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Site profile

Collation of background information and data sources for the CSIRO GISERA H.2 Project – Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland.

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Important disclaimer

Foreword

The purpose of this report is to collate background information and data sources used for the CSIRO GISERA H.2 Project – *Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland*. The H.2 project is the first study of the potential human health impacts of CSG activities to implement the CSG health study framework (Figure 1) developed in the GISERA H.1 project—*Human Health effects of Coal Seam Gas—Designing a Study Framework* (Keywood et al., 2018).

The CSG health study framework (Keywood et al., 2018) provides a method to assess and prioritise studies of potential human health effects from CSG activities for specific locations and CSG activities. The H.2 project focuses on a single study site in Queensland and covers the identification and screening stages of the health study framework for physical and chemical stressors.

The study site has had a significant level of CSG development, with two operators and activities spanning over a decade. This report covers:

- a description of CSG and CSG activities
- regulation of CSG activities in Queensland
- a brief description of the study site, including:
    - geography, including demographics and land use
    - biophysical characteristics, including the geology, hydrogeology and groundwater use
- a description of the CSG activities in the area
- a summary of some of the data sources used for the study

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Acknowledgments

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The project team has been very appreciative of the time and effort that the Local Stakeholder Reference Group and Technical Reference Group members have provided to the project and thanks them for their valuable input.

The project team also acknowledges the cooperation of Origin and Shell in their provision of data necessary to complete the project.

Part I Coal seam gas overview

1 What is coal seam gas?

Coal seam gas (CSG) is a natural gas resource where the reservoir and source for the gas are coal seams. In the Surat Basin, this gas is primarily methane and derived largely from biogenic processes, where microorganisms convert coal into gas. The gas is adsorbed to the coal and its production requires the pressure on the coal seam to be reduced so the gas can be released (desorbed). The pressure reduction is achieved by reducing water levels in the reservoir.

The following section describes CSG resources and their development lifecycle.

1.1.1 Natural gas resources overview

Natural gas resources are petroleum resources that contain gaseous hydrocarbons. The key characteristics of petroleum reservoirs are the types of hydrocarbons they contain and how the hydrocarbons are stored as these determine the technologies used to extract them. These characteristics are determined by the geology and geological history of the basin.

Hydrocarbons

Petroleum resources consist of accumulations of organic compounds known as hydrocarbons. Hydrocarbons consist of chains of hydrogen and carbon atoms in varying configurations, naturally occurring in the following states:

- Gases, for example methane
- Liquids, for example crude oil
- Solids, for example asphalt

Globally, hydrocarbons are primarily utilised as a combustible fuel source, however, they are also important components in manufacturing of materials, such as road pavements and plastics. Approximately 21% of Australia’s electricity generation came from combustion of natural gas in 2017-2018 (Australian Government, 2019).

Natural gas is a mixture of combustible hydrocarbon molecules that exist in a gaseous form at subsurface temperatures and pressures. Natural gas is predominantly methane (CH_4), but also often contains some larger molecule such as ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}). Oil contains heavier, longer chains of carbon and hydrogen which are liquid in the subsurface. Some compounds are intermediary between oil and gas, existing in gaseous form in subsurface conditions, but condense to liquid once brought to the surface, hence are termed condensates. Oil and gas also contain some inorganic compounds, such as nitrogen, carbon dioxide, water and hydrogen sulfide.

Figure 1 shows the typical composition of different hydrocarbon classes. CSG typically has a high methane content with minor amounts of heavier gases and nonorganic compounds such as CO_2. Dry gas is predominately methane, with a small proportion of heavier gases and little to no condensate. Wet gas contains a higher proportion of heavier hydrocarbon gases and condensates. Volatile oil reservoirs contain condensate and light oils, with some amount of natural gas. Black oil reservoirs contain heavy oils as well as lighter compounds and can also contain a significant amount of gas. Some of the condensate and liquid hydrocarbons can form more complex, longer chain molecules, such as volatile organic compounds, polycyclic aromatic hydrocarbons and benzene, toluene and xylene. These compounds are not prevalent in CSG.

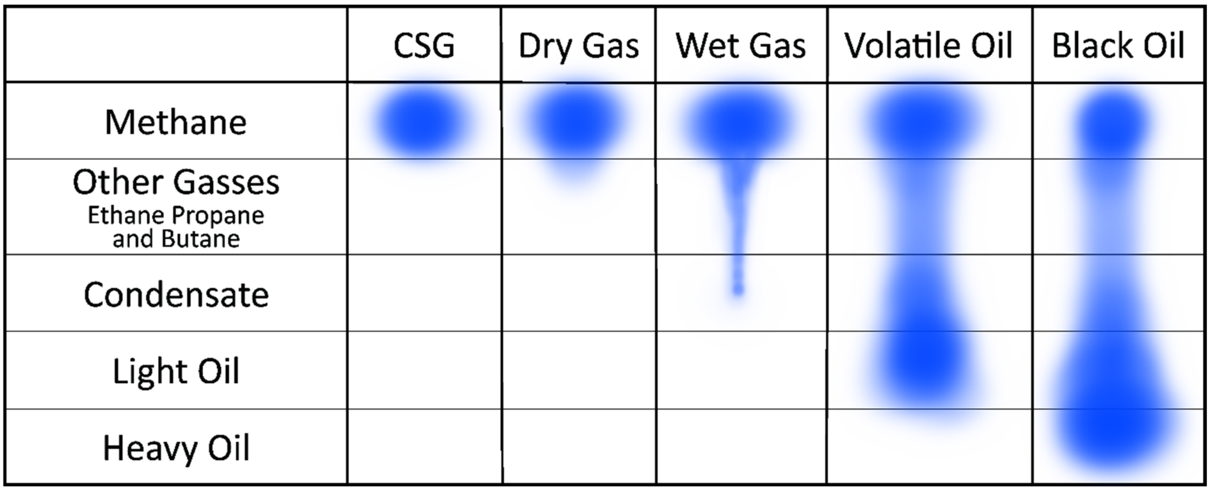


Figure 1: Generalised components of natural gas and crude oil resources

For illustrative purposes only, proportions of different components not to scale. The compositions vary markedly for different resources.

Geology of oil and gas resources

Petroleum deposits are formed when organic-rich sediments deposited in aquatic environments become lithified by increasing heat and pressure as they become buried. Under the right temperature and pressure conditions and over millions of years, the organic material may undergo a series of physical and chemical changes to be transformed into petroleum. Strata that have the potential for generating petroleum are collectively referred to as 'source rocks.' Examples of source rocks include marine shales, carbonaceous mudstones and coal.

The generation potential of a source rock depends on the type and concentration of organic material within the rock, as well as its thermal maturity. Thermal maturity is related to the maximum temperature and pressure conditions, and the duration of exposure experienced by the source material. Typically, the generation of hydrocarbons progresses from oil to gas with increasing thermal maturity, however, some source rocks only produce predominantly gas.

Petroleum systems

The set of geological conditions and processes that form hydrocarbon accumulations are referred to as petroleum systems, consisting of six main elements (Magoon & Dow, 1994).

- source rock
- burial depth and temperature
- reservoir rock
- migration pathways
- trap
- seal

Based on the configuration of these elements, petroleum systems can be classified as either conventional or unconventional resources.

A key characteristic for petroleum reservoirs is permeability. Permeability is a measure of how easily fluid may move through a rock and is a critical parameter in producing oil and gas.

Conventional petroleum systems

In a conventional petroleum system, hydrocarbons are generated within organic-rich source rocks, then expelled through various chemical and physical processes. Once released, the relative buoyancy of hydrocarbons causes them to move upwards, along migration pathways such as permeable fractures and porous rock strata. Migration continues until a barrier is reached in the form of a trap, or the hydrocarbons are lost from the system through groundwater interactions or released at the surface. Traps are geological or stratigraphic structures that provide accommodation space for hydrocarbons to accumulate, such as a dome-shaped folds, or a lens of porous sandstone surrounded by low permeability shale. The trap must also be sealed by low permeability strata such as shale, to prevent hydrocarbons from being lost from the trap. Many conventional traps are layered in order of specific gravity and buoyancy, with a gas cap at the apex, underlain by oil (as shown for the 'Vertical Well' in Figure 2).

Petroleum resources in conventional systems are typically extracted by a combination of techniques that includes taking advantage of natural underground pressure gradients, artificial lift driven by pumping and fluid injection.

Unconventional Petroleum Systems and CSG

In unconventional petroleum systems, oil and gas accumulate in a reservoir that does not fit the conventional reservoir model. Unconventional systems represent resources where some aspect of the conventional system has not eventuated (e.g. hydrocarbons have not been expelled from the source rock) or is unable to occur (e.g. 'tight' low permeability rocks preventing migration). In the past, unconventional resources were largely ignored, due to the technical challenges of extraction and high costs of development. However, increasing global demand for energy in conjunction with advancements in drilling and extraction technology have led to many unconventional resources becoming economically feasible to extract.

Examples of unconventional petroleum systems:

- **shale oil and gas** – (shown as 'Horizontal Well' in Figure 2) organic content in shales is converted into oil and gas, but some of that fluid was expelled due to the low permeability of the shale; they must be produced by stimulating the formation through hydraulic fracturing
- **tight oil/gas** – hydrocarbons migrate from the source rock and accumulate in a very low permeability reservoir; usually produced by stimulating the formation through hydraulic fracturing
- **CSG** – (shown as 'Coal Seam Gas' in Figure 2) the coal seams are both the source rock and the reservoir rock; gas is adsorbed to the surface of the coal, and production requires the

hydrostatic pressure within the seam to be reduced via reduction of water levels to liberate gas; hydraulic fracturing may be used to stimulate low permeability seams.

Unconventional resources typically require additional technology or capital expenditure to extract the hydrocarbons compared to conventional oil and gas.

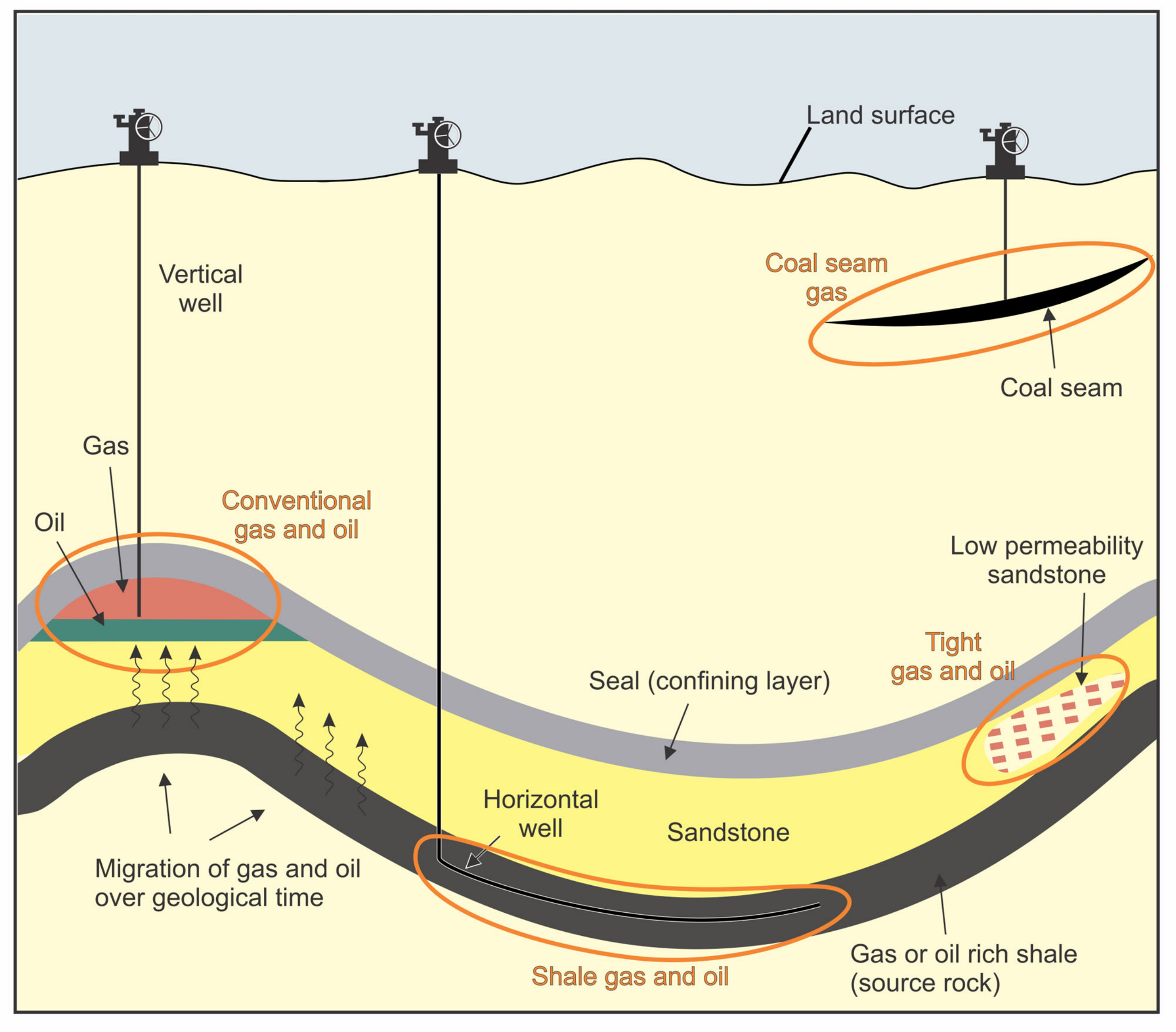


Figure 2: Examples of sonventional and unconventional reservoir types

Modified from http://www.eia.gov/oil_gas/natural_gas/special/ngresources/ngresources.html

Geology of CSG resources

Coal is a type of sedimentary rock formed predominantly of plant material that has been physically and chemically altered by heat and compaction during prolonged burial, through a process called coalification (Flores, 2014). The primary constituents of coal include organic matter, called macerals, and nonorganic components derived from mineral matter. Due to its high concentration of organic material, coal is a prolific source rock for natural gas, specifically methane.

Coal deposits are described in terms of their type and rank. Coal type describes the provenance of the original material that formed the deposit, ranging between end members of humic (woody peat sources) and sapropelic (algae, pollen, and fungal sources) (O'Keefe et al., 2013). Rank describes the thermal maturity of coal seams; rank increases with increased temperature and pressure conditions, and the duration of burial. The lowest rank of coal is lignite, also known as brown coal, progressively increasing in rank to sub-bituminous, bituminous, to the highest-rank end-member of anthracite. As coal thermally matures, volatiles and moisture are driven off, and the calorific value and carbon content increases (Moore, 2012; O'Keefe et al., 2013).

Coal seams within the Walloon Subgroup are largely of sub-bituminous rank (Ryan et al., 2012).

Coal gas species come from either biogenic or thermogenic origins. Biogenic processes that generate methane can occur at any stage during the coalification process, provided the subsurface conditions allow for the survival of methanogenic microbes. Biogenic methane is formed from the breakdown of organic material by methanogenic microbes in peat and coals, or by microbial alteration of pre-existing gases.

