied the composted organics will ensure nutrients are not leached from the root zone. A suggested rate of incorporation is 30% by volume of compost.

Measures need to be taken to ensure dispersive and/or heavy clay subsoil are not stripped and mixed with the “topsoil”. Inclusion of these materials can result in a hard setting, or crusting planting media that impedes seed germination, restricts water entry and enhances erosion of the revegetated area.

As mentioned previously, stockpiles should be constructed on the contour, protected from run-on water with diversion banks or similar device upslope, and formed with run-off control devices immediately down slope.

The duration of stockpiling should be minimised to reduce nutrient rundown and colonisation by weeds. Stockpiling should not be commenced until immediately before bulk earthworks start and revegetation or rehabilitation of disturbed areas should proceed as soon as works are completed.

However, stockpiles that are to remain throughout the production period for use during decommissioning should be sown with an appropriate plant mix and managed to ensure adequate ground cover is maintained. This will minimise erosion and leaching of nutrients from the soil material and will provide a seed source when the material is eventually used. Such stockpiles can be landscaped into low mounds to improve visual amenity and reduce dust, noise and wind.

5.1.5 Minimising impact at minor watercourse crossings

Minor watercourses that drain to the major streams and creeks in the area generally have soils and soil conditions similar to the adjoining land – sometimes with a thin veneer of unconsolidated alluvium. Crossings for access tracks and pipelines on minor watercourses require special attention because many of the streams will have dispersive texture contrast soils or clay soils on their banks and bank slopes can be very steep, creating a severe to extreme erosion hazard.

Tracks should only cross watercourses at points where the turbulence of stream flow is least and there is no active undercutting of either bank and no dumping of sediments within the stream bed. Crossing at bends in stream or close to where two streams meet should be avoided. Such areas often represent sections of active, unstable stream flow with a potential high risk of stream bank erosion if disturbed.

At stream crossing points, there should be as little disturbance to the stream bank as possible. Unless absolutely necessary, vegetation on the stream bank should not be disturbed and any cleared vegetation should not be placed in the watercourse. Following disturbance, these crossing points should be restabilised as soon as possible by refilling and slightly compacting, capping with at least 200 mm of suitable "topsoil" and revegetating the site.

5.2 Special measures

In addition to measures described in section 5.1, which should be applied universally across the entire study area, a number of special measures are recommended for specific areas.

5.2.1 Dissected terrain

There is a moderate to severe topography constraint on approximately 7,385 ha (1.6% of the entire study area). This land comprises hills and mountains north of Miles with *Shallow sands and sandy loams* and *Sandy texture contrast soils (dispersive)* as the major soil management groups and dissected plateaus south of the Moonie Highway where *Sandy texture contrast soils (dispersive)* are the main soil management group.

Building hardstand areas for wells, foundations for ancillary facilities and access tracks will involve extensive cut and fill operations and may require specialist equipment.

This land also has very shallow depth to bedrock and a severe to extreme stoniness and rock outcrop constraint. The presence of dispersive texture contrast soils on steep slopes also creates an extreme erosion hazard. The soils have severe soil fertility constraints and disturbed areas will not revegetate readily without boosting the soil fertility.

It will be extremely difficult to control erosion during construction and to revegetate and rehabilitate any disturbed areas. There is a high risk of pipelines being exposed and undermined after a few large rainfall events.

It would be preferable to exclude this land from development but if it must be included appropriate mitigation measures should include:

- avoiding location of ancillary facilities within the area;
- keeping access tracks to a minimum;
- locating any essential tracks on gentle grades diagonally across the slope rather than perpendicular to it;
- minimising drainage line crossings or, where necessary, locating entry and access points at an angle to the drainage line and leaving sufficient capacity for uninterrupted stream flow;
- incorporating all special erosion control measures described in section 5.2.2; and
- incorporating general all-purpose fertilisers into local "topsoil" material used as planting media during revegetation or importing special planting media.

5.2.2 Sloping areas with dispersive texture contrast soils

Any land with slopes above 1% and containing dispersive texture contrast soils has a moderate to extreme soil erosion hazard. Special precautions in addition to those described in section 5.1 need to be adopted on this land:

- Clearing and grubbing operations should avoid inverting the soil, leaving clay subsoil on top.
- Any clay subsoil that is exposed on cut batters or areas of hard fill should be treated as soon as possible through amelioration, capping (with planting media or impermeable material) or both.
- Grubbing operations outside any earth works footprint must leave at least 100 mm of undisturbed soil material (surface and/or subsurface layers) on top of the clay subsoil.
- The land surface outside an earth works footprint should be levelled immediately after any clearing and grubbing operations are finished. The levelling should create a slight convex shape that spreads run-off water away from the disturbed area rather than allowing it to concentrate.
- In particular, any holes should be filled with soil material from the surface and/or subsurface layers. If necessary, suitable "topsoil" should be brought in from elsewhere to ensure no clay subsoil remains exposed. The levelled surface may have to be lightly compacted to ensure it is not easily moved by raindrop splash and running water.
- The land surface on top of laid pipelines and adjacent service tracks should be left in a slight convex shape that spreads run-off water away from the pipeline or track rather than allowing it to concentrate.
- The pipeline mound should have a cap of at least 200 mm of suitable, ameliorated "topsoil" and this planting media should be seeded with appropriate plant species.
- If a pipeline or access track is not mounded, slope length along the disturbed area should be reduced by placing run-off control devices (such as "whoa boys", sediment fences, straw bale banks or geotextile socks) at regular intervals to intercept and slowly spread water off the area; such devices should be used even on very gentle slopes of 1-2%.

5.2.3 High value cropping land

Cropping land within the CSG field is extremely important to the region and the State (see section 4.11). Much of the GQAL as well as other areas not designated as GQAL are currently cropped. The best or "prime" cropping land is in Agricultural Land Class A which comprises almost 21% of the CSG field. Based on the development scenario provided for this assessment, the proposal will create a significant impact on all cropping land (see section 4.11). However, the severest impact in terms of loss of production and loss of land value will be on areas designated as Agricultural Land Class A.

The impact will be ongoing throughout the production phase of the gas fields, estimated at 25 to 30 years. However, well construction will occur progressively and not all cropping land will be affected at the same time.

The development scenario involves landholder consultation when locating wells and a possible partial remediation of the well sites to a smaller area during production. These strategies will help reduce the impact.

To avoid significantly diminishing productivity of the cropping land, drill sites and access tracks should not be located within areas of cultivation. They should be placed on areas that will not be cultivated such as along paddock boundaries. Where the only option is placement within a cultivation area, the wellheads should be positioned to cause the least obstruction to the normal working pattern and to overland flow of stormwater within the paddock. Access tracks should be located along internal headlands or along contour banks.

When production ceases, removal of hardstand and gravel material and any associated operational materials and the re-establishment of initial topography and drainage will be required. Any soil fertility or structural impacts within the hardstand areas should also be remediated.

5.2.4 Areas with severe subsoil salinity

Salinity at or near the surface is not a significant constraint within the CSG field. However, subsoil salinity can:

- reduce revegetation efforts on disturbed areas;
- affect plant growth surrounding disturbed areas if saline water is released from excavations and thus increase erosion hazard; and
- corrode inappropriately designed foundations for infrastructure.

The *Sandy texture contrast soils (dispersive)* have moderate to extreme subsoil salinity and subsoil salt levels in the *Grey-brown cracking clays* are very high to extreme. More intensive salinity sampling is recommended wherever major earthworks involving concrete and steel are to be located on these soils. The sampling should be aimed at clarifying the depth at which salt levels reach problematic levels.

Medium to high salt levels can retard plant growth and care should be exercised when excavating or dealing with subsoil from the *Loamy texture contrast soils (dispersive)*, *Loamy texture contrast soils (non-dispersive)* and *Brown cracking clays* as well as from the *Sandy texture contrast soils (dispersive)* and *Grey-brown cracking clays*.

Excavated subsoil should be buried deep or capped with at least 300 mm of suitable "topsoil" following construction activities. This will allow plants that are being established to achieve a reasonable root layer before encountering the saline material.

If saline subsoil is to be stockpiled for a short period, the stockpile should be bunded to prevent water running onto the pile from further upslope and to detain run-off water within the stockpiled area.

5.2.5 Borrow pits

Borrow pits are used to provide local sources of crushed aggregate, gravel, sand and soil during construction and some are used during the production phase for on-going maintenance. Unlike most other excavations, borrow pits are not fully rehabilitated when they are no longer required.

Borrow pits may impact on the environment both during and after their active use through:

- accelerated soil erosion on disturbed cut faces and in the floor of the pit; and
- leaching of soluble salts from exposed soil material onto surrounding land and into local waterways; and
- loss of productive rural land and interruptions to its efficient use, especially in high value cropping land.

Environmental impact can be controlled by:

- adopting relevant standard erosion control measures (section 5.1.3);
- implementing relevant special measures on sloping areas with dispersive texture control measures (section 5.2.2);
- careful location of pits in dissected terrain (section 5.2.1) and outside cultivations areas within the high value cropping land (section 5.2.2); and
- bunding any pits that expose saline subsoil.

Apart from careful site selection, implementation of run-off control devices is essential to prevent water running over the cut faces from further upslope and to detain run-off water within the disturbed area.

The final cut faces should be left as close to vertical as possible to minimise erosion due to raindrop splash.

5.2.6 Evaporation ponds

Storage/evaporation ponds can take a relatively large area of land and need to be adequately sealed to prevent leakage of the saline wastewater into the ground below. To avoid environmental impact, they should be preferably located where:

- soils have an appropriate clay base for sealing the pond;
- outside cultivation areas within the highly productive cropping land; and
- required cut and fill operations are minimal.

If a clay base of sufficient depth is not available at a preferred site, the pond will need to be covered with either compacted, imported clay or an artificial liner. If cut and fill operations are required on sloping land there is a high risk of exposing in the cut sections:

- permeable layers of soil or weathered rock in shallower profiles; and
- dispersive clay subsoil in deeper profiles.

In both situations, the pond will need to be lined as described above.