Thermogenic gases including carbon dioxide and methane begin to be generated at temperatures approaching or above 70 °C. Thermogenic gas is mainly produced from the thermocatalytic conversion of coal (Faiz & Hendry, 2006). The populations of different gases within coal seams are influenced by chemistry of the source material (i.e. related to coal rank and type), and how it is expelled or preserved (e.g. permeability, basin formation history, hydrogeology, and depositional environments) (Faiz & Hendry, 2006).

The gas in coal seams within the Walloon Subgroup is predominantly biogenic in origin.

Through the process of coalification, coal typically develops a series of permeable fracture networks called cleats; these fracture systems typically become more closely spaced as the rank increases (Thomas, 2012). Cleats form as perpendicular sets; a pervasive set that is called the face cleat, and a second set abutting the first, called a butt cleat. The natural cleat system in coal, along with other ground fractures, provide permeable pathways for gas production. In the case of very low permeability seams, additional stimulation techniques such as hydraulic fracturing may be used to increase the connectivity of existing fracture networks, or to create new ones.

Around 10% of CSG wells in the Walloon Subgroup have been hydraulicly fractured.

Comparisons of CSG to conventional systems

In relation to CSG, the key challenges associated with the development of these types of reservoirs are:

- **Liberation of gas**: gas in coal seams is adsorbed to the surface area of the coal and held in place by groundwater pressure. Therefore, the gas reservoir of the coal seam is ‘capped’ by the pressure of groundwater, which must be reduced (by pumping water out of the coal seam) to a reach critical desorption pressure and allow gas to flow. This requires extra effort and cost compared to producing from a conventional reservoir, where hydrocarbons flow freely under natural reservoir pressure upon drilling through the cap rock.

- **Production**: Gas flow pathways from the coal seam to the production well are restricted to the inherent cleat systems in the seam, and existing or man-made fracture networks, rather than the well-connected porosity of a conventional sandstone reservoir.
- **Extent**: Coal seams as reservoirs are typically laterally extensive, and require large numbers of wells to extract the resource, compared to conventional reservoirs which can typically be extracted by a relatively small number of wells.

1.2 CSG project life cycle

The life cycle of CSG projects is largely similar to that of other hydrocarbon resources, and consist of five main stages; exploration, appraisal, development, production, and finally decommission and rehabilitation (Figure 3). The schedules and activities defining how a CSG project might proceed varies between projects, depending on the geology of resource, economic, environmental and social factors.

Among the most significant differences between CSG and conventional petroleum resources are the lateral extent of the resource and the low permeability of the reservoir, which requires large numbers of wells to be drilled in order to access the resource. Horizontal wells may be used to access more of the resource from each well and hydraulic fracturing may be required in low permeability reservoirs to allow sufficient production rates.

1.2.1 Exploration

The main aims of the exploration phase of a CSG project are to determine the presence of a resource, define its extent and characterise the reservoir. The key activities during the exploration phase include:

- **Analysis** of precompetitive data (data provided by government agencies) and company reports from previous explorers. This allows current explorers to determine areas to focus on, what additional data need to be collected, and to plan appropriate exploration activities.
- **Geophysical surveys**. The primary type of geophysical data collected for CSG exploration is seismic survey data. Seismic surveys use an energy source to create waves of energy that travel through rock, and records their reflections from subsurface strata using arrays of receivers at the surface, called geophones. This reflection data can then be used to create images of the subsurface. Seismic surveys can be conducted in 2D along a single line, or in 3D as perpendicular arrays covering an area. Seismic surveys generally have low environmental impact where they use existing access routes such as roads, but larger 3D surveys may require some clearing for vehicle access tracks. Other types of geophysical surveys are magnetic and gravity surveys, which can be conducted using airborne or land-based methods requiring single vehicle access.
- **Drilling of exploration wells**. Wells are drilled into the target strata to test for the presence of a resource, as is in the case of CSG, coal seams bearing gas. Drilling methods are described in section 1.3.1.

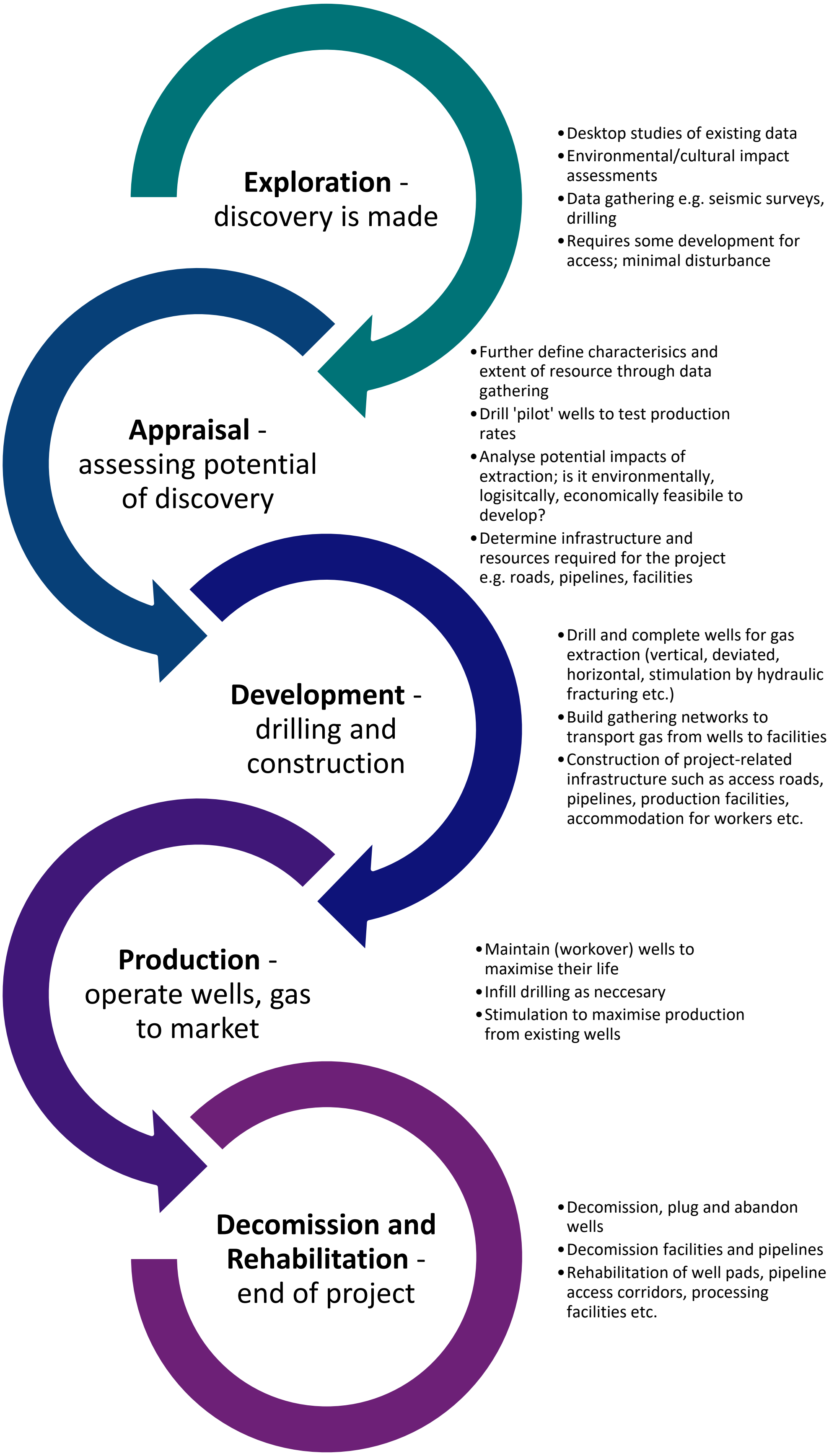


Figure 3: Schematic of the life cycle of a CSG project.

Most exploration wells are drilled vertically and may target and test multiple zones where feasible. Key information collected from a CSG exploration well includes the presence and thickness of coal, permeability of the coal seams and overlying formations; the gas content of the coal, subsurface temperatures and pressures; geochemistry of coal; geomechanical properties such as strength and elasticity, and the presence of natural fracture systems. These data may be gathered by wireline logging or formation testing in situ, or collected from core samples obtained during drilling which are then tested in a laboratory.

The exploration phase generally consists of a drilling campaign of multiple wells and the number of wells is dependent on the size of the area being explored and the complexity of the subsurface geology.

Production testing may also be conducted on selected wells during this phase, to investigate the productivity of the gas resource. Well configurations including horizontal drilling and hydraulic fracturing may also be conducted to test well productivity and explore development options. Produced gases from these exploration wells are generally flared, unless there is existing infrastructure nearby to collect it.

The exploration phase typically involves construction and clearing activities for essential infrastructure, well pads and access tracks. Laydown yards for supplies, water collection, storage and treatment facilities and temporary accommodation for drilling crews are some examples of infrastructure that may be required during the exploration phase.

Cultural heritage and environmental surveys are also often included in the exploration phase, to develop relationships with local communities and communicate information as resource exploration progresses. Petroleum companies are required to conduct these activities in accordance with the regulatory framework, to ensure that impacted regions have been identified and are appropriately managed. Work conducted during this time can also inform on the cultural, heritage and environmental issues to be addressed and managed if there is subsequent development.

The exploration phase for a project typically lasts 3 to 5 years, depending on the complexity and geology of the resource, and other social, economic and environmental factors, primarily commodity prices and market accessibility.

1.2.2 Appraisal

The appraisal phase aims to further define and characterise a resource identified from the exploration phase. Data gathered during this phase will inform a final investment decision on whether to proceed to the development phase. External financial and commercial factors also play an important role in investment decisions.

The appraisal phase can take several years, and activities often overlap with those undertaken during the exploration phase. The activities in the appraisal stage are like those undertaken during the exploration phase, however, appraisal programs are more focused on proving the drilling and production engineering methods that would enable commercial production of gas from the identified resource.

Key activities during the appraisal phase include:

- **Drilling of appraisal wells, production pilots** to further delineate and characterise the strata, and to test configurations of wells in order to optimise production. This includes trialling different drilling methods such as vertical vs horizontal wells reservoir stimulation methods such as hydraulic fracturing methods, and well completion designs. Production pilots for CSG are commonly drilled in configurations of four or more wells.
- **Extended production testing** is carried out over several months with the aim of determining the estimated ultimate recovery for each well. This parameter is critical in defining the technical and commercial viability of a development. Gas produced during production testing is typically flared.
- **Additional geophysical surveys** may be conducted to better define extent of the resource.

In addition to resource characterisation, key information-gathering activities are conducted during the appraisal phase to define the necessary materials and requirements for developing ancillary infrastructure needed for the project. This might include identifying water resources, selecting suitable sites for camps and facilities, delineating access routes for equipment and gathering networks, and the estimated of costs associated with these requirements.

Activities undertaken during the appraisal stage require similar infrastructure to the exploration phase and infrastructure may be reused between the two phases. Further data may be collected on cultural, heritage and environmental values to facilitate planning of a potential development phase.

1.2.3 Development

The development phase in a CSG project lifecycle involves the construction of the initial production infrastructure for CSG production. During this phase, large numbers of wells are drilled at development well spacing determined from appraisal phase production testing, and construction of all infrastructure to process gas and transport it to market gets under way. This period usually is the most intensely active in the life of a CSG field.

The duration of this phase depends on what pre-existing infrastructure is available in the area, and what else is required to support the project. Development and production phases often overlap as the first wells come online and begin production, as drilling continues to ensure consistent supply to facilities. Operations can continue to grow over time, as fields are added to and expanded from the exploration and appraisal of surrounding areas.

Activities at this phase include the following:

- **Drilling of development wells**. Wells are drilled and completed to produce gas for market. Well counts depend on the optimised spacing for maximum recovery, the average production rate for each well, the average rate of production decline for each well, and the combined total production volumes required to maintain facilities. Hydraulic fracturing may also be required depending on the permeability of the reservoir.
- **Development of field infrastructure**. Significant infrastructure is constructed during this period, including:
    - access roads

- gathering networks (pipelines) for delivery of produced gas and oil to processing facilities
- processing plants to allow the separation of different components of the gas/oil and impurities such as carbon dioxide and hydrogen sulfide
- compression facilities for the delivery of gas to transmission pipelines
- power supply for processing plant, compression stations and other infrastructure
- water supply (water bores, storage dams and treatment facility)
- storage areas, laydown yards, workshops, administrative offices and camps for drilling and construction crews.

1.2.4 Production

The production phase begins once development of the resource has reached the stage where gas commercial quantities of gas can be produced. CSG wells experience declining production throughout their life span, and so new wells must continue to be drilled to maintain required production rates throughout the life of the project. Production from existing wells may be improved by performing a ‘work over,’ which involves cleaning out any fine material that has accumulated in the well, and potentially restimulating some coal seams.

During production, the main activities include:

- workover of production wells (to improve productivity)
- infill drilling and hydraulic fracturing to replace depleted production wells
- construction of additional pipelines for gathering networks
- production and processing of gas/oil
- plugging and abandoning of depleted wells, and rehabilitation of associated well pads.

1.2.5 Rehabilitation

At the end of their production, wells must be plugged and abandoned; facilities, compression stations and pipelines must be decommissioned (if they cannot be used for other resources); and all sites must be rehabilitated in compliance with requirements set out in production and environmental approvals, as well as any other regulatory approvals specific to the project.

Abandonment of wells is a continuous process throughout the life of the field as early-producing wells reach the end of their life while older wells continue production.

Activities during the rehabilitation phase are likely to include:

- decommissioning, plugging and abandoning of wells; and rehabilitation of well pads
- decommissioning and rehabilitation of pipelines and pipeline access corridors
- decommissioning of the processing plant and compression stations, and rehabilitation of associated sites

- decommissioning of associated infrastructure, including power and water supplies, laydown yards, workshops, administrative offices, workers' accommodation and access tracks/roads.

1.3 CSG activities overview

The process for extracting CSG is determined by the characteristics of the resource. The resource is accessed through wells, which allow water to be removed from the targeted coal seams, which in turn allows gas to flow. The water that is brought to the surface is gathered and treated before being returned to the environment. The gas is gathered, any remaining water is removed, and then it is compressed and sent via pipelines to market. Well fields are distributed over a large area to access the laterally extensive resource. Figure 4 shows a flow diagram of activities in a typical CSG field development. The following section describes these activities.