6. Conclusions

Jurassic and Cretaceous sedimentary rocks underlie one-half of the CSG field but in many areas have been altered by prolonged deep weathering during the Tertiary period with intervening phases of erosion and deposition.

The resultant altered rocks now cover approximately 22% of the CSG field and represent remnant fragments of a once extensive Tertiary land surface.

In addition, a wide expanse of unconsolidated sediments covers more than 38% of the CSG field. These sediments are the products of the erosion and deposition phases both during and following the Tertiary period.

Places where Jurassic and Cretaceous sedimentary rocks have been little weathered now represent only 22% of the area whilst recent alluvium is on approximately 10% of the CSG field.

As a result of extensive landscape reshaping during, and at the close of, the Tertiary period, level to gently undulating plains now cover 50% of the CSG field. Rises and undulating plains occupy almost 22% of the area and low hills and rises occur on a further 22%.

Plateaus are restricted (4% of the area) to small locations north of Miles and in the south-eastern corner whilst hills and mountains occur in only one very small area south-west of Guluguba.

Twelve soil management groups have been identified within the CSG field; varying from *Shallow sands and sandy loams* to deep *Melonhole clays*. All the clay soils, the *Deep sands and sandy loams*, the *Loamy texture contrast soils (non dispersive)* and small areas of *Sandy texture contrast soils (dispersive)* and *Loamy texture contrast soils (dispersive)* are considered to have some cropping potential, according to NRW. Land with any cropping potential is generally designated as GQAL for the purpose of protecting agricultural productivity under State Planning Policy 1/92.

Minor sheet and rill erosion are evident between erosion control structures in the cropping land and minor sheet erosion is the main form of erosion evident in grazing and forestry land. The few instances of rill, gully and tunnel erosion that are evident throughout the CSG field are predominantly due to nearby road works.

Constraints to construction and production activities associated with the proposal and potential impacts on the geology and soils are:

- topography;
- depth to bedrock;
- stoniness and rock outcrop;
- erosion hazard;
- soil fertility;
- "topsoil" depth;
- salinity;
- dust generation; and
- loss of GQAL.

Shallow sands and sandy loams and *Shallow loams and clay loams* have the largest number of moderate, severe or extreme constraints and impacts. In contrast, the *Sandy or loamy gradational soils* and the various clay soil management groups have the fewest, or least severe, constraints and impacts.

The potential reduction in productivity of highly productive cropping land, mainly on the clay soils, represents an extremely important impact for the region though the development scenario does include some strategies that will help reduce the impact.

Erosion hazard, soil fertility and dust generation are the constraints and impacts associated with the dispersive texture contrast soils that are rated as moderate or worse. If the erosion hazard is not appropriately managed, resultant erosion and sedimentation can have a pronounced impact on the environment and the soil fertility constraint associated with these soils means that the appropriate management procedures must involve correct revegetation practices.

A range of mitigation measures are available for addressing the constraints and impacts and for ensuring that the QC LNG proposal does not adversely affect the environment. Mitigation measures that can be applied universally to the entire study area are:

- removing all drilling by-products from the CSG field or safely diffusing fine material from drill pits onto the nearby landscape;
- timing all major disturbance to avoid the November to February period;
- adopting a range of standard erosion control measures on all sloping land;
- only stripping “topsoil” to recommended depths and ameliorating stockpiled “topsoil” before using as planting media; and
- minimising impact at stream crossings on minor watercourses.

In addition, a number of special measures are recommended for specific areas and issues. These include:

- avoiding major disturbance within dissected terrain (hills and mountains west of the Leichhardt Highway between North Dulacca and Guluguba and dissected plateaus between Tara and the Moonie Highway);
- implementing additional measures and management practices on all sloping land with dispersive texture contrast soils;
- avoiding significant disturbance to the highly valuable cropping land;
- taking precautions to adequately deal with subsoil that may have significant subsoil salinity;
- implementing appropriate run-off control measures at borrow pits; and
- avoiding unsuitable areas or using liners for evaporation ponds.

7. References

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Attachment A
Field inspection sites

Site	Soil management group	Latitude (˚S)	Longitude (˚E)
Original study area			
1	Sandy TC soils (dispersive)	26.8851	150.311
2	Sandy TC soils (dispersive)	26.8888	150.295
3	Melonhole clays	26.9416	150.475
4	Deep sands and sandy loams	26.9624	150.501
5	Loamy TC soils (dispersive)/Dark cracking clays	26.9529	150.615
6	Loamy TC soils (dispersive)	27.0033	150.646
7	Loamy TC soils (dispersive)	27.0105	150.639
8	Loamy TC soils (dispersive)	26.9944	150.671
9	Loamy TC soils (dispersive)	27.1380	150.784
10	Loamy TC soils (dispersive)	27.1768	150.76
11	Sandy TC soils (dispersive)	27.1691	150.741
12	Loamy TC soils (dispersive)	27.3099	150.711
13	Shallow sands and sandy loams	26.8919	150.276
14	Dark cracking clays	26.8964	150.142
15	Loamy TC soils (dispersive)	26.8520	150.172
16	Melonhole clays	26.7845	150.301
17	Loamy TC soils (non dispersive)	26.7367	150.314
18	Sandy TC soils (dispersive)	26.7167	150.308
19	Sandy TC soils (dispersive)	26.7157	150.294
20	Sandy TC soils (dispersive)	26.6697	150.271
21	Sandy TC soils (dispersive)	26.6831	150.27
22	Melonhole clays	26.7458	150.087
23	Loamy TC soils (non dispersive)	26.8083	150.007
24	Loamy TC soils (dispersive)	26.2166	149.676
25	Sandy TC soils (dispersive)	26.2185	149.691
26	Grey-brown cracking clays	26.2806	149.72
27	Dark cracking clays	26.2807	149.72
28	Sandy or loamy gradational soils	26.4099	150.004
29	Sandy TC soils (dispersive)	26.4131	149.937
30	Shallow sands and sandy loams	26.4218	149.941
31	Loamy gradational soils	26.4217	149.955
32	Sandy TC soils (dispersive)	26.4271	150.057
33	Sandy TC soils (dispersive)	27.0005	150.378
34	Melonhole clays	26.9432	150.46
35	Sandy TC soils (dispersive)	27.3281	150.911
36	Loamy TC soils (dispersive)	27.3202	150.991
37	Loamy TC soils (dispersive)	27.2662	151.065
38	Dark cracking clays	27.2626	151.074
39	Dark cracking clays	27.3763	150.669
40	Loamy TC soils (dispersive)	27.3624	150.683
41	Sandy TC soils (dispersive)	27.3482	150.715
42	Sandy TC soils (dispersive)	27.1481	150.663
43	Sandy TC soils (dispersive)	27.1072	150.627
44	Shallow sands and sandy loams	27.0959	150.709
45	Dark cracking clays	26.9175	150.639
46	Dark cracking clays	26.8703	150.747
47	Deep sands and sandy loams	26.5208	150.092
48	Melonhole clays	26.6772	150.376
49	Deep sands and sandy loams	26.8556	150.759
50	Dark cracking clays	26.8615	150.752
51	Dark cracking clays	26.7800	150.826

Site	Soil management group	Latitude (˚S)	Longitude (˚E)
Addendum study area			
61	Sandy TC soils (dispersive)	26.3296	150.002
62	Sandy TC soils (dispersive)	26.3098	149.968
63	Sandy TC soils (dispersive)	26.2871	149.922
64	Grey-brown cracking clays	26.2518	149.922
65	Grey-brown non-cracking clays	26.2446	149.938
66	Grey-brown cracking clays	26.2050	149.934
67	Loamy TC soils (dispersive)	25.9427	149.822
68	Grey-brown cracking clays	25.9696	149.810
69	Grey-brown cracking clays	25.9786	149.802
70	Loamy TC soils (dispersive)	26.0040	149.804
71	Grey-brown non-cracking clays	26.0072	149.806
72	Grey-brown non-cracking clays	26.0394	149.812
73	Dark cracking clays	26.0821	149.804
74	Dark cracking clays	26.1257	149.804
75	Dark cracking clays	26.1446	149.827