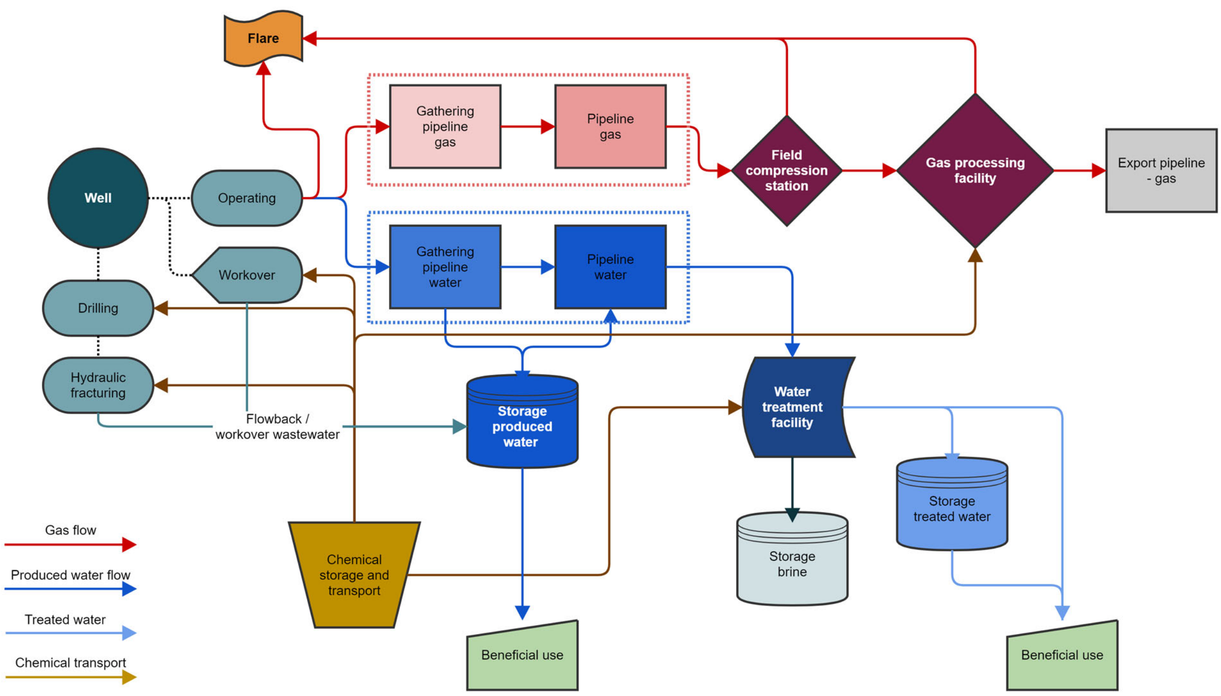


Figure 4: Key components of a typical CSG development in Queensland (note that less than 10% of CSG wells in the Surat Basin have been hydraulically fractured).

1.3.1 CSG wells and drilling

The drilling technology used in Surat Basin has progressed significantly since the first well was drilled into the Walloon coals in the 1920s to produce water (APPEA, 2015). A variety of CSG well designs developed to accommodate gas production from coal seams. The well configuration for CSG generally comprise three types, vertical, deviated and horizontal wells (Figure 5).

Vertical wells are drilled through several coal seam layers and normally are designed to target multiple CSG reservoirs. Deviated wells are drilled using directional drilling technics to be inclined from the vertical and are used to avoid surface features or reduce the surface footprint by drilling muiltiple wells from one well pad. Horizontal wells, (including configurations known as surface to in-seam (SIS) wells), are firstly drilled vertically from the surface to a specific depth and then deviated to the horizontal direction into the coal seam, increasing the contact area between the well and reservoir and hence gas production (Bennett & others, 2012; Towler et al., 2016).

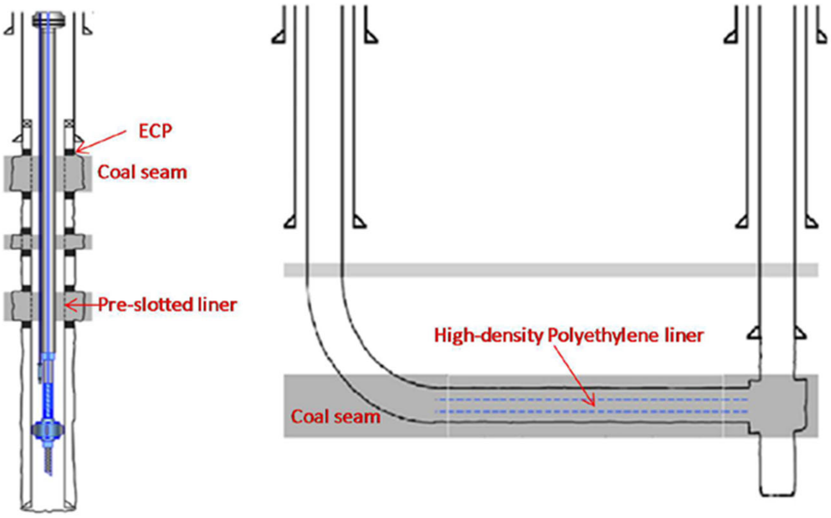
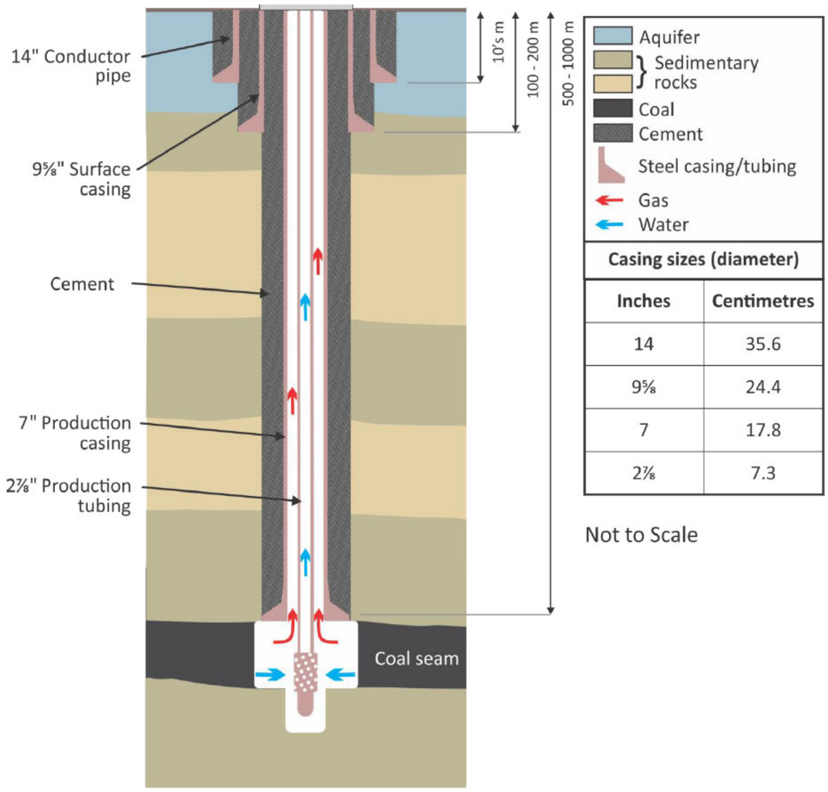


Figure 5: Typical CSG well design; vertical well (left) and surface to in-seam (SIS) well (right) (Jeffrey et al., 2017).



Casing sizes (diameter)	
Inches	Centimetres
14	35.6
9⅝	24.4
7	17.8
2⅞	7.3

Figure 6: Schematic diagram of casing series installed in a vertical drilled well (Huddlestone-Holmes et al., 2018).

The drilling process commences with the surface hole section that is "spudded" at a predefined location. The initial section of the well is then drilled to a shallow depth where the conductor casing is run into the drilled hole and cemented in place as shown in Figure 6. The conductor casing provides a foundation for the well, holds back unconsolidated surface soil layers, isolates shallow groundwater and allows for well control equipment to be installed at the surface. The surface hole is then drilled and the surface casing installed and cemented in place. The main purposes of the surface casing are to protect shallow groundwater aquifers and to contain pressures that might occur in the subsequent drilling process. The final stages are to drill the production hole down to the total depth in the target coal layers followed by the installation of production casing installation, as shown in Figure 6. Each installed casing is a sequentially smaller in size than the previous installed casing such that shallow portions of the well feature multiple concentric casings (API, 2009; Thakur et al., 2014). Groundwater is protected from contamination by a combination of steel casings and cement sheaths.

The casing sections are cemented, and pressure tested to ensure zonal isolation is achieved for each casing. The advantages of installation of multiple casing include (APLNG, 2017):

- isolation of nontargeted formations
- preventing containment transfer to the ground water
- well stability and well control.

After well establishment, the production casing is the main casing exposed to fluid flow. The production casing provides the flow path for gas and produced water to be extracted from coal layers or stimulation fluids to be injected into that layer. A final completion string (or production tubing, Figure 6) is installed in production casing which may include monitoring equipment such as pressure sensors or pumps to help produce gas and water from the well.

The drilling activities are managed in accordance with industry best practice, company standards, and local regulations (APLNG, 2017; Origin Energy, 2017; Queensland Department of Natural Resources, 2019). According to best practice guidelines recommended by American Petroleum Institute (API), the drilling and completion of an oil and gas well may consist of the following sequential activities (API, 2009):

- building the location and setting up the drilling rig
- drilling the hole
- logging the hole to record subsurface conditions
- running the casing (steel pipes)
- cementing the casing in place
- logging through the casing to evaluate cement quality
- perforating the casing at the target layer (depending on completion design)
- well stimulation or hydraulic fracturing
- installing artificial lift equipment (if necessary)
- monitoring well performance and integrity.

The integrity of a drilled well describes its ability to prevent the uncontrolled flow of fluids (including gas) into or out or the well. Well integrity is necessary during all stages of a well’s life cycle, including after it has been formally decommissioned. A primary requirement for all CSG wells is that well integrity is maintained at all times (Queensland Department of Natural Resources, 2019).

Cementing

Cementing is a critical part of the drilling process. Cement is used to hold casing in place, maintain well control and provide zonal isolation through the life of the well. It prevents fluid migration between subsurface formations through the annulus between the casing and the drilled hole, and between different casings. Cementing operations are conducted by pumping cement slurry down the inside of the casing and circulating it back up through the casing-casing or casing-drilled hole annulus. In this operation top and bottom wiper plugs are used to prevent contamination of the injected cement by drilling fluid as shown in Figure 7. The cement slurry is mainly comprised of cement (~68%) and water (~30%). Similar to drilling muds, the cement slurry contains additives (~2%) to modify the properties for desired design purposes (Origin Energy, 2017). A typical cement composition for CSG wells is presented in Figure 8.

Proper cement placement requires that the cement completely occupies the void space around the casing and up to a suitable height (cement top) above the bottom of the drilled hole. The cementing operation usually comprises two stages of lead and tail cements. The lead cement has lower density whereas the tail cement possesses higher density and mechanical strength. The main functionality of tail cement is to isolate sensitive intervals of the well. To assure cementing performance, it is necessary to have suitable borehole conditioning prior to the operation. Utilising casing centralisation, and pipe movement helps to achieve better isolation of the target zones (Thakur et al., 2014).

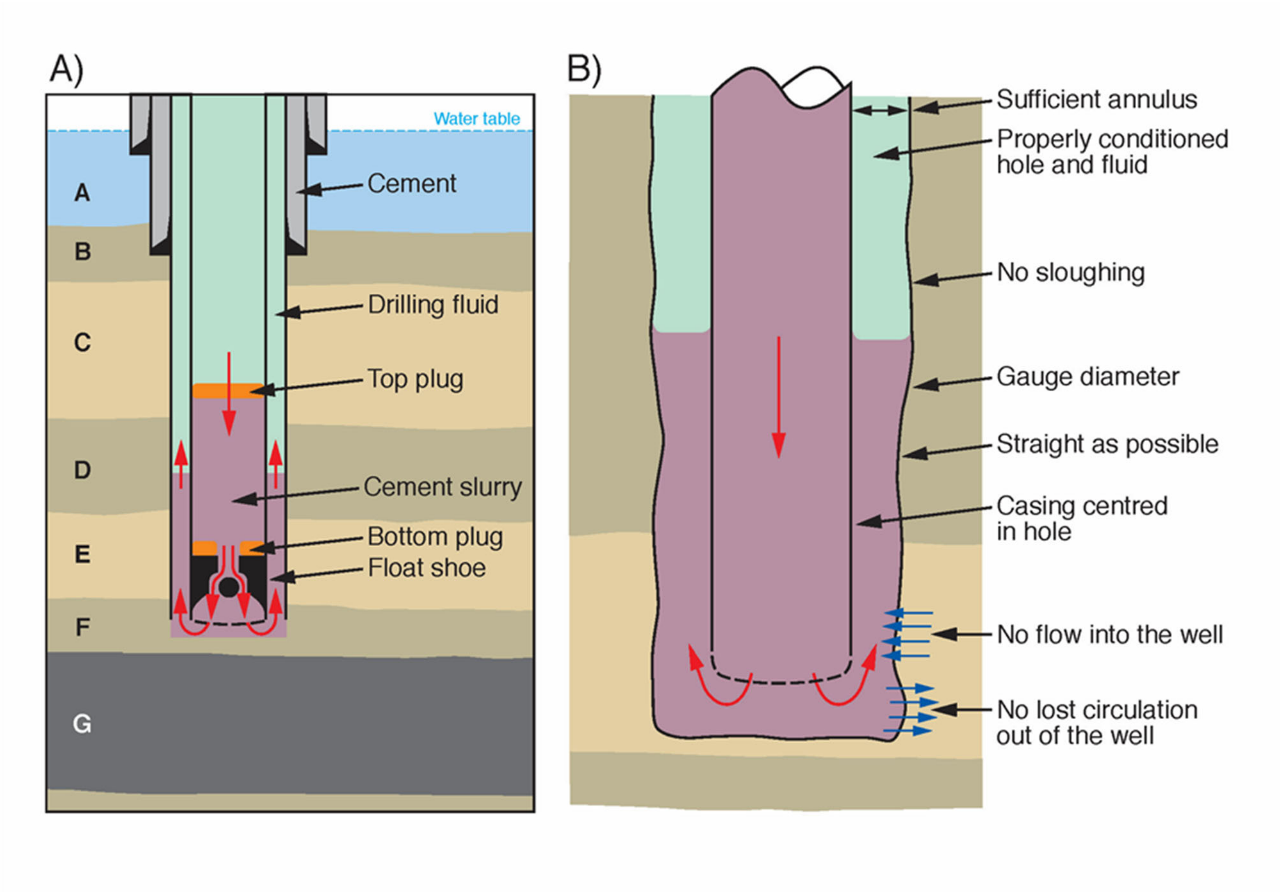


Figure 7: Schematic illustration of the cementing operation (Huddlestone-Holmes et al., 2017).

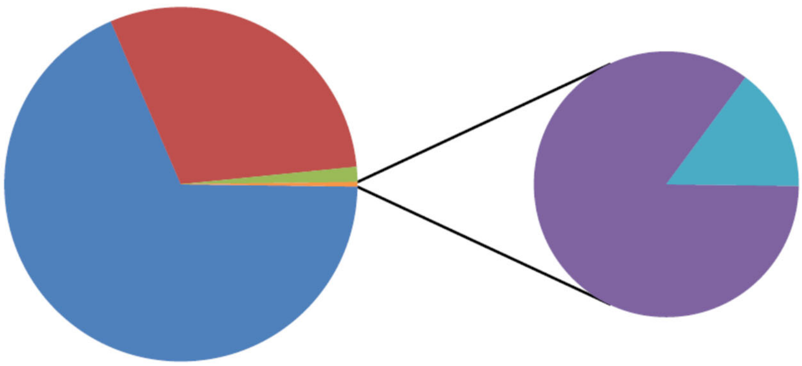


Figure 8: Typical components of cement mixture in CSG drilling process (Origin Energy, 2017).