Attachment B
Soil analytical results

Laboratory Order #	Field Reference	pH	EC	Cl	Ca	Mg	K	Na	AL	CEC	ESP	Ca:Mg	Al	Olsen P	OM	Total N
			(dS/m)	(mg/kg)	(meq%)	(meq%)	(meq%)	(meq%)	(meq%)	(meq%)	(%)		(%)	(mg/kg)	%	(%)
	Sandy TC soils (dispersive)															
B038552-01	S1 0-100	4.9	0.04	17	0.54	0.63	0.16	0.16	0.10	1.6	10	0.9	6.3	7	1.3	0.41
B038552-02	S2 500-600	6.6	0.34		0.4	8.01	0.6	3.55	0.04	12.6	28	0.1	0.3			
B038552-09	S11 0-100	5.0	0.04	15	1.14	1.16	0.6	0.09	0.32	3.3	3	1.0	9.7	5	1.8	0.54
B038552-10	S11 700-900	5.4	0.26		0.43	5.64	0.81	2.48	0.17	9.5	26	0.1	1.8			
B038552-29	S32 0-100	4.6	0.08	50	1.16	0.75	0.34	0.17	0.16	2.6	7	1.6	6.2	8	2.2	0.54
B038552-30	S32 505-600	6.3	2.01		<0.01	8.21	0.25	3.92	0.11	12.4	32	0.0	0.9			
B038552-31	S33 0-100	6.0	0.30	390	1.68	1.19	0.1	1.99	0.04	5.0	40	1.4	0.8	4	0.6	0.41
B038552-32	S33 800-900	9.3	0.28		1.71	5.75	0.15	3.69	<0.02	11.3	33	0.3	0.2			
B038552-33	S35 0-100	6.3	0.04	4	4.47	2.27	0.54	0.3	<0.02	7.6	4	2.0	0.3	3	1.6	0.54
B038552-34	S35 500-600	8.6	0.64		4.88	7.66	0.33	3.65	0.03	16.6	22	0.6	0.2			
	Loamy TC soils (dispersive)															
	- on recent alluvium															
B038552-15	S15 0-100	5.4	0.06	10	4.57	1.83	0.55	0.13	0.06	7.1	2	2.5	0.8	25	2.2	0.95
B038552-16	S15 400-500	7.6	0.19		6.14	4.25	0.21	2.02	0.03	12.7	16	1.4	0.2			
	- on other material															
B038552-05	S6 0-100	5.7	0.09	43	3.37	3.07	0.4	0.53	0.05	7.4	7	1.1	0.7	3	4.3	1.08
B038552-06	S6 100-200	5.5	0.15		0.66	2.68	0.08	1.36	0.08	4.9	28	0.3	1.6			
B038552-07	S10 0-100	5.6	0.09	24	4.1	4.32	1.13	0.68	0.06	10.3	7	1.0	0.6	5	4.9	1.28
B038552-08	S10 500-600	4.2	0.77		0.35	7.16	0.43	3.97	4.30	16.2	25	0.1	26.5			
B038552-11	S12 0-100	6.3	0.09	23	7.07	3.84	0.77	0.64	0.04	12.4	5	1.8	0.3	4	3.9	1.35
B038552-12	S12 500-600	8.3	0.70		7.73	7.03	0.43	3.89	0.03	19.1	20	1.1	0.2			
B038552-35	S36 0-100	5.8	0.11	61	0.98	2.65	0.23	1.15	0.04	5.1	23	0.4	0.8	9	1.3	0.54
B038552-36	S36 500-600	5.2	0.55		0.54	5.02	0.17	3.47	0.25	9.5	37	0.1	2.6			
B038552-37	S40 0-100	6.6	0.06	3	11.66	2.59	0.92	0.21	0.04	15.4	1	4.5	0.3	9	4.0	1.62
B038552-38	S40 500-600	8.9	0.70		21.65	6.8	0.84	3.9	0.03	33.2	12	3.2	0.1			
	Loamy TC soils (non dispersive)															
B038552-21	S17 0-100	6.0	0.04	9	2.64	1.99	0.18	0.29	<0.02	5.1	6	1.3	0.4	4	1.0	0.41
B038552-22	S17 400-500	6.1	0.05		4.15	2.91	0.18	0.46	0.03	7.7	6	1.4	0.4			
B038552-23	S23 0-100	5.7	0.31	89	8.62	4.62	0.69	0.58	0.06	14.6	4	1.9	0.4	9	3.5	1.49

Laboratory Order #	Field Reference	pH	EC	Cl	Ca	Mg	K	Na	AL	CEC	ESP	Ca:Mg	Al	Olsen P	OM	Total N
			(dS/m)	(mg/kg)	(meq%)	(meq%)	(meq%)	(meq%)	(meq%)	(meq%)	(%)		(%)	(mg/kg)	%	(%)
B038552-24	S23 500-600	9.0	0.66		22.91	10.3	0.31	3.66	<0.02	37.2	10	2.2	0			
	Dark cracking clays															
B038552-14	S14 0-100	7.9	0.10	12	19.52	7.22	1.26	0.39	0.11	28.5	1	2.7	0.4	5	2.3	0.61
B038552-39	S46 0-70	6.2	0.08	19	8.22	5.35	0.59	1.16	<0.02	15.3	8	1.5	0.1	8	3.2	1.15
B038552-40	S46 400-500	8.4	0.55		20.71	12.9	0.46	3.58	<0.02	37.7	10	1.6	0.1			
B038552-43	S50 0-100	7.9	0.26	109	17.68	11.37	1.17	2.95	0.05	33.2	9	1.6	0.2	23	4.0	1.22
B038552-44	S50 500-600	8.7	0.60		17.19	12.49	0.79	3.75	0.03	34.3	11	1.4	0.1			
	Grey-brown cracking clays															
B038552-25	S26 0-100	6.7	0.21	37	25.01	5.1	1.89	0.79	<0.02	32.8	2	4.9	0.1	32	6.8	2.70
B038552-26	S26 500-600	4.4	1.53		17.19	5.86	0.35	4.31	2.54	30.3	14	2.9	8.4			
	Melonhole clays															
B038552-03	SITE 3 0-100	5.7	0.34	346	5.89	6.28	0.65	2.32	0.04	15.2	15	0.9	0.3	8	4.1	1.62
B038552-04	S3 500-600	4.7	1.42		2.56	8.05	0.4	3.96	0.19	15.2	26	0.3	1.3			
B038552-17	S16d 0-100	6.3	0.13	36	17.31	5.61	1.32	1.1	0.03	25.4	4	3.1	0.1	41	4.0	1.35
B038552-18	S16d 500-600	8.0	0.42		15.16	6.77	0.38	3.46	<0.02	25.8	13	2.2	0.1			
B038552-19	S16m 0-100	5.8	0.34	196	14.48	4.35	0.74	1.78	0.04	21.4	8	3.3	0.2	12	7.2	2.43
B038552-20	S16m 400-500	8.3	1.01		23.3	10.14	0.49	3.77	<0.02	37.7	10	2.3	0			
	Deep sands and sandy loams															
B038552-41	S47 0-100	7.0	0.09	12	8.38	2.67	1.16	0.18	0.05	12.4	1	3.1	0.4	11	5.1	1.55
B038552-42	S47 800-900	6.9	0.03		4.09	2.65	0.44	0.35	0.04	7.6	5	1.5	0.5			
	Shallow sands and sandy loams															
B038552-13	S13 0-100	3.9	0.06	24	0.33	0.5	0.16	0.15	1.76	2.9	5	0.7	60.7	4	4.7	0.95
	Sandy or loamy gradational soils															
B038552-27	S28 0-100	4.2	0.04	11	0.31	1.09	0.12	0.14	0.98	2.6	5	0.3	37.1	4	2.2	0.81
B038552-28	S28 600-700	6.5	0.05		<0.01	5.65	0.03	1.02	0.12	6.8	15	0.0	1.8			