Drilling mud

Drilling fluids are usually referred to as drilling muds and are a vital component of the drilling process. While drilling is in progress, mud is circulated down the drill string and back up to the surface between the drill string and the drilled hole (or casing). Drilling fluid is comprised of a base fluid and chemical additives. The base fluid forms the majority of the mud's volume and can be in the form of either a liquid (typically water) or a gaseous mixture such as air-foam. Drilling additives are added to the base fluid to adjust or improve mud properties such as density, viscosity, pH and fluid loss. Additives are selected based on the specific drilling conditions, geology and reservoir pressures.

Some main functionality of drilling mud includes:

- well pressure control
- lifting drill cuttings to the surface
- cooling and lubricating the drilling bit and drill string
- maintain the wellbore integrity during drilling process

Drilling muds used in CSG wells are mainly water, as shown in Figure 9, with varying amounts of additives used to provide and maintain the required chemical and rheological properties (Origin Energy, 2017).

Some examples of the types of drilling additives used are shown in Table 1. The composition of drilling fluids is determined on a well-by-well basis, although it is common for wells drilled in one area or as part of a single drilling campaign to use a standard approach. Some wells will not use any drilling additives and be drilled using water and clays derived from the formation being drilled, while others may require a more complex mixture of additives. These requirements are determined by local conditions and any problems encountered during drilling. For example, if a clay rich formation is encountered during drilling additional additives may be required to stabilise the well. If the well intersects fractured ground, then loss control materials may be required. Drilling additives are also selected to avoid damage to the target reservoir formation and drilling equipment. The composition of the drilling fluid may be adjusted throughout drilling operations or for specific activities (cleaning out the well before cementing, for example).

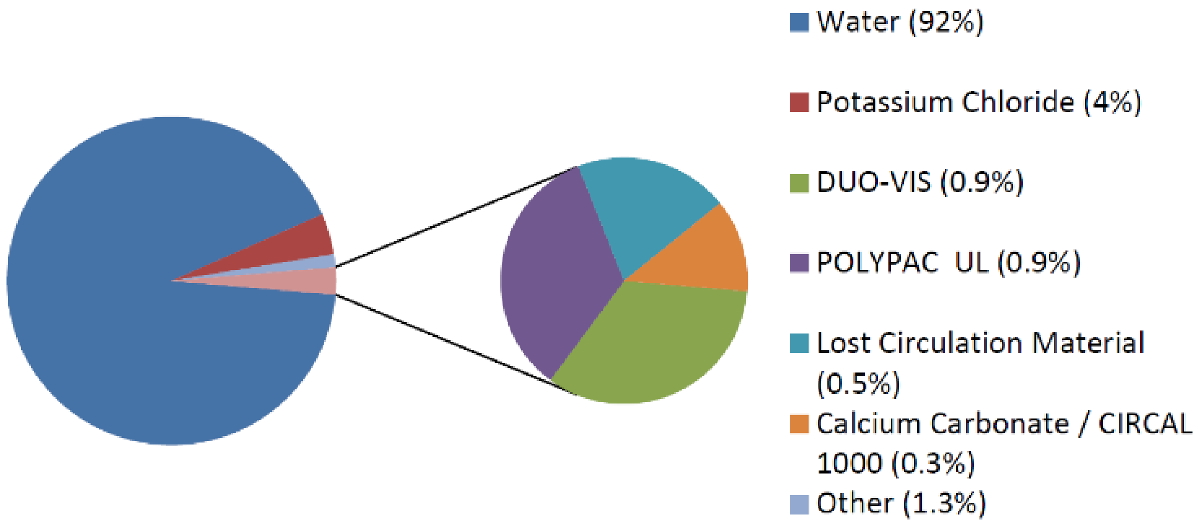


Figure 9: An example of drilling mud composition used in the CSG drilling process. Composition will vary dependent on local geological conditions and operational requirements (Origin Energy, 2017).

Drilling fluids are used to manage well pressures to avoid uncontrolled flow of fluid into or out of the well during drilling:

- If the pressure of the drilling fluid in the well exceeds the pressure of fluid in the formation, drilling fluid will flow out of the well (if there is sufficient permeability). In this case drilling fluid is lost to the formation.
- If the pressure of fluid in the formation exceeds the pressure of the drilling fluid in the well then fluids will flow into the well. In this case drilling fluid is gained from the formation.

Losses and gains of drilling fluid are generally undesirable. Drilling practices and additives are used to prevent losses or gains by managing pressures (through the use of weighting agents like salt or barite) or by creating a low permeability barrier on the walls of the wellbore (through the use of clays that clog permeable pathways). For most wells, the majority of drilling fluid used in the well is returned to the surface throughout the drilling process. There are occasions where a substantial volume of drilling fluid is lost to the formation.

The amount of drilling fluid used in a well is related to the well's diameter and depth (its volume). For example, an 8 ¾" diameter well that is 800 m deep has a total volume of around 25 000 litres. The amount of drilling fluid at a well site will include the fluid in the well and in holding tanks or pits, and is in the order of 50 000 to 100 000 litres.

Well completion

Well completion is the strategy and methods utilised for making a well ready for production, or any other intended purpose such as monitoring, following the drilling process. To provide an interface with the drilled wellbore, a wellhead is installed at the surface on top of wellbore. The wellhead allows the wellbore to be "shut in" as required, for instance, when suspended. It also provides a connection to the surface infrastructures such as pipelines, pumps and separators for gas production.

Table 1: Examples of additives used in drilling fluids used in CSG wells and their purpose.

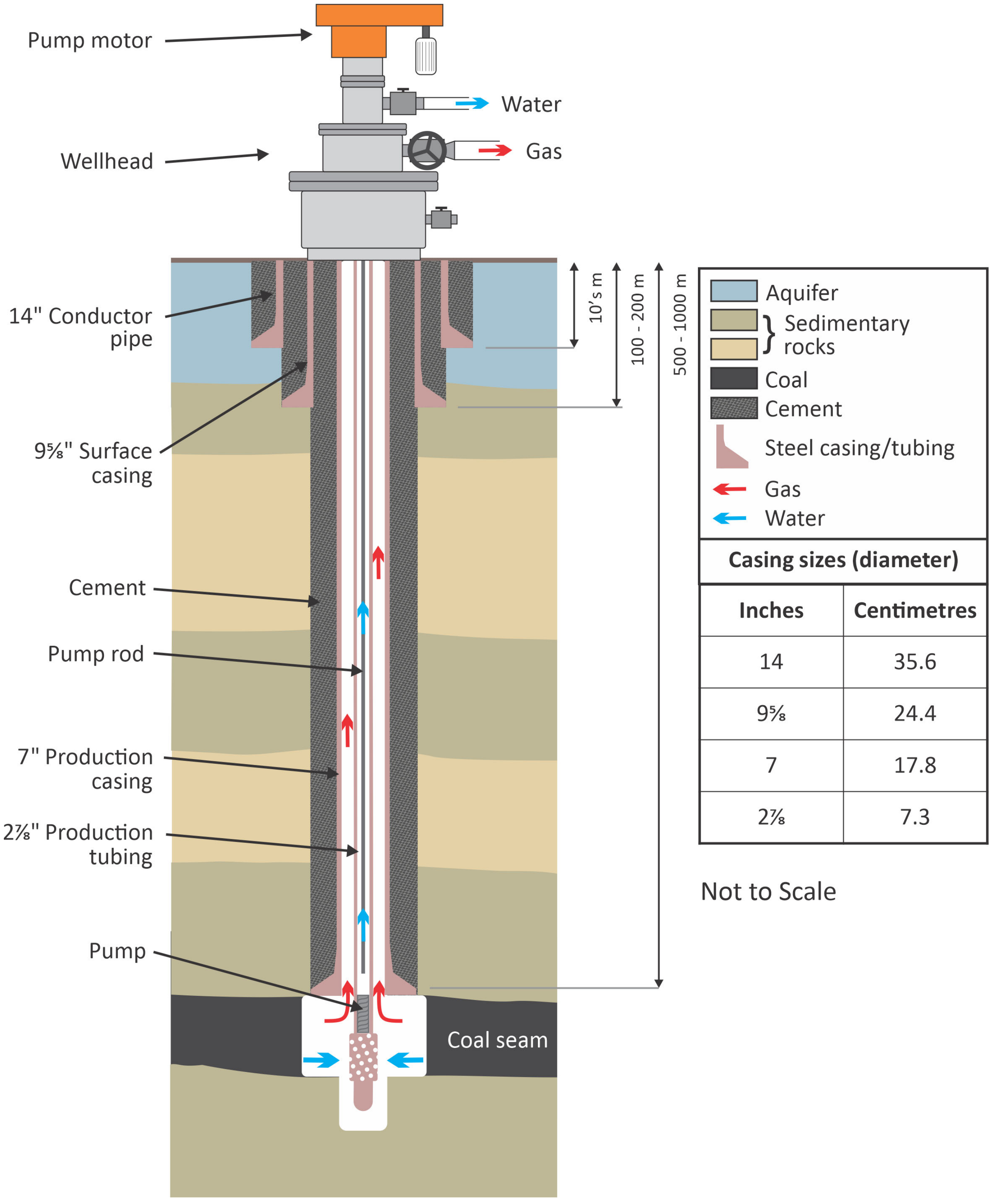
Additive type	Purpose and description	Common additives
Clay inhibitor	Some clays in the formation being drilled may react to fresh water, causing well instability or clogging. Adding salt to the drilling fluid prevents the process from occurring.	Salts, typically KCl
Weighting agents	Increasing the density of the drilling fluid allows it to provide support to the formation being drilled and prevent the inflow of water or gas into the well.	Bentonite clay (also called "Gel"), Barite, Salts
Viscosifiers	Increasing the viscosity of the drilling fluid increases its ability to lift drill cuttings out of the well.	Bentonite clay, polymers (such as polyanionic cellulose)
Loss control	Preventing the loss of drilling fluid from the well during drilling is important to maintaining well integrity. Loss control materials block permeability within the formations being drilled to prevent the loss of drilling fluid.	Bentonite clay, polymers, natural or synthetic fibres
Lubricants	To increase the lubricating properties of the drilling fluid either at the drill bit or along the drill string to increase drilling performance.	Polymers
Surfactants	Modify the surface tension of the drilling fluid to improve cleaning of the well (drill cuttings removal), to decrease foaming in certain formations, or to remove other additives from the well.	Detergents, defoamers
Biocides	Biocides are used to prevent microbial growth in the drilling fluid in surface tanks or pits and in the well.	Glutaraldehyde

Artificial lift

The fluid pressure within the coal seam is usually not sufficiently high for water and gas to flow to the surface naturally. It is common practice to artificially lift water to the surface, allowing the gas to flow. Artificial lifting may include a single or combination of methods such as (Oyewole et al., 2008):

- sucker rod pump (SRP)
- progressing cavity pump (PCP)
- electrical submersible pump (ESP)
- hydraulic jet pump
- gas lift
- foam lift

A CSG well is normally completed with a pump as the artificial lift method. Fluid may flow in both tubing and annulus. In a typical CSG well, water is produced through the tubing and gas flows via the adjacent annulus (Gaurav et al., 2012). The two most common pumping technologies used in CSG wells are ESP and PCP. Figure 10 shows a schematic diagram of a CSG wellbore equipped with a PCP driven be a motor at the surface having three cemented casings and a production tubing.



Casing sizes (diameter)	
Inches	Centimetres
14	35.6
9⅝	24.4
7	17.8
2⅞	7.3

Figure 10: Typical completion of a vertical CSG well (not to scale) (Huddlestone-Holmes et al., 2018).

1.3.2 Hydraulic fracturing

Hydraulic fracturing is used in CSG to improve the connectivity of the well to the reservoir (Holditch et al., 1988). Fluid is pumped under pressure through a well to open existing fractures and create, propagate and open new fractures in a low permeability rock. CSG reservoirs have permeabilities that mean that only a proportion of CSG wells require hydraulic fracturing to stimulate higher levels of production. Hydraulic fracturing is an advanced engineering activity and there are a range of factors considered during the design and planning of stimulation activities. These include:

- stresses within the coal seam and adjacent formations
- coal seam pore pressure
- coal seam permeability
- mechanical properties of the coal seam and adjacent formations
- coal layer thickness and the thickness of the adjacent rock layers
- the presence of any existing faults.

Hydraulic fracturing operations

Hydraulic fracturing operations are usually conducted over a short period, typically less than two weeks. These operations require a range of equipment and materials to be brought to the well site, consist of multiple activities and involve a process involving repetitive stages.

Hydraulic fracturing in CSG wells requires the mobilisation of a significant amount of plant and equipment. The most important component is the large trailer-mounted pump units. A number of these hydraulic fracture pump units work together to inject hydraulic fracturing fluid at the required pressure and flow rate to propagate the hydraulic fracture. Hydraulic fracturing fluids, as commonly used in CSG hydraulic fracturing operations, are typically composed of water (~90%), sand (~10%) and other chemical additives (~0.5%) that are blended and pumped from tanks and holding ponds, then through the hydraulic fracture pumps to the wellhead. Figure 11 shows an example of a hydraulic fracturing site layout (referred to as a 'hydraulic fracture spread' in industry) in the Surat Basin. In addition to the hydraulic fracture pumps, other equipment used includes storage tanks for water and sand, chemical storage trucks, monitoring equipment, blending units, manifolds and high-pressure piping. Hydraulic fracturing of a CSG well may be conducted over one or more intervals along the production zone of the well, called 'hydraulic fracture stages.' Hydraulic fracturing of each stage treats a discrete volume of the reservoir. This staged approach allows more control of the hydraulic fracturing process. It is also generally not possible to hydraulically fracture the whole well in one step. For each hydraulic fracture stage, the steel casing in the well must be perforated to allow the hydraulic fracturing fluid to flow into the reservoir, and subsequently to allow gas and oil to flow from the reservoir into the well during production. This step is typically done using a perforation gun that uses small explosive charges to punch holes in the casing. Preperforated casing can also be used during the construction of the well, however, this is less common. The interval of the well is then isolated with packers or other mechanical device, which allow the hydraulic fracturing fluid to be focused on that stage. The hydraulic fracturing fluid is then injected. This injection process may consist of a number of steps, such as:

1. **Spearhead/acid step**. This step involves injection of diluted acid to clear debris from the well and allow hydraulic fracturing fluids unhindered access to the target interval.

2. **Pad step**. This step involves injection of hydraulic fracturing fluid without proppant to initiate the hydraulic fracturing in the target interval. In this step, additives such as friction reducers and clay stabilisers are used to facilitate fluid flow.
3. **Proppant step**. Once the hydraulic fractures have initiated and opened sufficiently widely, proppant material (usually sand) and gelling agents (guar or xanthate gum) are added. The increased viscosity of the fluid improves the transport of proppants into the created hydraulic fractures. The proppant will remain in the formation once the pressure is reduced and 'prop' open the fracture network, thus maintaining the enhanced permeability created by the hydraulic fracturing program.
4. **Breaker step.** Gel breakers are used to liquefy gelled hydraulic fracturing fluid to promote flowback and recovery of some of the hydraulic fracturing fluid at the surface. This step is only required if gels are used.
5. **Flowback step.** After the injection is complete, the hydraulic fracturing and formation fluids are allowed to flow back to the surface to be collected and treated.
6. **Flush step.** Fresh water is pumped down the well to flush out any excess proppant and gels.

Once the injection is complete, the process is repeated for each stage along the production zone of the well.