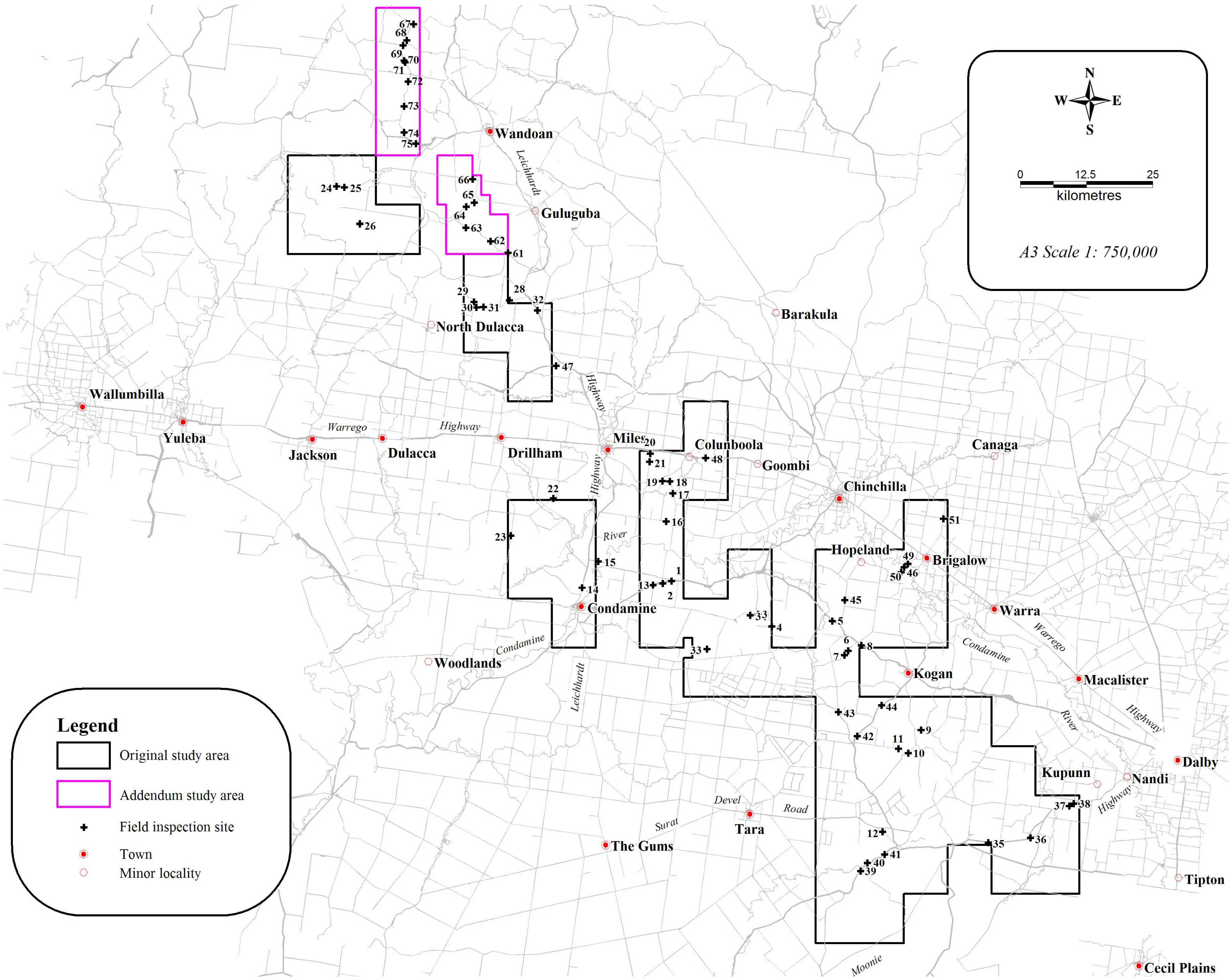

Figure 1. Coal Seam Gas field

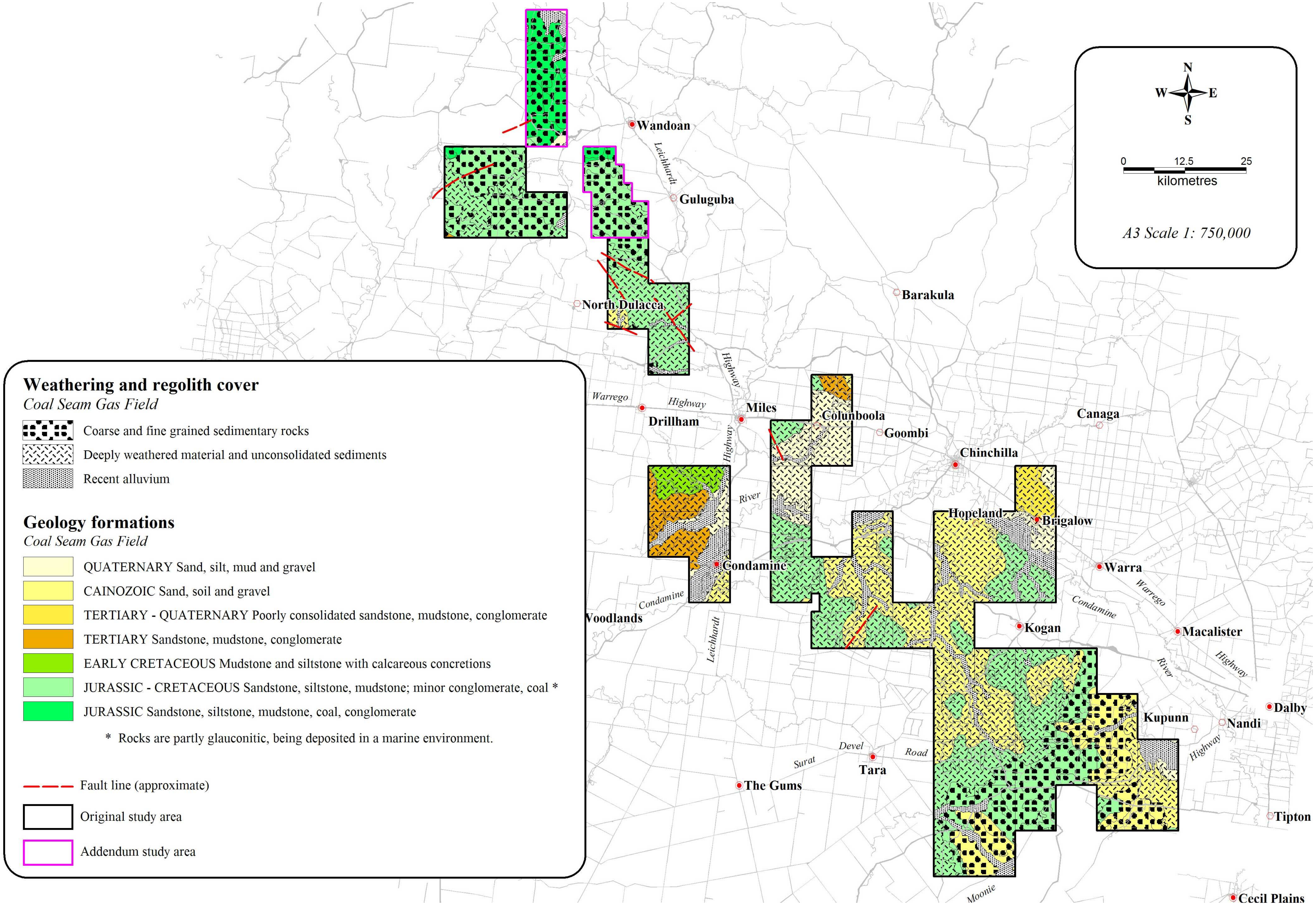

Figure 2. Weathering, regolith cover and underlying geology

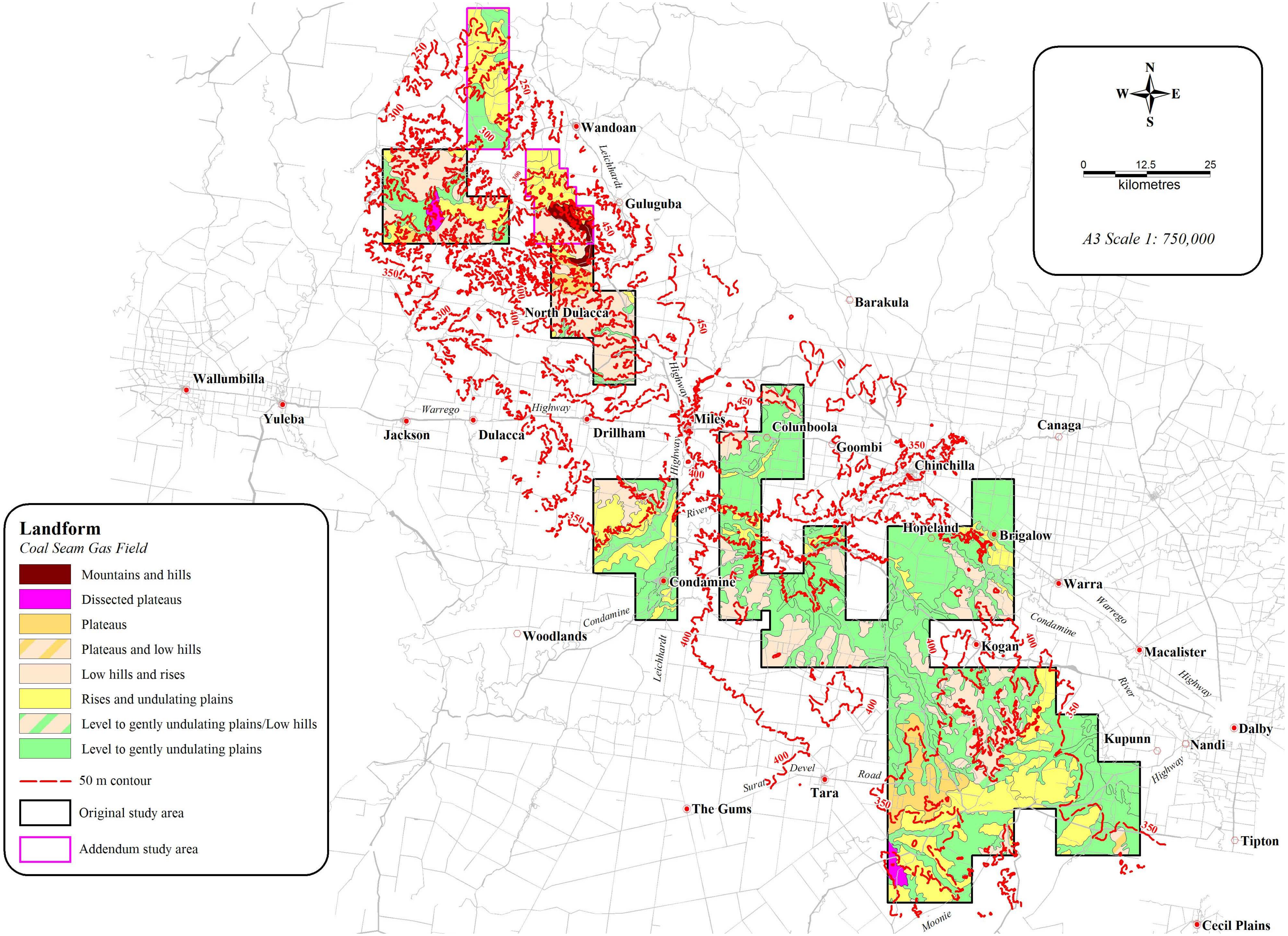

Figure 3. Landform

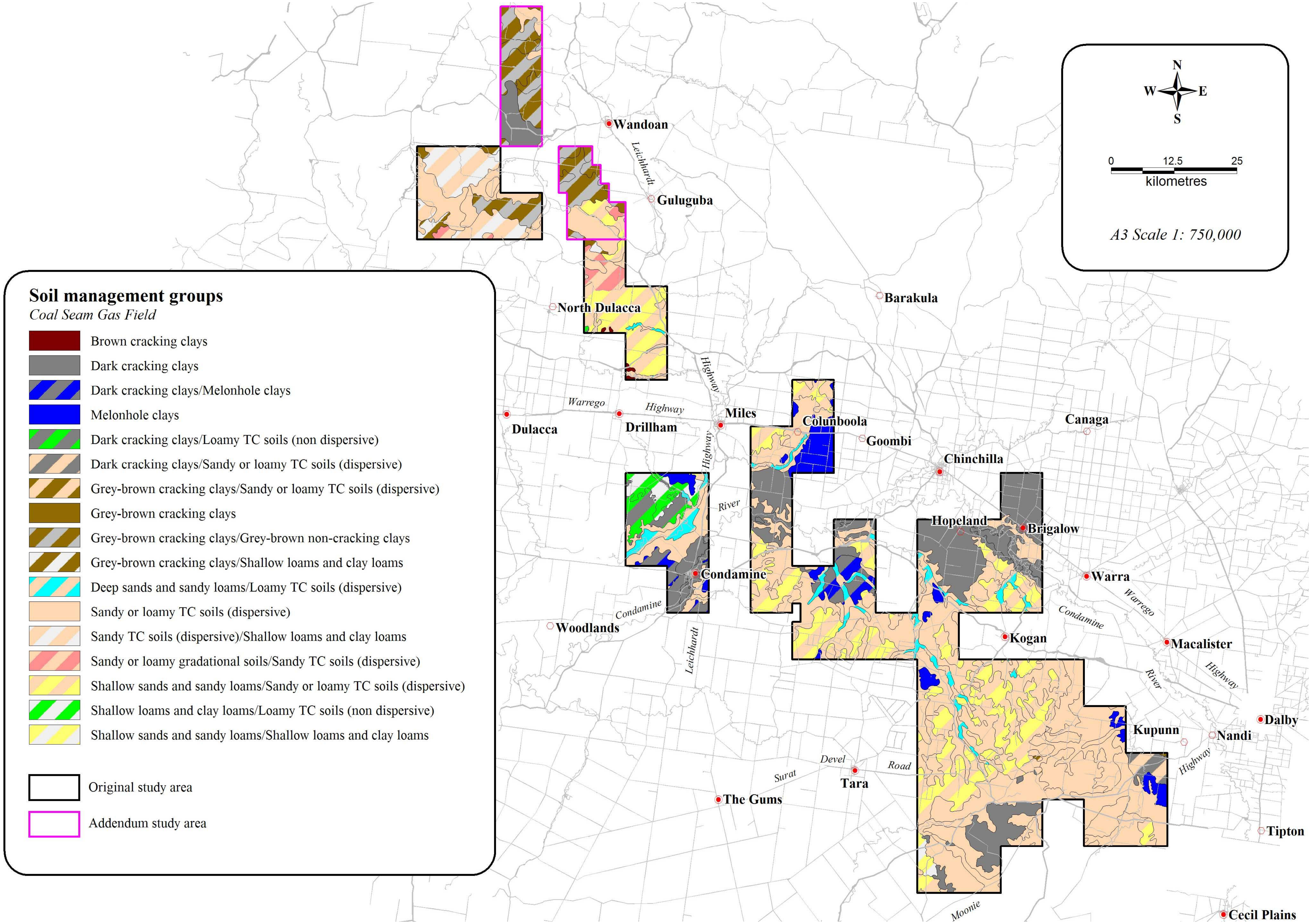