Figure 11: An example of a hydraulic fracturing site in the Surat Basin, Queensland.

Hydraulic fracturing fluids

Hydraulic fracturing fluid is a mixture of water, proppant and additive chemicals. It is pumped down the well under pressure to initiate and grow hydraulic fractures. The ideal hydraulic fracturing fluid will maximise the connected reservoir volume and long-term permeability of the created fracture network. Considerations for the design of a suitable hydraulic fracturing fluid include:

- leak-off rate into formation matrix and natural fracture network
- control of unwanted biological (e.g. algae) growth in fracture fluid
- chemical interaction with formation rock and formation fluid
- friction losses during injection and effective transport of sand (proppant)
- remaining fluid residue post treatment
- cost
- wear on hydraulic fracturing pumping equipment
- risk of harm from exposure to chemicals.

Hydraulic fracturing fluid systems used in CSG developments can be divided into three different categories: gel systems, slickwater systems, and energised/foamed systems (nitrogen or carbon dioxide) (Ahmed et al., 2009; Palmer, 1992). The gel systems are beneficial in terms of their capacity to carry proppant (Palmer, 1992). However, these systems may damage the formation permeability by permanently plugging cleats in the coal if the gel does not break down. In slickwater systems, very high pumping rates are required due to the poor proppant-carrying capabilities of the thinner fluid. Foamed systems provide good outcomes and reduce the risk of damage caused by interactions between the coal and the fracture fluids. However, the risk of formation permeability damage exists even with foamed systems. For example, the surfactants employed in these systems can adversely affect the coal's natural wettability and decrease the rate of dewatering (Ahmed et al., 2009). All three fluid systems are water based, although the foamed systems can be foams or emulsions made with nitrogen or carbon dioxide.

The most common hydraulic fracturing fluid systems used in CSG are gel systems. The volumes of hydraulic fracturing fluid can be significant, with CSG treatments commonly using up to 1-5 ML of fluid per well. The fracturing fluid consists of water (the largest component), proppant which are transported into the fractures to prevent from closing after the high fluid pressure is removed, and chemical additives (Figure 12).

Proppant is usually silica sand, however, resin-coated sand, ceramics or bauxite (aluminium oxide) may also be used (Beckwith, 2010). Proppants are graded into specific size ranges, which are described based on mesh size. For example, in a 40/70 mesh sand, 90% of the particles will pass through a 70 mesh sieve (420 µm diameter) and coarse enough to be retained by a 40 mesh sieve (212 µm diameter). The size range of proppants used in hydraulic fracturing is between 200 mesh (75 µm) and 16 mesh (1.20 mm).

Hydraulic fracturing fluid additives

The category and concentration of chemical additives mixed into the fracturing fluid depend on the site requirements to serve different purposes according to specific formation characteristics including:

- enabling the fluid to develop into a gel and keep the sand in suspension (allowing more sand to be spread throughout the fractures and less water to be used)
- allowing the gel to break down after the process is finished

- enabling clays to be stabilised and to avert swelling
- enabling pH levels to be balanced
- avoiding bacteria transfers from surface water to the coal seams.

As highlighted in Figure 12, hydraulic fracturing fluid formulations are composed mostly of water and sand (proppant). Additives depicted on the right-hand side of Figure 12are used to improve the performance of the fracture treatment, prevent corrosion of the equipment and suppress algal growth. A typical shale gas or shale oil slickwater hydraulic fracturing fluid contains 3–12 additives (Figure 12a). A gel typically requires a higher volume of additives (Figure 12b), compared to slickwater fracturing.

Table 2 provides the purpose and description of additives used in hydraulic fracturing. There is no standard composition for hydraulic fracturing fluid, and the exact composition will depend on the objectives of the hydraulic fracturing operation and local conditions.

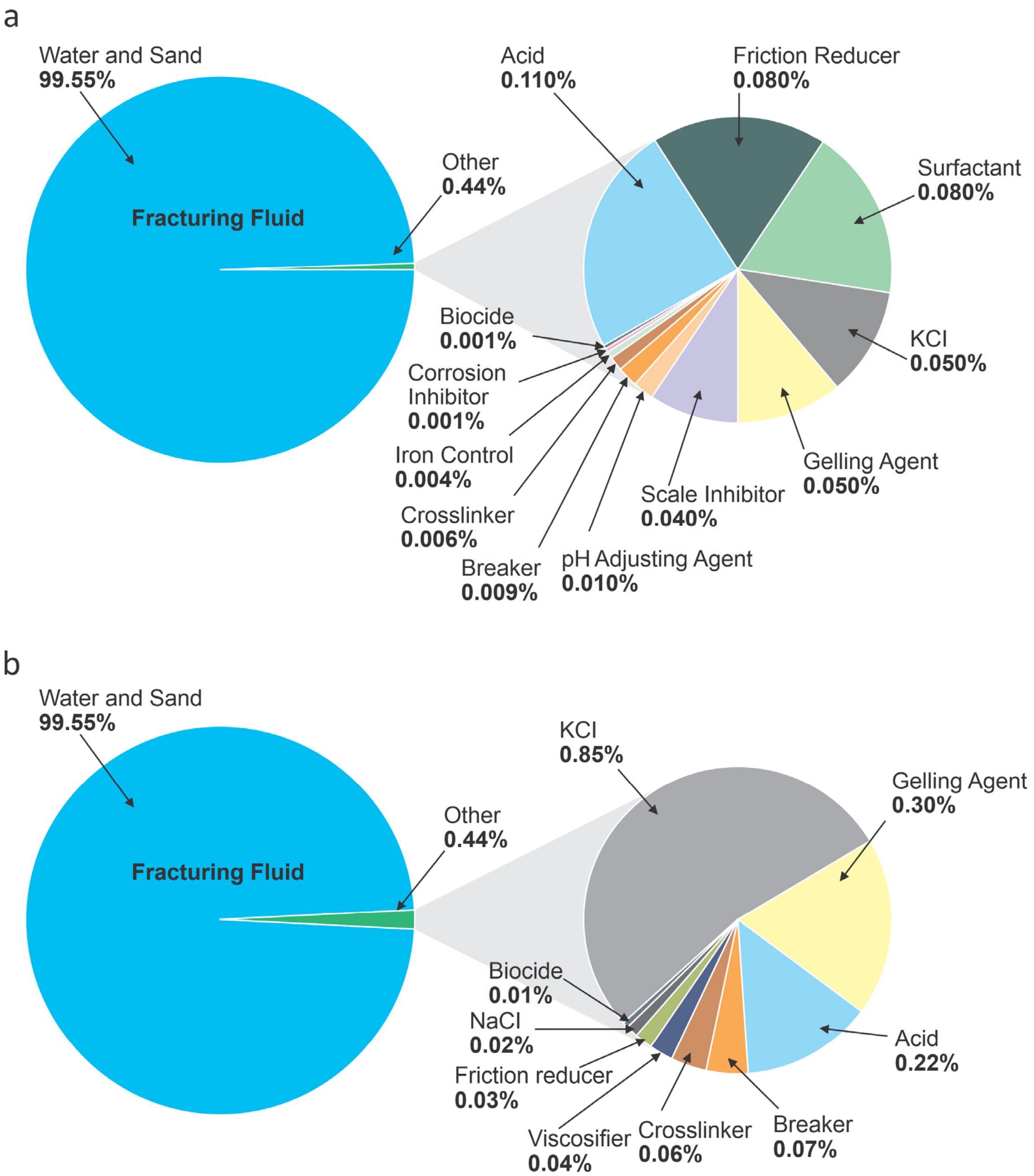


Figure 12: Examples of additive types and concentrations (v/v) of additives in hydraulic fracturing fluids for (a) a slickwater system and (b) a gel system.

Source: Adapted from Arthur et al. (2009) for (a) and Aecom Australia Pty Ltd (2017) for (b).

Table 2: Purpose and description of hydraulic fracturing fluid additives.

Additive type	Purpose and description	Common additives
Water	Creates hydraulic fractures and transports proppant	Fresh water (less than 500 parts per million total dissolved solids)
Proppant	Maintains fracture openings to allow the flow of gas. Stays in formation embedded in fractures (used to 'prop' fractures open)	Sand Clay or alumina ceramics
Friction reducer	Reduces friction pressure, which decreases the necessary pump energy and subsequent air emissions	Non-acid form of polyacrylamide Petroleum distillate Mineral oil

Acid	Helps dissolve minerals and initiate cracks in the formation	Hydrochloric acid Muriatic acid Carbonic acid
Biocide	Inhibits the growth of bacteria that can destroy gelled fracture fluids or produce methane-contaminating gases	Glutaraldehyde 2,2-dibromo-3-nitrilopropionamide
Surfactant	Modifies surface and interfacial tension, and breaks or prevents emulsions, aiding fluid recovery	Naphthalene 2-Butoxyethanol Methanol/isopropanol 1,2,4-Trimethylbenzene Poly(oxy-1,2-ethanediyl)-nonylphenyl-hydroxy Ethoxylated alcohol
Crosslinker	Cross-linking gels enable higher viscosities to be achieved	Borate salts Potassium hydroxide
Scale inhibitor	Prevents mineral deposits that can plug the formation	Polymer phosphate esters Phosphonates Ethylene glycol Ammonium chloride
Corrosion inhibitor	Prevents pipes and connectors rusting	N,N-dimethylformamide Methanol Ammonium bisulfate
Breaker or gel breaker	Introduced at the end of a fracturing treatment to reduce viscosity, release proppants into the fractures and increase the recovery of the fracturing fluid	Peroxydisulfates Sodium chloride
Clay stabiliser	Prevents the swelling of expendable clay minerals, which can block fractures	Potassium chloride Salts (e.g. tetramethyl ammonium chloride)
Iron control	Prevents the precipitation of iron oxides	Citric acid
Gelling agent	Increases the viscosity of the fracturing fluid to carry more proppant into fractures	Guar gum Cellulose polymers Petroleum distillates
pH adjusting agent	Adjusts and controls the pH to enhance the effectiveness of other additives	Sodium or potassium carbonate Acetic acid
Tracers	Tracers used to determine the extent of a fracturing operation and the amount of hydraulic fracturing fluid recovered during flowback. Includes chemical and radioactive tracers	Fluorobenzoic acids Radionucleides

Sources: Adapted from; P. Cook et al. (2013), Council of Canadian Academies (2014) and The Ground Water Protection Council (2016) The Ground Water Protection Council and Interstate Oil and Gas Compact Commission, (2016)

Queensland regulations restrict the use of additives that may contain polycyclic aromatic hydrocarbons and BTEX chemicals (benzene, toluene, ethylbenzene and xylene). The allowable levels of BTEX chemicals in hydraulic fracturing fluids are so low that these chemicals cannot be added. A risk assessment must be conducted for hydraulic fracturing operations as part of an environmental authority application, and the impacts of the chemicals used is one of the aspects that must be addressed.

Flowback

Once hydraulic fracturing is completed, flowback water will flow to the surface (or be pumped to the surface). The flowback water contains the chemicals added to the hydraulic fracturing fluid, as well as components present in the formation water. The initial composition will be close to that of the hydraulic fracturing fluid but will become gradually more dominated by the formation water.

Chemicals added to fracturing fluids may also break down in the subsurface or react with the formation or formation water. Flowback water needs to be treated before it can be disposed of, in most cases. The exact composition is location dependent, which will dictate the level of treatment required.

In Queensland, operators must monitor the quality and quantity of flowback water until one-and a-half times (150%) the volume of fluid injected during hydraulic fracturing has returned to the surface.

1.3.3 Surface facilities

CSG production requires pressure decline in the coal seams, which is largely achieved through water production. Once a well has been drilled to intersect the coal reservoir it provides the pathway for gas and water to arrive on the surface. These two fluids are separated, water transported to treatment points and the gas is transferred to production facilities where it is dehydrated, compressed and piped to the market.

Gathering systems

By the completion of a production well, CSG and water are produced to the surface, usually at low pressures. Gas and water gathering systems are then required to collect and transfer the gas and water to production facilities. The gathering system includes:

- wellhead facilities such as a water-gas separator vessel, electrical generator, electrical control panel, piping and control valves
- low-pressure pipelines to separately transfer gas and water from the wellhead to the production facilities
- medium-pressure pipelines to transport gas between production facilities
- compression to boost the pressure of gas in pipelines, if required
- vents and drains on pipelines to allow gas to be released from water pipelines and water from gas pipelines

Production facilities

Gas in the gathering systems is transferred to production facilities located several kilometres away from the well pads. The main functions of the production facilities are to dehydrate the gas to meet the required gas quality and to compress the gas to the required pressure for transport via pipelines. Production facilities work in combination with gathering systems (including field compressors) to manage the flow of gas from the well field.

Water treatment and storage

Gas production from coal seams often requires the extraction of large volumes of water to depressurise the underground reservoir allowing the gas to flow. This dewatering process may take weeks or up to several years, depending on the properties of the coal seam. Production of water is likely to continue throughout the production life of a resource. The bulk volume of produced water depends on the (Millar et al., 2016; Towler et al., 2016):

- volume of water in the coal seams
- rate and volume of water and gas production
- permeability of the coal seam
- number of the wells.

In Queensland, the design of water treatment and storage facilities must comply with Queensland's Coal Seam Gas Water Management Policy (Queensland Department of Environment and Heritage Protection, 2012). This policy encourages the beneficial use of CSG water in a way that preserves the environment and maximises its productive use as a valuable resource, as shown in Figure 13. The CSG water is mainly used for benefits of:

- environment
- existing or new water users
- existing or new water-dependent industries.

Treatment and disposal of CSG water may be considered to avoid or minimise the impact on the environment.

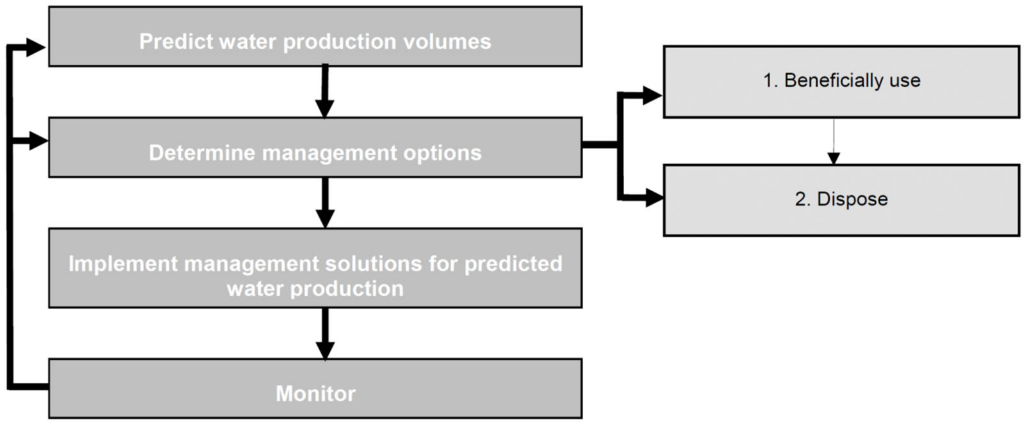


Figure 13: Strategic management options for CSG water (Queensland Department of Environment and Heritage Protection, 2012).

Typical infrastructure required for the treatment and storage of CSG water includes (Arrow Energy, 2010; QGC, 2014):

- feed and treated water storage dams
- water treatment facilities usually through reverse osmosis
- brine storage dams, as brine is a by-product of reverse osmosis
- treated CSG water and brine distribution systems.

The characteristics of feedwater, or untreated CSG water, transported to water treatment facilities changes as according to the reservoir properties in the various fields from it is derived from. The CSG water from the Surat Basin typically has the following properties:

- pH of approximately 7 to 11

- salinity in the range of 3000 to 8000 mg/L
- fine suspended particles
- ions including calcium, magnesium, potassium, fluoride, bromine, silicon and sulfate
- trace metals and low levels of nutrients

Water treatment process for CSG water usually includes desalination and the most common approach is reverse osmosis. A CSG water treatment plant will typically incorporate the following key components (Millar et al., 2016):

- Storage of Raw CSG Water – the holding ponds are used to store the water prior to water processing. These storage ponds allow contained solids to settle out of the raw CSG water.
- Solids Removal – the water is first filtered to remove large particles including any soil particles and sediments, algae and other foreign materials.
- Ultra-Filtration (UF) – further filtration to remove fine material which may clog the membranes in the RO plant. At the end of this step the CSG water is free from solids but still saline.
- Ion-Exchange (IX) –calcium (Ca++) and magnesium (Mg++) are removed from the filtered water prior to entering the RO plant.
- Reverse Osmosis (RO) – the main desalination step which removes 90-99% of salt from the water with the help of filters with pore size of 0.0001 micron.
- Amendment – the treated water from an RO plant may be amended to meet end use requirements. For example, extracted calcium and magnesium are often added to the treated water to modify the Sodium Adsorption Ratio to make it more compatible with certain soil types for irrigation.

In the RO process, the saline water is forced against a semipermeable membrane under high-pressure. Water molecules pass through the membrane leaving behind the larger molecules of salt and other compounds. The concentrated brine is then gathered for further processing. The desalinated water, also called permeate water, has a very low concentration of impurities and often requires amendment before it can be used .

The brine that results from RO may undergo further treatment to increase the volume of water recovered and further concentrate the brine for disposal. These may include thermal or mechanical processes.

2 CSG regulation

This overview considers the main legislation that applies to the production of CSG resources, relating to impacts on the environment and public health. The two most significant pieces of legislation are the *Petroleum and Gas (Production and Safety) Act 2004* (P&G Act) and the *Environmental Protection Act 1994* (EP Act). The *Water Act 2000* (Water Act) is also important for the management of water use and mitigating impacts on water resources. The following description is based on Huddlestone-Holmes et al. (2017).

2.1 Resource authorities

The P&G Act governs all onshore gas development in Queensland and it prescribes the different types of petroleum resource authorities that can be granted. Under the P&G Act, companies/ developers can apply for a resource authority and if granted this gives them the rights to explore for and/or develop petroleum resources within a defined area. The different types of resource authorities are:

- Authority to Prospect (ATP) – allows the authority holder to explore, test and evaluate feasibility of production for petroleum, oil, CSG and natural gas. Activities authorised under an ATP include drilling and hydraulic fracturing of exploration wells, although there are limitations on the total area of significant disturbance (1% of the tenure area).
- Potential Commercial Area (PCA) – allows the authority holder to retain part of an ATP beyond its term to provide extra time to commercialise the resource. Further drilling, hydraulic fracturing and testing of exploration and appraisal wells are authorised under a PCA.
- Petroleum Lease (PL) – allows the authority holder to explore, test and produce petroleum, oil, CSG and natural gas. Authorised activities include drilling and hydraulic fracturing of production wells, infield infrastructure and the production of gas and oil.
- Petroleum Pipeline Licence (PPL) – allows the authority holder to construct and operate a pipeline on an area outside an existing PL or ATP.
- Petroleum Facility Licence (PFL) – allows the authority holder to construct and operate a facility for processing, refining, storing or transporting petroleum on an area that is not already covered by a PL or PPL.
- Petroleum Survey Licence (PSL) – allows the authority holder to enter land to survey the proposed route or a pipeline or assess the suitability of land for a PFL. Only activities that have minimal impact on land are permitted.
- Data Acquisition Authority (DAA) – allows the authority holder to conduct limited geophysical survey activities and collect data on an area of land that is contiguous to but outside the area of an existing ATP or PL.

- Water Monitoring Authority (WMA) – allows the holder of an ATP or PL to comply with their obligations to make good any impacts caused to surrounding water bores as a result of the activities carried out on the ATP and/or PL.

The high-level process for most petroleum resource projects is as follows:

- The project proponent applies for an ATP through a tender process. This process is regulated through the P&G Act, and administered by the Queensland Department of Resources. The holder of an ATP, or any other form of authority, is also referred to as the 'authority holder.'
    - An applicant for an ATP must obtain an environmental authority (EA) from the Queensland Department of Environment and Science (previously the Department of Environment and Heritage Protection) before the ATP can be granted. This is a requirement of the P&G Act for the award of the ATP. The requirements for the EA are discussed further in Section 2.2.
- The holder of an ATP must comply with the conditions of that authority and the EA, and obtain and comply with any other permits and authorities that may be needed under other legislation. If their work plan changes, the project proponent must amend their initial work program under the ATP, and may also need to amend the EA.
- The holder of an ATP may apply to have their ATP declared as a potential commercial area to allow them to continue to evaluate the potential for production and market for the resource. The relevant EA would have to be maintained and/or amended to reflect any planned activities.
- If the project proponent confirms that their ATP has a petroleum resource that is likely to be commercially viable, they can apply for a PL. This process is regulated through the P&G Act. The project proponent must submit an initial development plan as part of their application.
    - An applicant for a PL must obtain a new EA from DES, or amend an existing EA, for the development plan before the PL can be granted.
    - At this point, the project may trigger the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) if it will impact on a matter of national environmental significance. In this case, the project will need to be referred, an environmental assessment that meets EPBC Act requirements may be required, and the activities will need to be approved by the relevant Australian Government minister before they can proceed. The EPBC Act contains specific water triggers related to CSG and coalmining.
    - The DES may require an environmental impact statement (EIS) to be prepared by the development proponent before the EA can be granted. The requirements for an EIS are regulated by the EP Act.
    - If the project is deemed to be a 'coordinated project' under the *State Development and Public Works Organisation Act 1971* (SDPWO Act), an EIS will be required. A coordinated project is one that has been identified by the Coordinator-General as involving one or more of:

    - complex approval requirements, involving local, state and Australian governments
    - significant environmental effects
    - strategic significance to the locality, region or state, including for infrastructure, economic and social benefits, capital investment or employment opportunities it may provide
    - significant infrastructure requirements.
- The operator of a project must operate in accordance with the conditions of their PL and EA (which includes requirements for the rehabilitation of the project area before relinquishment). They must also meet the requirements of all other legislation relevant to their activities.

2.2 Environment Authorities

The EP Act regulates petroleum and gas activities in Queensland and defines things such as EA requirements, the environmental impact assessment process, and offences such as breaching conditions of an EA. An EA under the EP Act is required to carry out all petroleum and gas activities. The EA defines the environmental conditions and risk management requirements that must be complied with for a specific activity and development. The EA conditions are based on an assessment of the potential environmental impacts to environmental values that may occur when carrying out the various project activities. EA applications are assessed by the administering authority of the EP Act, the Department of Environment and Science.

EAs are supported by a range of other regulatory instruments, including the Environmental Protection Regulation 2008 (EP Reg), policies (Environmental Protection (Air) Policy 2008, Environmental Protection (Noise) Policy 2008, and Environmental Protection (Water) Policy 2009), guidelines, procedures and eligibility criteria.

An EA covers aspects of activities including:

- general environmental protection
- waste management
- protection of acoustic values
- protection of air values
- protection of land values
- protection of biodiversity values
- protection of water values
- rehabilitation
- well construction, maintenance and stimulation activities
- dams.

Requirements for applications for EAs are detailed in s. 125 of the EP Act, as well as in the application guidelines published by the administering authority from time to time. In general, an application for an EA should include:

- identification of the environmental values in locations where the proposed petroleum activities will be undertaken and the potential impact of the proposed activities on these values.
- a detailed risk assessment that includes identification of the risks to, and impacts on, environmental values caused by the activities within the project area and extending beyond to surrounding areas, including regional and cumulative impacts. As well as providing these risks and impacts, the authority holder is also required to provide background information and raw data used in conducting the assessment.
- description of the management practices that will be used to control the risks of impacts on environmental values. The environmental protection commitments in the management plan should describe the incremental protection objectives and any performance indicators, the standards they will be assessed against, and control strategies that will be used to ensure that the objectives are achieved. Management plans for different environmental values (e.g. a noise management plan), as well as risk assessments and management plans for key activities (e.g. risk assessment and management plan for hydraulic fracturing), may also be required.

The advanced stage of development of the CSG sector in Queensland is reflected by specific provisions in the EP Act and EP Reg. Changes to regulations have also required changes to EA conditions through time. There are also policies, guidelines and approvals related to CSG, primarily focused on management of water. These regulatory instruments cover aspects of the EP Act, as well as requirements under other Acts, including the *Waste Reduction and Recycling Act 2011* (Waste Act) and the *Water Act 2000* (Water Act). For example, the Streamlined model conditions for petroleum activities (Queensland Department of Environment and Heritage Protection, 2016) include specific conditions around the handling of produced water from CSG projects. These conditions cover aspects of approvals under the Waste Act (Queensland Department of Environment and Heritage Protection, 2014a, 2014b), because produced water is considered to be a waste material, as well as aspects of the EP Act that define prescribed waste materials.

In summary, the EA for a petroleum project becomes the main regulatory instrument for setting the environmental approvals and conditions for a petroleum activity. The information required for an EA application (information about how the environmental risks will be managed, such as an EIS, and risk assessments related to specific activities such as stimulation activities) provides the assessment of potential impacts of the activity. The conditions in an EA set out the objectives of the proposed approaches for the management of these impacts. An EA also includes reporting requirements related to events that may lead to a breach of EA conditions.

Part II Study site

3 Study site

The criteria for the selection of the study site for this project required:

- the area to contain extensive CSG infrastructure including wells, water treatment facilities and gas processing plants in the operational phase (producing gas)
- that CSG infrastructure in the area is operated by a minimum of two operating companies
- hydraulic fracturing to have been conducted in a proportion of the wells
- an area with diverse land use (irrigated agriculture, dryland agriculture, grazing, state forest, towns)

The study selected an area bounded by the Warrego Highway to north, between Chinchilla and Miles, extending south towards Tara (Figure 14). This area contains a diverse range of CSG activities involving two operators (Australia Pacific Liquefied Natural Gas (APLNG) and QGC), has a range of land uses with moderate population densities. The area has also had a limited amount of hydraulic fracturing.

4 People

The following profile provides an overview of the population in the study site. This is not intended to be a definitive exploration of the demographic, social or economic determinants of health for the region. The primary data source is the of Population and Housing conducted by the Australian Bureau of Statistics. Data from the census is reported at a range of spatial scales.

- **Statistical Area 3** (SA3) provide a regional breakdown and generally have a population of between 30 000 and 130 000 people. In regional areas, they represent an area serviced by regional cities that have a population over 20 000 people.
- **Statistical Area 2** (SA2) areas represent suburbs within cities or catchments of rural towns. Their purpose is to represent a community that interacts together socially and economically.
- **Statistical Area 1** (SA1) areas allow for detailed spatial analysis of Census data at a neighbourhood scale within larger regions.

The study site lies entirely within the Darling Downs (West) - Maranoa Statistical Area 3 (SA3[1]), and the Chinchilla, Miles-Wandoan, and Tara SA2 areas (**Error! Reference source not found.**). The following discussion uses data from the SA1 areas shown in Table 3 unless otherwise noted and provide an overview of the population of the region.

4.1 Population characteristics

The total population in the SA1 areas that cover the study site was 3464 people, with 1815 male and 1662 female. Table 4 has a breakdown of the population across each of the SA1 areas and a comparison to national averages. The population of the study site has more males than females, which contrasts with the rest of Australia. The study site also has a higher proportion of indigenous peoples, but a lower number of people born overseas or who speak a language other than English at home compared to the national average. The median age is higher in most of the SA1 regions than for the rest of Australia. Figure 16 shows the age profile for the study site in comparison with the overall Australian population. The profile is similar although the study site has a lower proportion of 20 to 39 year-olds. The highest population density is in the township of Miles. Chinchilla lies outside of the study site and has a population of 5877 and a median age of 33.

[1] SA3's provide a regional breakdown and generally have a population of between 30,000 and 130,000 people. In regional areas, they represent an area serviced by regional cities that have a population over 20,000 people.

Table 3: Statistical Areas from the 2016 Census used for population statistics for this study.

SA2 Name	SA1 7	AREA km^2	Intersects Study site	Included	Town	Note
Miles - Wandoan	3117503	1.67	Yes	Yes	Miles	Township of Miles
Miles - Wandoan	3117504	1.44	Yes	Yes	Miles	Township of Miles
Miles - Wandoan	3117505	1.86	Yes	Yes	Miles	Township of Miles
Chinchilla	3117213	826.89	Yes	Yes	Rural	Most of this SA1 area is in the study site.
Miles - Wandoan	3117507	824.62	Yes	Yes	Rural	Approximately half of this SA1 area is in the study site.
Miles - Wandoan	3117512	1515.16	Yes	Yes	Rural	Approximately half of this SA1 area is in the study site. Includes Condamine, which is west of the study site
Tara	3117806	225.33	Yes	Yes	Rural	Approximately two-thirds of this SA1 area is in the study site.
Tara	3117807	791.77	Yes	Yes	Rural	Approximately on third of this SA1 area is in the study site.
Chinchilla	3117211	41.87	Yes	No	Chinchilla	Excluded, very small overlap with study site (about two properties based on cadastral data)
Chinchilla	3117215	606.05	Yes	No	Rural	Excluded, very small overlap with study site (about four properties based on cadastral data)
Miles - Wandoan	3117506	903.00	Yes	No	Rural	Excluded, very small overlap with study site (about 50 properties based on cadastral data)
Tara	3117810	2219.65	Yes	No	Rural	Excluded, very small overlap with study site (about 10 properties based on cadastral data)
Chinchilla	3117201	0.33	No	No	Chinchilla	Used to provide statistics for the Town of Chinchilla, which lies immediately to the north-west of the study site
Chinchilla	3117202	0.30	No	No	Chinchilla	
Chinchilla	3117203	0.38	No	No	Chinchilla	
Chinchilla	3117204	2.30	No	No	Chinchilla	
Chinchilla	3117205	1.24	No	No	Chinchilla	
Chinchilla	3117206	2.30	No	No	Chinchilla	
Chinchilla	3117207	0.50	No	No	Chinchilla	
Chinchilla	3117208	0.32	No	No	Chinchilla	
Chinchilla	3117209	0.79	No	No	Chinchilla	
Chinchilla	3117210	1.26	No	No	Chinchilla	
Chinchilla	3117212	18.97	No	No	Chinchilla	
Chinchilla	3117219	0.76	No	No	Chinchilla	
Chinchilla	3117220	0.75	No	No	Chinchilla	