Figure 4. Distribution of soil management groups

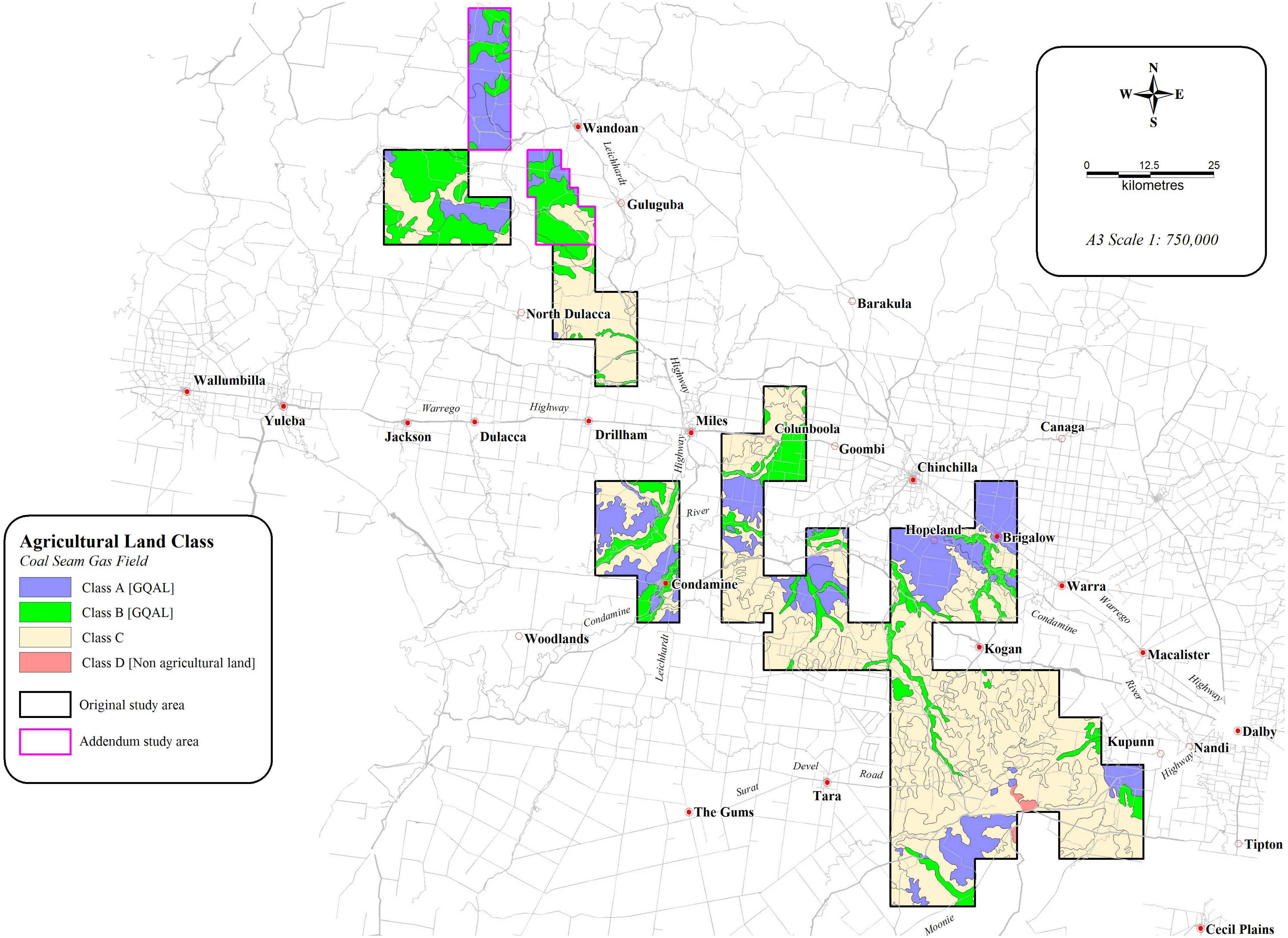

Figure 5. GQAL within the Coal Seam Gas field

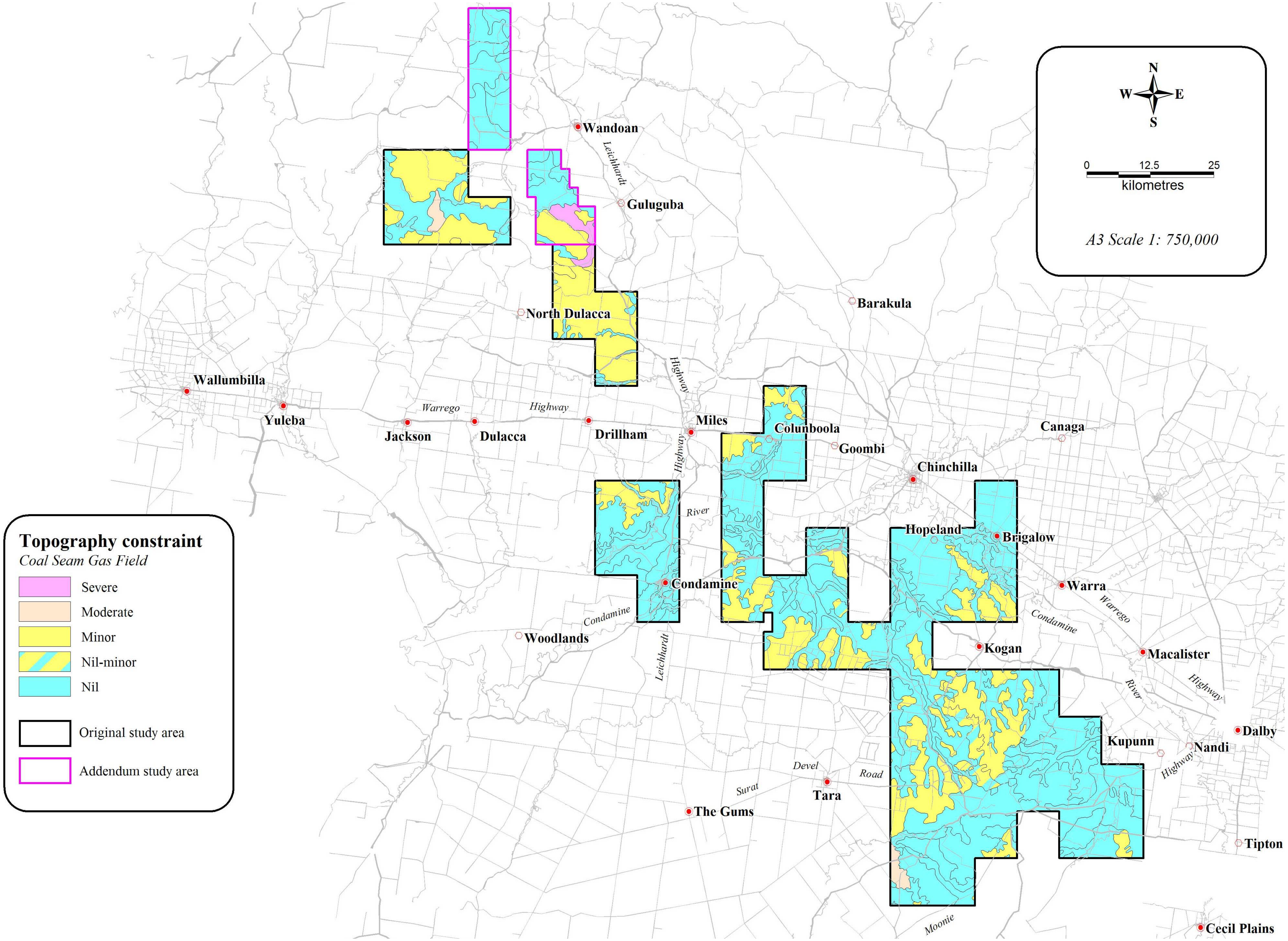

Figure 6. Topography constraint across the Coal Seam Gas field