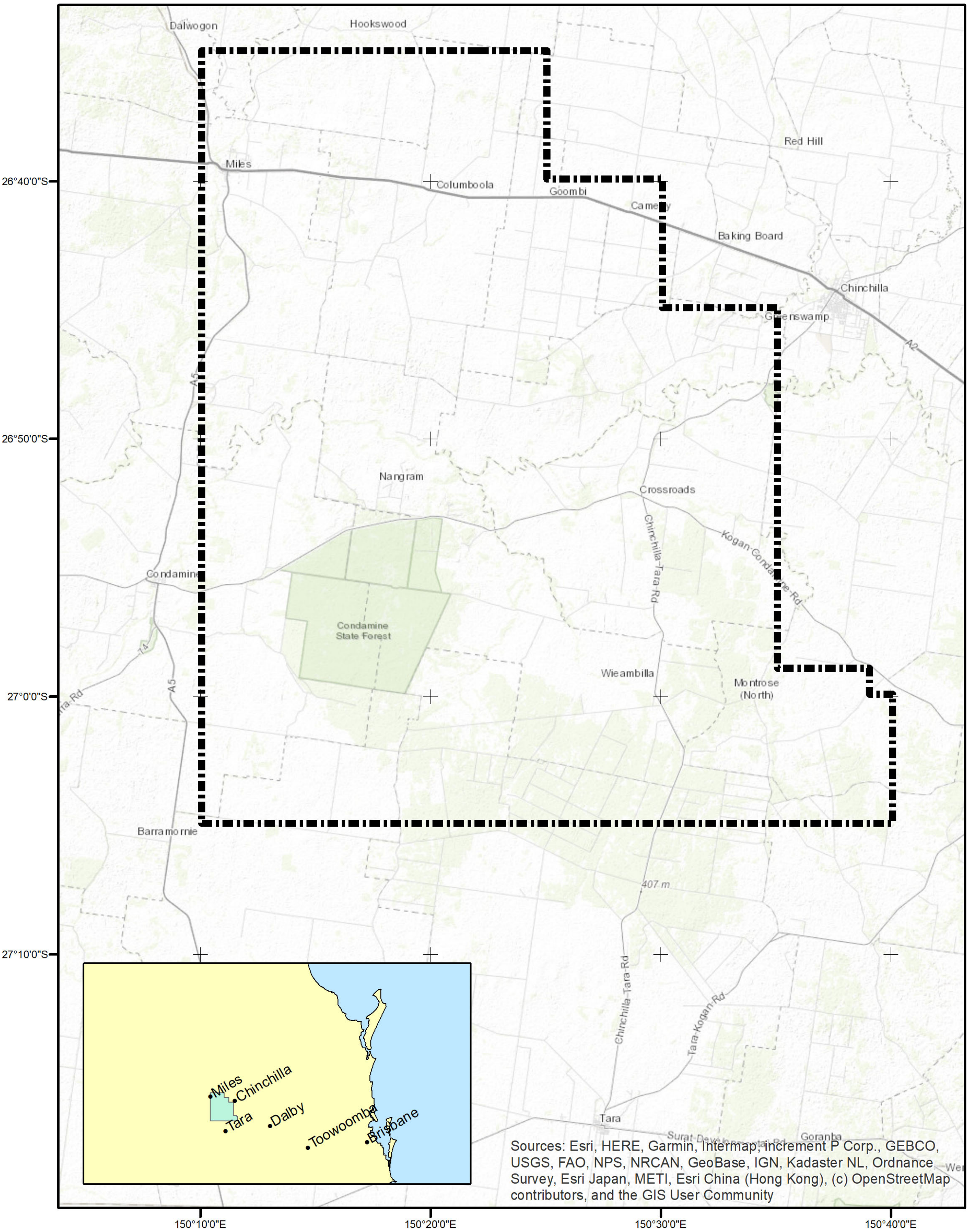


Figure 14: Location of the study site shown in with the black dashed line.

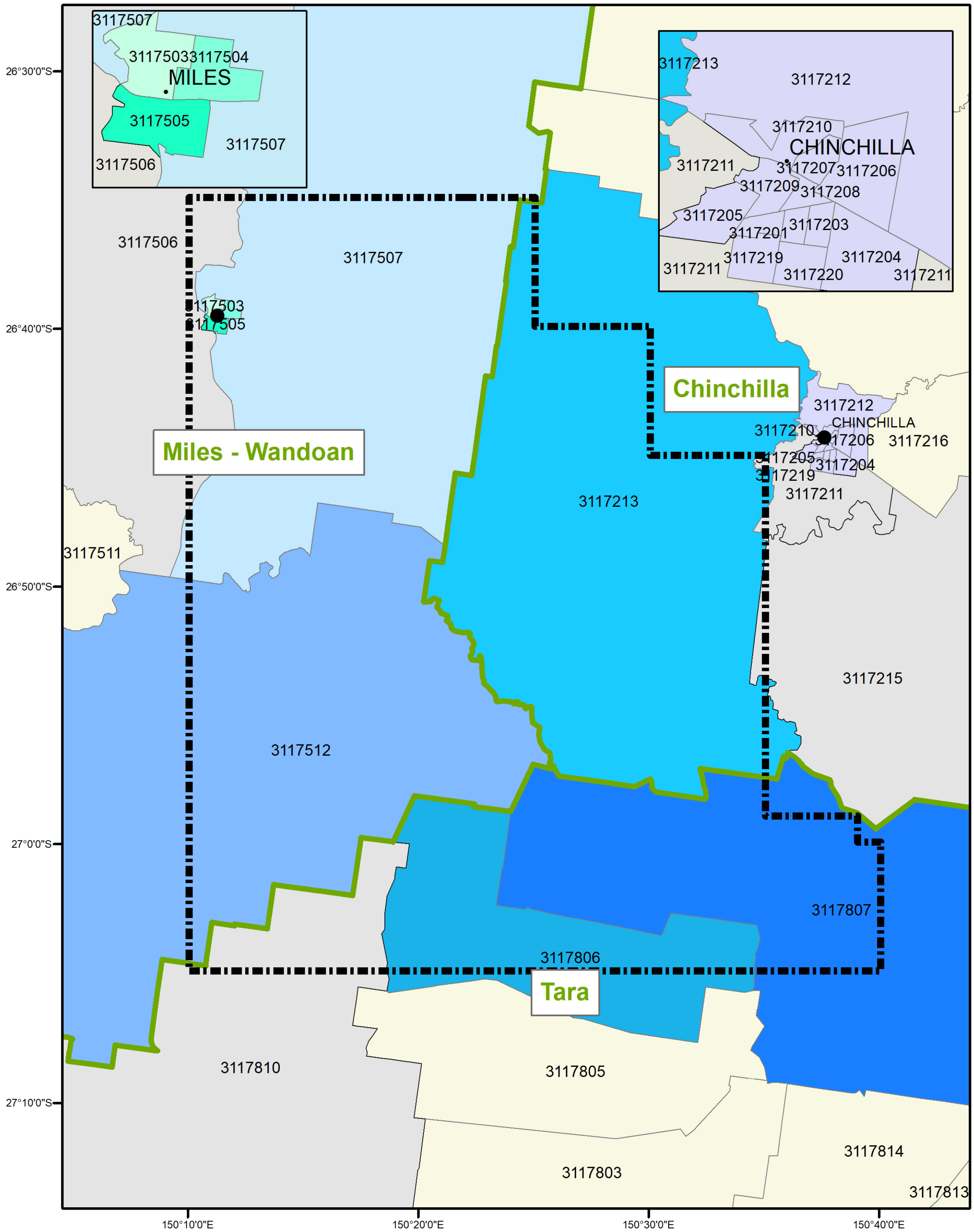


Figure 15: Map of statistical Areas from the 2016 Census used for population statistics for this study. See also Table 3. Blue shaded SA1 areas were included for population data. Grey shaded SA1 regions were not used as they only had a small overlap with the study site. SA2 boundaries shown in green.

Table 4: Key population characteristics for the study site and Australia. See Table 3 and Figure 15 for a description of the.

Data sourced from Australian Bureau of Statistics (2017, 2021).

SA1 Region	Males (no.)	Males (%)	Females (no)	Females (%)	Total (no.)	Indigenous (%)	Born overseas (%)	Language other than English (%)	Median Age (years)	Population Density (people/km²)	Median weekly income ($)
3117213	211	54.5%	172	44.4%	387	3.1%	5.7%	4.3%	42	0.47	586
3117503 (Miles)	196	51.7%	183	48.3%	379	6.6%	9.1%	2.4%	35	227.63	659
3117504 (Miles)	271	44.3%	337	55.1%	612	7.7%	8.6%	3.0%	37	425.68	687
3117505 (Miles)	84	58.3%	66	45.8%	144	6.3%	12.3%	2.6%	47	77.26	518
3117507	301	53.4%	264	46.8%	564	6.7%	8.2%	2.2%	34	0.68	765
3117512	245	54.1%	213	47.0%	453	0.9%	10.4%	5.1%	38	0.30	843
3117806	311	54.4%	263	46.0%	572	7.7%	17.9%	4.0%	49	2.54	370
3117807	196	55.5%	164	46.5%	353	2.8%	10.1%	1.8%	41	0.45	441
Study site Totals	**1815**	**52.4%**	**1662**	**48.0%**	**3464**	**5.5%**	**10.1%**	**3.0%**		**0.83**	
National		**49.6%**		**50.4%**		**2.8%**	**25.9%**	**20.8%**	**37.2**		**662**

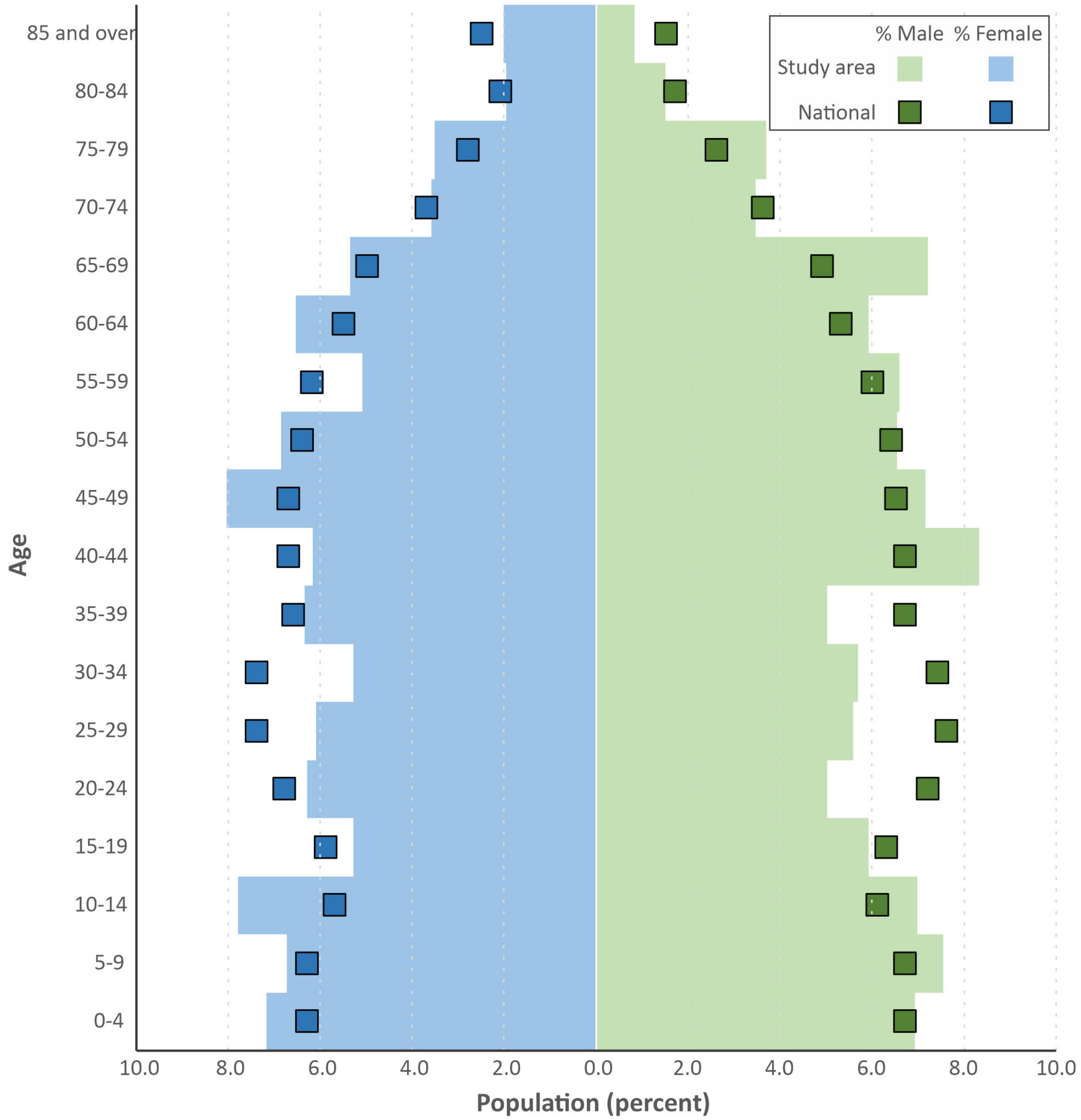


Figure 16: Age profile for the study site compared with Australian population (Australian Bureau of Statistics, 2017, 2021).

Data sourced from Australian Bureau of Statistics (2017, 2021).

4.2 Socioeconomic factors

Socioeconomic Indexes for Areas (SEIFA) is an Australian Bureau of Statistics (ABS) product that ranks areas in Australia according to relative socioeconomic advantage and disadvantage (Australian Bureau of Statistics, 2018), which the ABS broadly defines in terms of "people's access to material and social resources, and their ability to participate in society."

The Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) summarises information about the economic and social conditions of people and households within an area, including both relative advantage and disadvantage measures (Figure 17). A low score indicates relatively greater disadvantage and a lack of advantage in general, which can be seen in the south of the study site, towards Tara, and in the townships of Miles and Chinchilla. A high score indicates a relative lack of disadvantage and greater advantage in general.

The Index of Economic Resources (IER) focuses on the financial aspects of relative socioeconomic advantage and disadvantage, by summarising variables related to income and wealth (Figure 18). A low score indicates a relative lack of access to economic resources in general, and this can be seen also to the south of the study site, towards Tara. A high score indicates relatively greater access to economic resources in general and this can be seen in the north and east of Chinchilla.

The Index of Education and Occupation (IEO) is designed to reflect the educational and occupational level of communities (Figure 19). A low score indicates relatively lower education and occupation status of people in the area in general which can be seen near Tara. A high score indicates relatively higher education and occupation status of people in the area in general.

Employment data follow a similar pattern to the SEIFA data with unemployment highest to the south of the study site, followed by the townships with the highest levels of employment in the rural parts of the study site (Table 5). The industry of occupation statistics for the study site indicate that Agriculture, forestry and fishing (this is the ABS category name, fishing is not significant in the area) is the dominant industry sector, followed by Construction, then Education and Training (Table 6). The rural SA1 regions (3117213 and 3117512) are strongly biased towards agriculture whereas Miles is more diverse with more people employed in care, services and education sectors. The occupation statistics do not show any strong pattern Table 7 and Managers, Technicians and trades, Labourers and Machinery operators and drivers account for over half of workers in the study site.