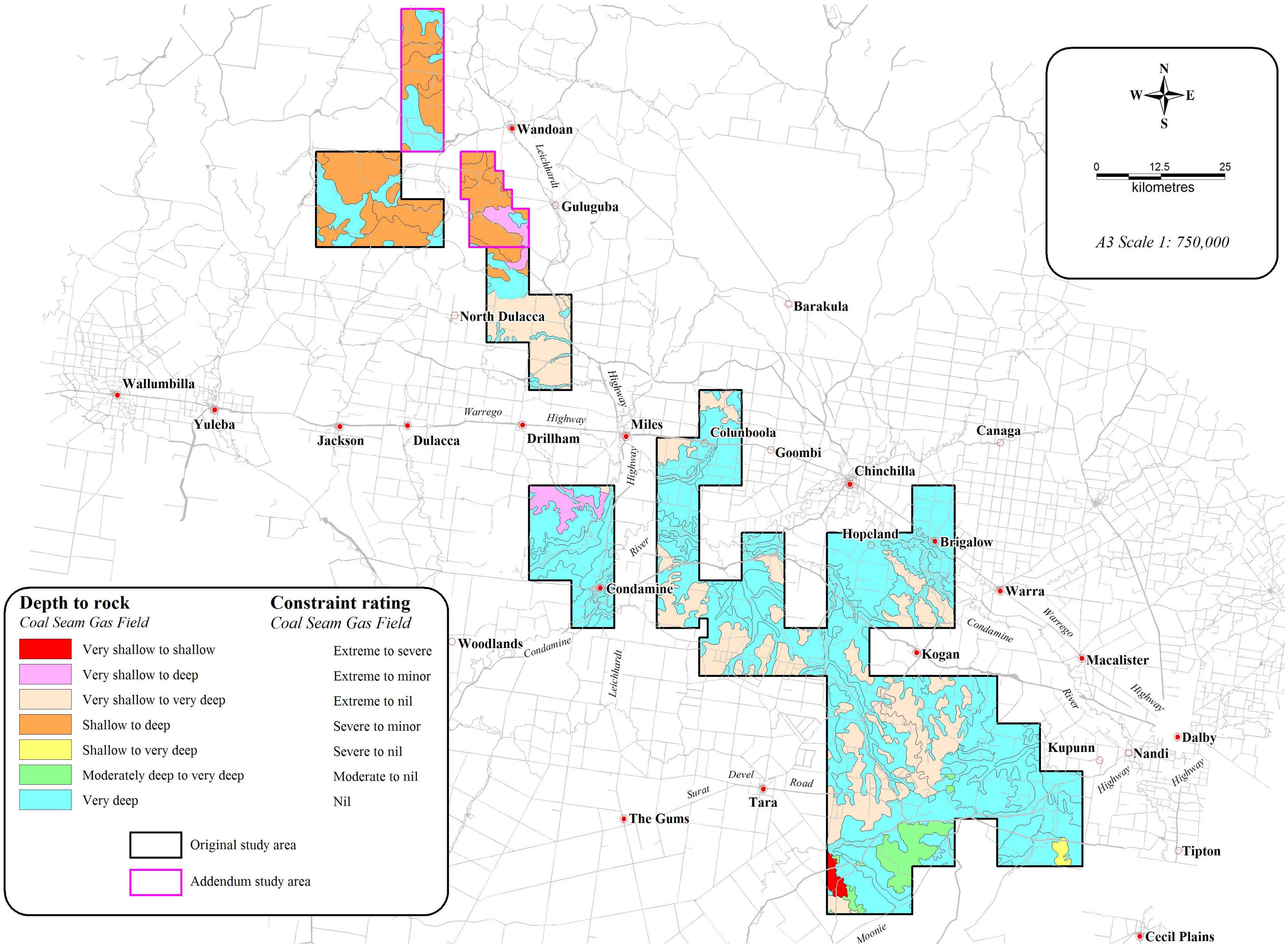

Figure 7. Depth to rock constraints across the Coal Seam Gas field

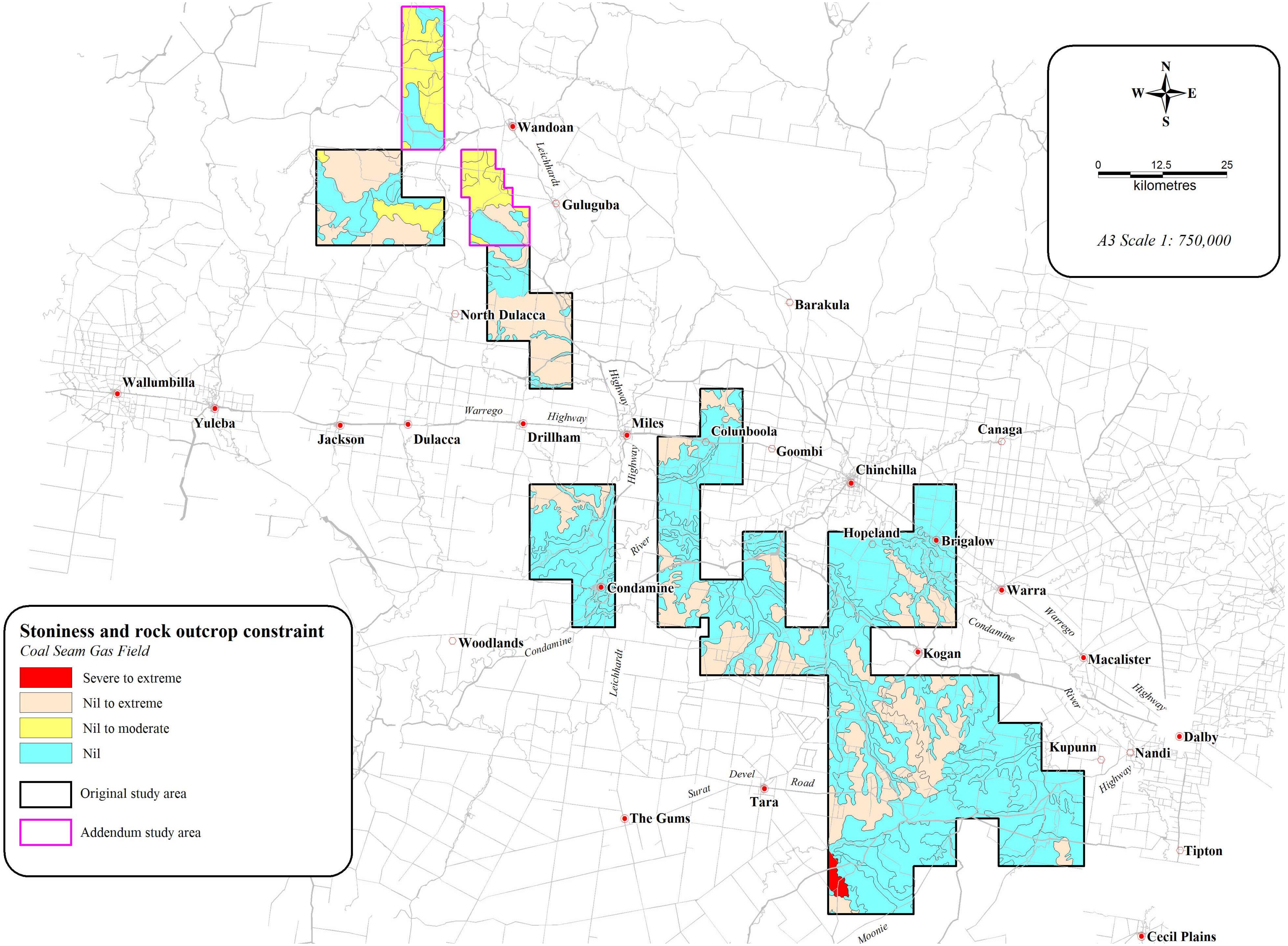

Figure 8. Stoniness and rock outcrop across the Coal Seam Gas field

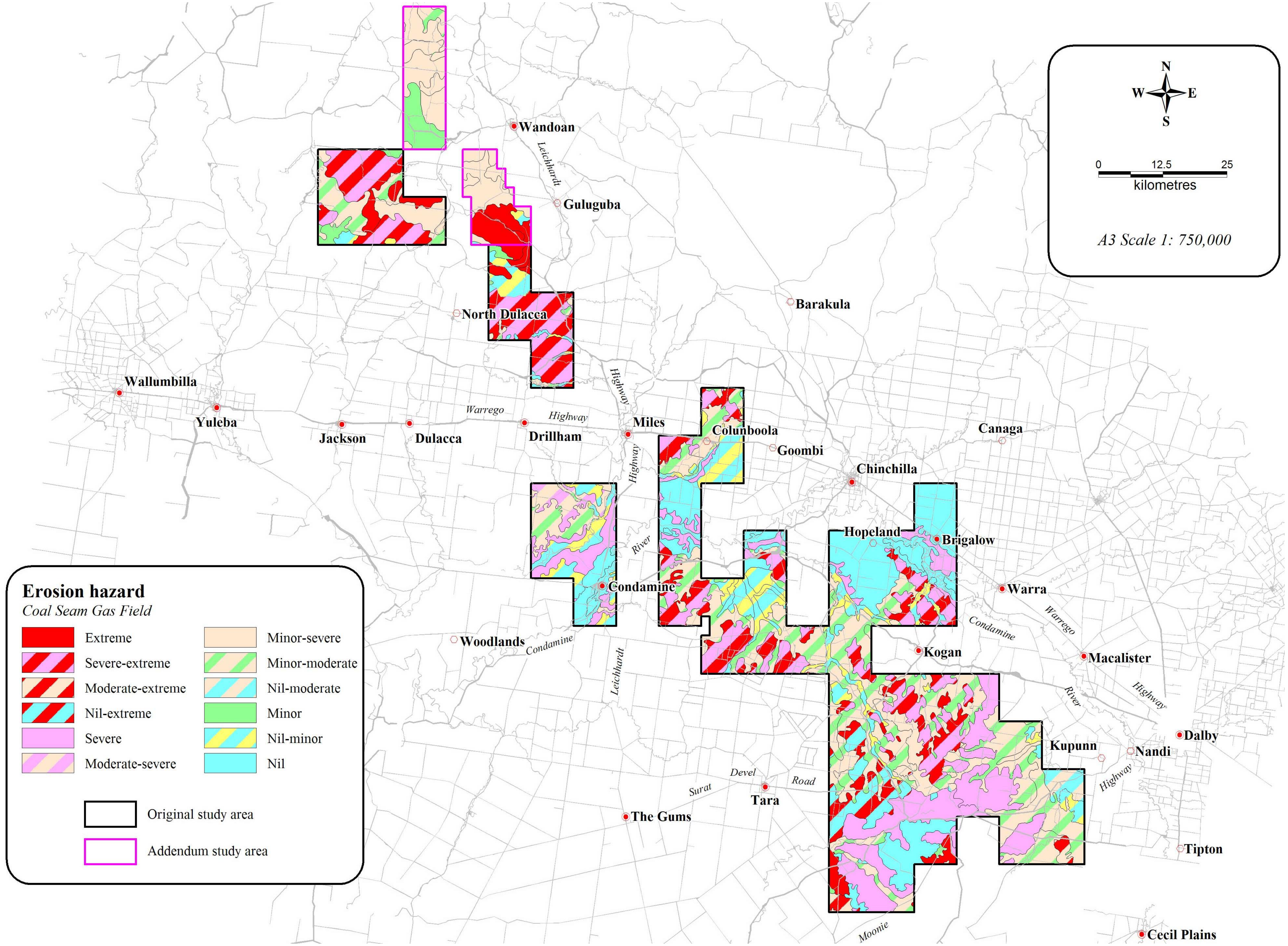

Figure 9. Distribution of erosion hazard

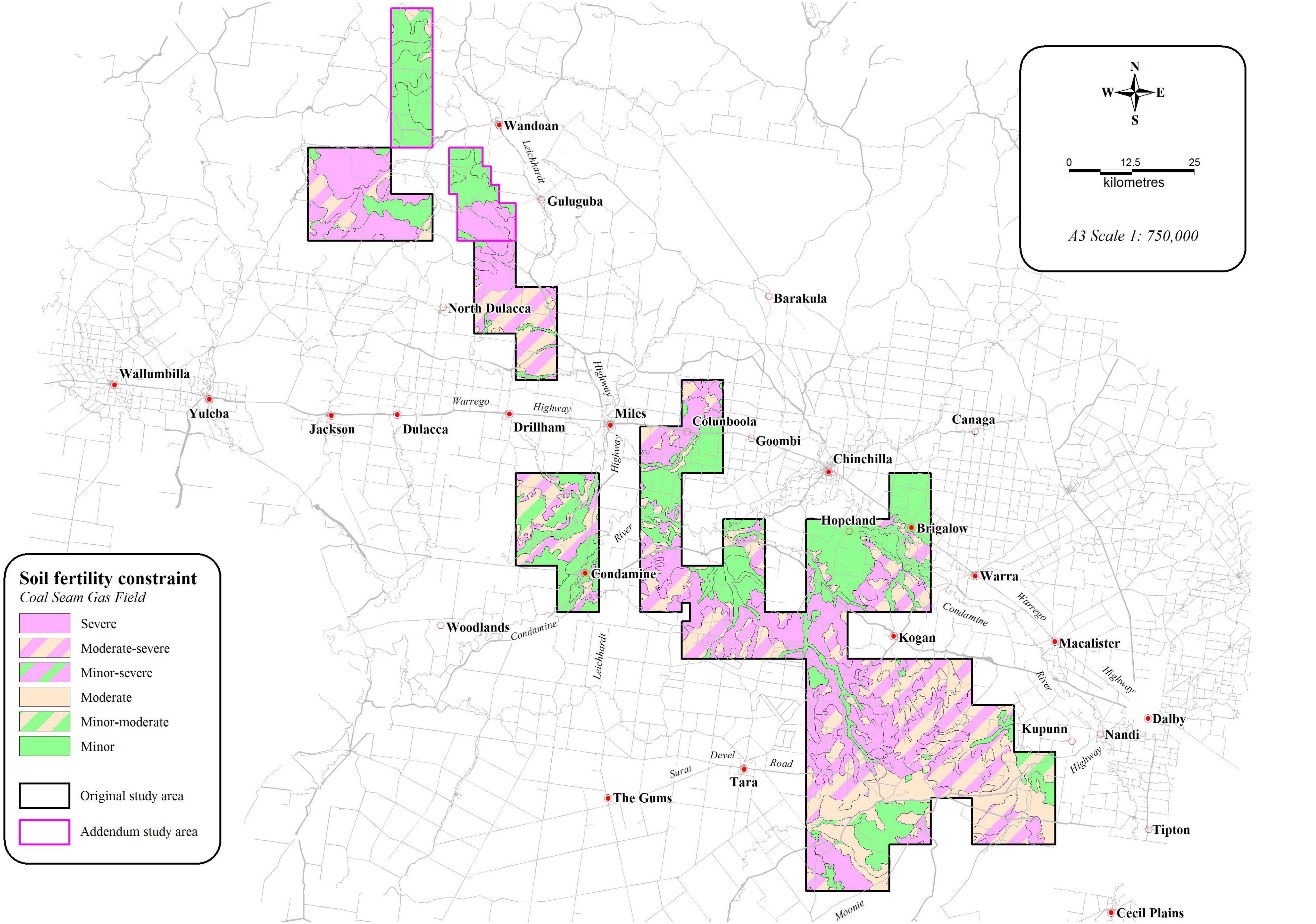

Figure 10. Soil fertility constraint across the Coal Seam Gas field

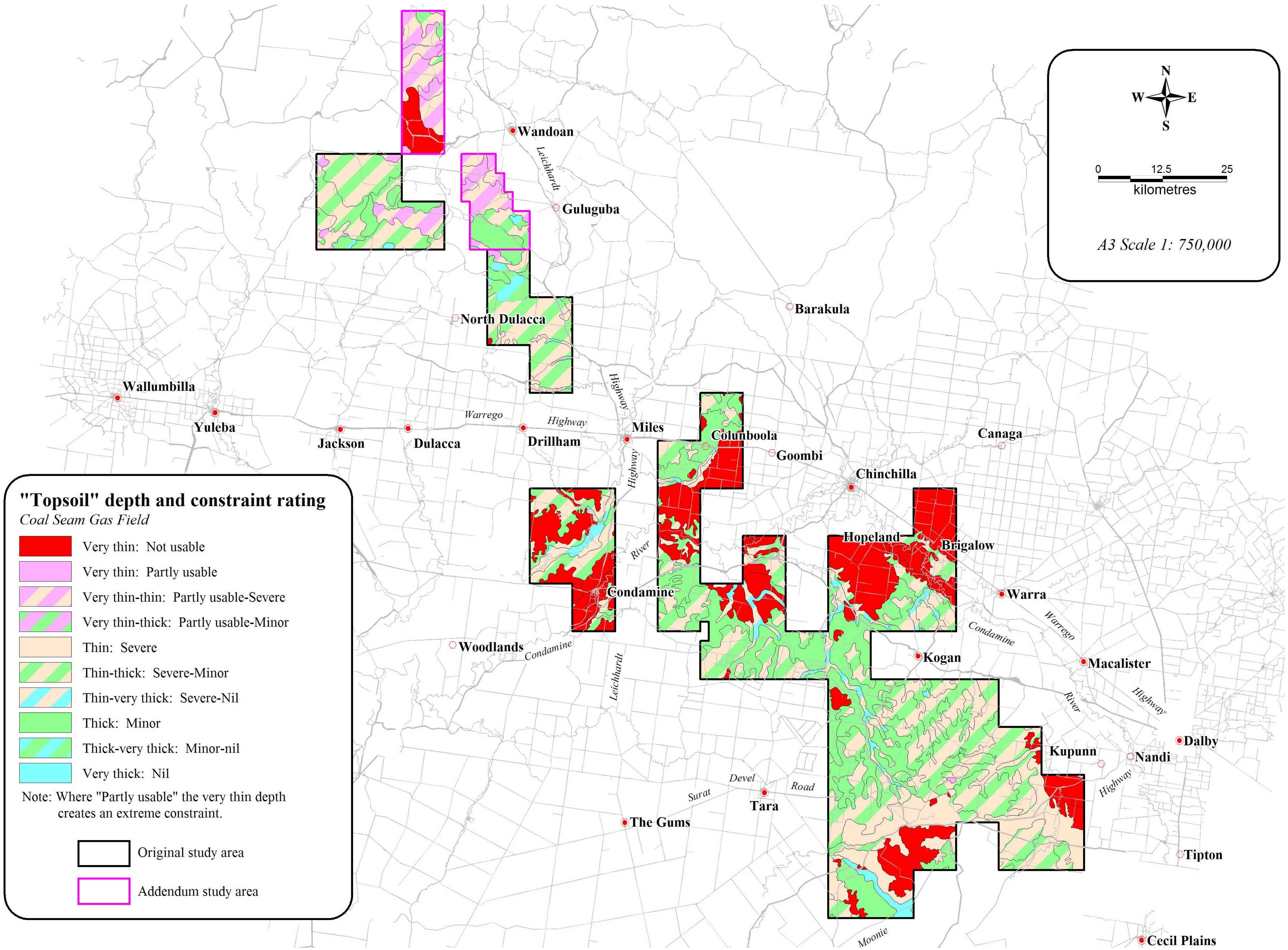

Figure 11. "Topsoil" depth as a constraint

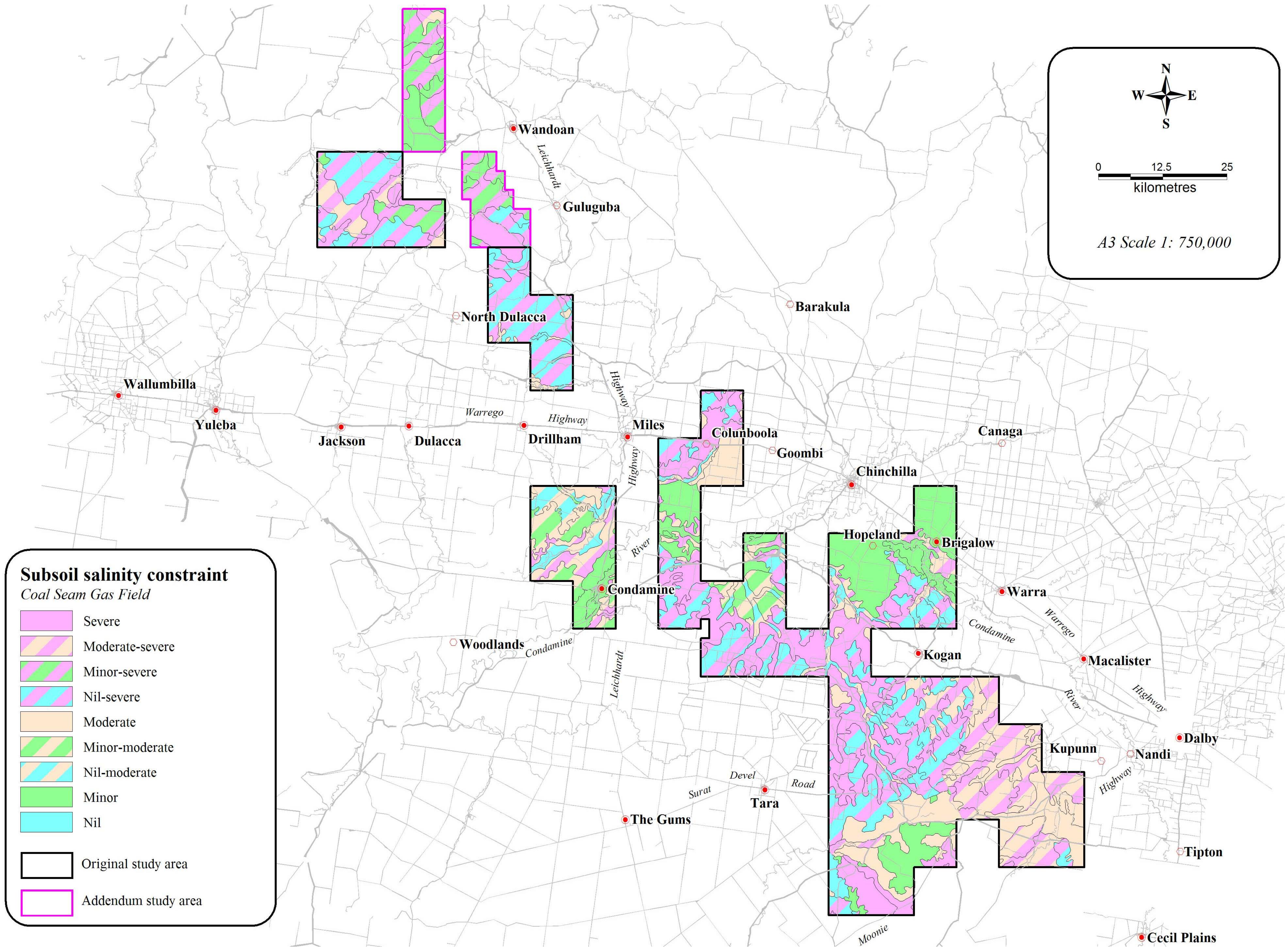

Figure 12. Subsoil salinity constraint across the Coal Seam Gas field

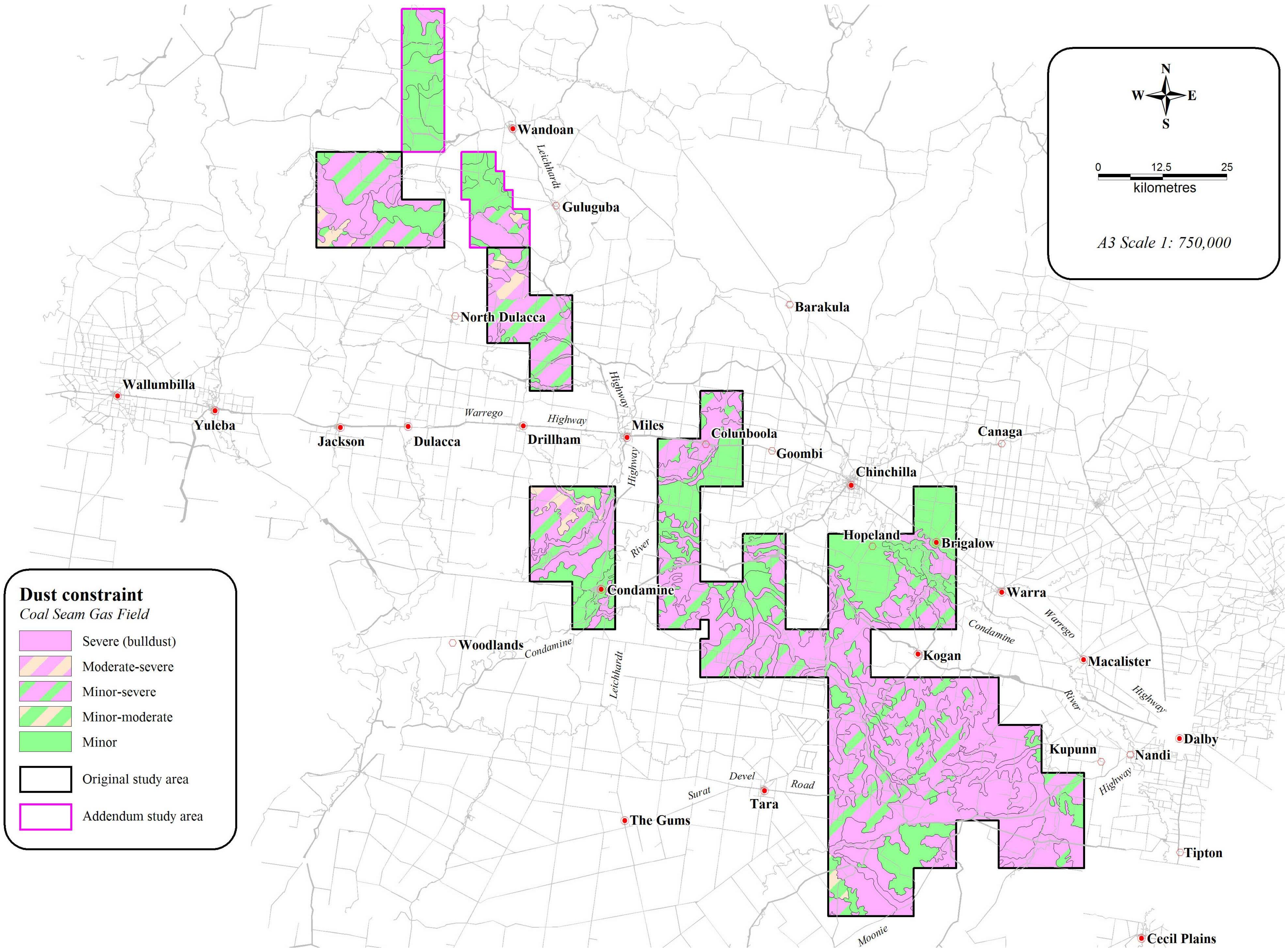

Figure 13. Dust constraint across the Coal Seam Gas field

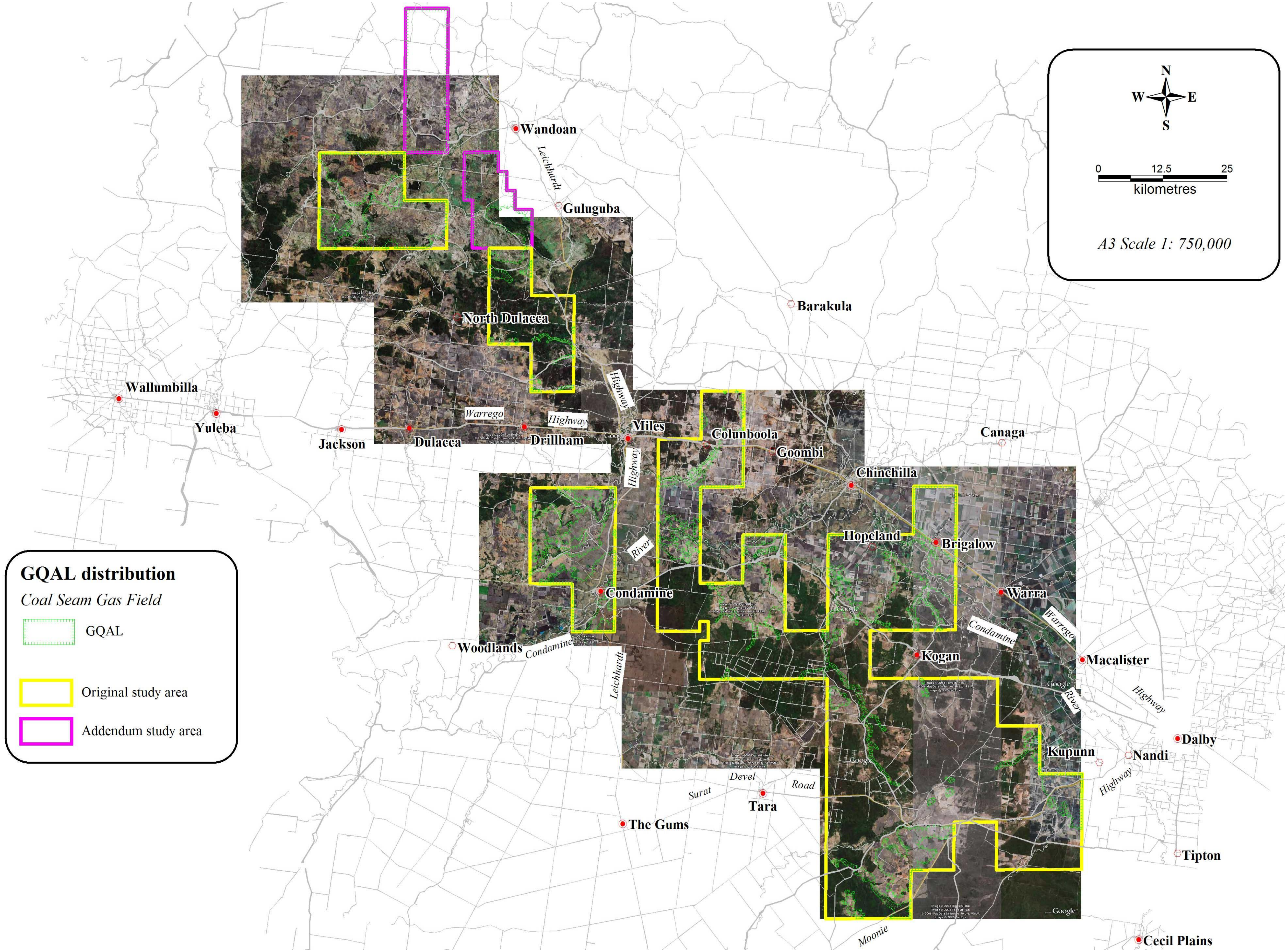

Figure 14. GQAL and current cropping patterns