Table 5: Employment status within the study site.

Data sourced from Australian Bureau of Statistics (2017).

	3117213	3117503 (Miles)	3117504 (Miles)	3117505 (Miles)	3117507	3117512	3117806	3117807	Totals
Persons aged 15 years and over	304	291	489	119	409	363	499	270	2744
Employed, worked full-time	114	104	163	27	165	191	54	48	866
Employed, worked part-time	48	45	74	16	77	50	29	46	385
Employed, away from work	15	9	14	3	23	18	6	9	97
Unemployed, looking for work	3	7	16	6	9	7	28	12	88
Unemployment (%)	1.7%	4.1%	6.1%	10.7%	3.3%	2.7%	23.9%	11.7%	6.2%
Not in the labour force	69	96	159	33	72	62	235	116	842
Total labour force	180	171	264	56	271	258	117	103	1420

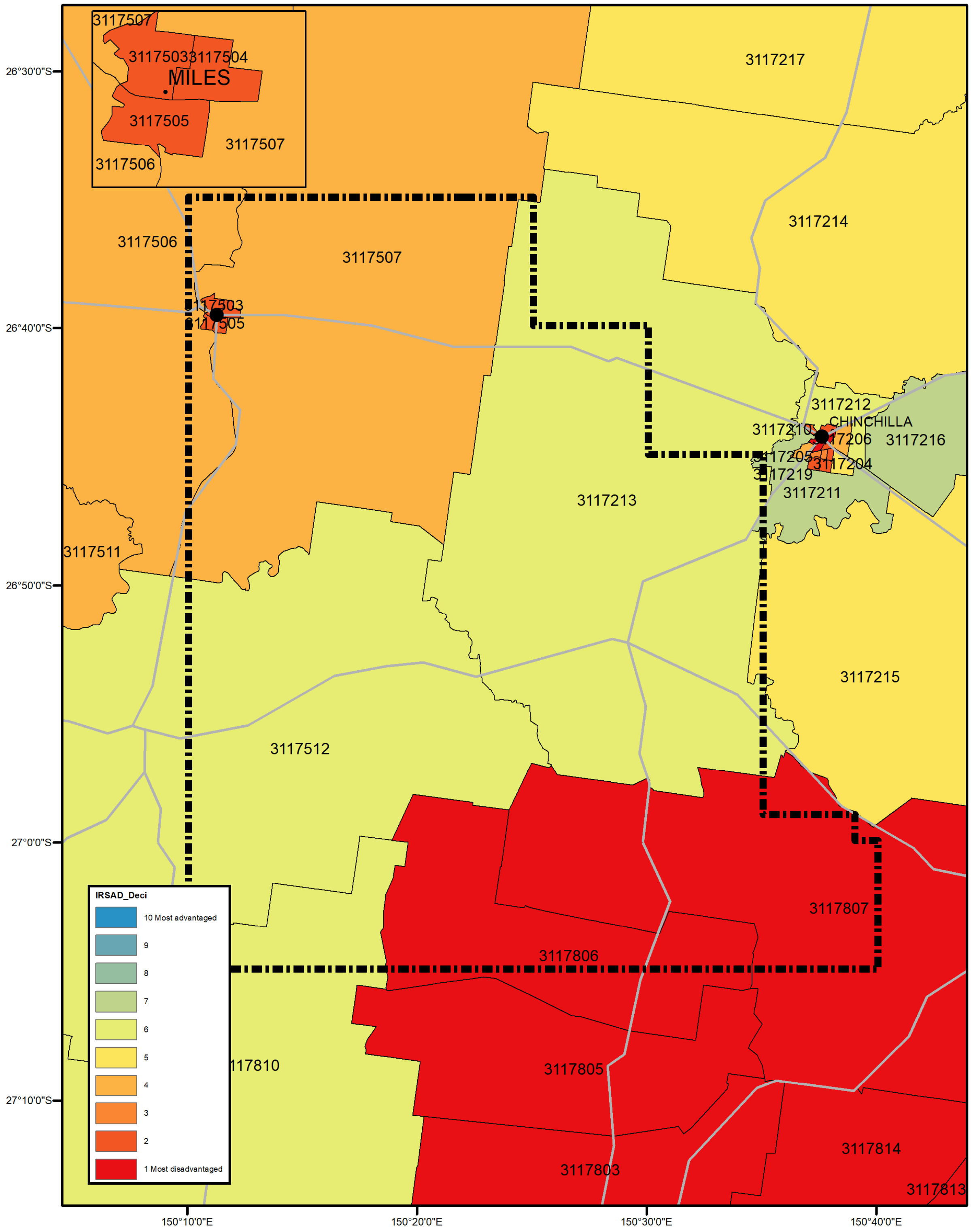


Figure 17: ABS Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD). This index ranks SA1 areas on a continuum from most disadvantaged to most advantaged.

Source. Data sourced from Australian Bureau of Statistics (2018).

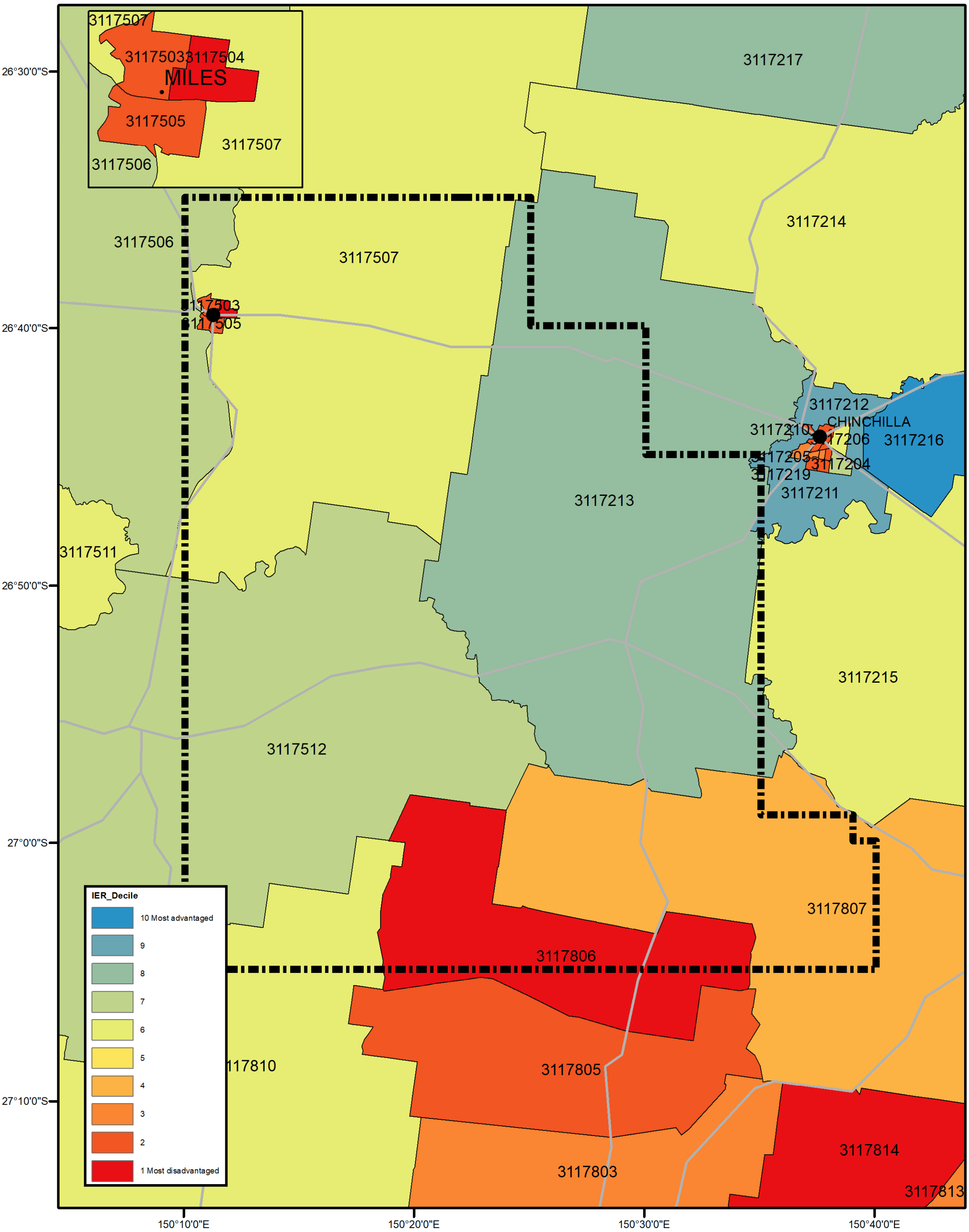


Figure 18: ABS Index of Economic Resources (IER). This index ranks SA1 areas on a continuum from most disadvantaged to most advantaged in terms of variables related to income and wealth.

Source. Data sourced from Australian Bureau of Statistics (2018).

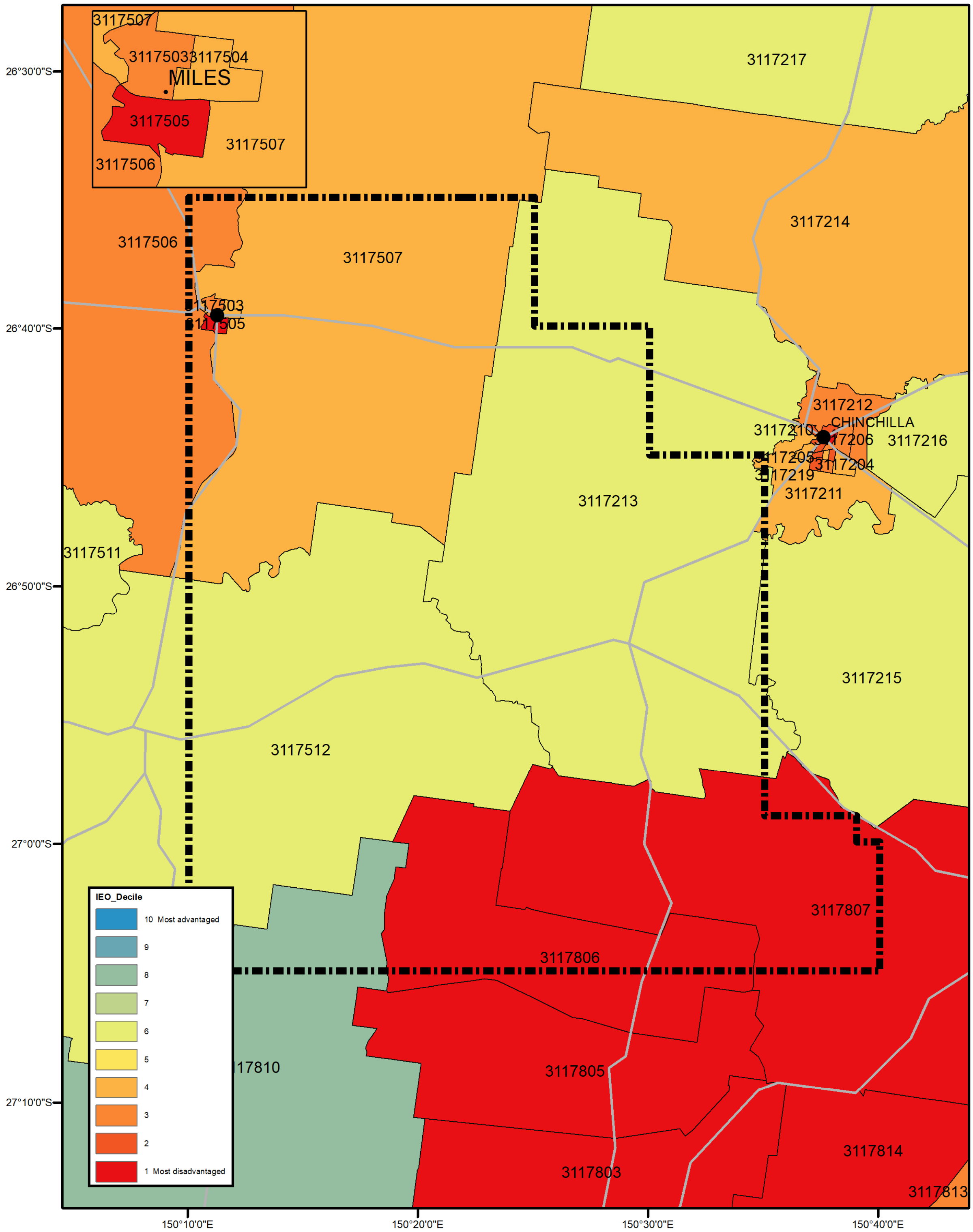


Figure 19: ABS Index of Education and Occupation (IEO). This index ranks SA1 areas on a continuum from most disadvantaged to most advantaged, reflecting the educational and occupational level of communities.

Source. Data sourced from Australian Bureau of Statistics (2018).

Table 6: Industry of employment in the study site.

Data sourced from Australian Bureau of Statistics (2017).

	3117213	3117503 (Miles)	3117504 (Miles)	3117505 (Miles)	3117507	3117512	3117806	3117807	Totals
Agriculture, Forestry and Fishing	67	12	5	3	32	150	7	21	**297**
Mining	13	15	20	3	23	0	0	4	**78**
Manufacturing	0	4	8	3	12	6	3	3	**39**
Electricity, Gas, Water and Waste Services	0	6	5	0	11	3	3	3	**31**
Construction	15	15	28	10	42	11	9	15	**145**
Wholesale Trade	10	3	9	0	3	5	3	3	**36**
Retail Trade	7	21	24	4	28	6	8	10	**108**
Accommodation and Food Services	3	23	7	7	13	11	11	10	**85**
Transport, Postal and Warehousing	9	11	11	3	14	9	6	4	**67**
Information Media and Telecommunications	0	3	0	0	0	0	0	0	**3**
Financial and Insurance Services	0	0	3	0	3	0	0	0	**6**
Rental, Hiring and Real Estate Services	0	0	3	0	5	3	0	0	**11**
Professional, Scientific and Technical Services	11	0	4	0	13	4	0	0	**32**
Administrative and Support Services	0	0	3	0	4	0	0	3	**10**
Public Administration and Safety	3	12	24	9	10	3	9	5	**75**
Education and Training	9	10	37	0	18	11	11	4	**100**
Health Care and Social Assistance	12	17	42	0	19	12	13	9	**124**
Arts and Recreation Services	0	0	0	0	3	0	0	0	**3**
Other Services	9	3	7	0	0	3	3	4	**29**
Inadequately Described/Not Stated	9	4	5	6	8	13	9	3	**57**
Totals	171	160	250	53	264	253	91	95	**1337**

Table 7: Occupations within the study site.

Data sourced from Australian Bureau of Statistics (2017).

	3117213	3117503 (Miles)	3117504 (Miles)	3117505 (Miles)	3117507	3117512	3117806	3117807	Totals
Managers	63	22	27	5	47	99	4	10	**277**
Professionals	17	14	33	0	28	20	6	0	**118**
Technicians and trades workers	22	34	40	11	50	12	16	23	**208**
Community and personal service workers	5	17	39	9	17	16	14	11	**128**
Clerical and administrative workers	21	13	35	3	30	20	3	6	**131**
Sales workers	12	20	19	9	19	0	5	4	**88**
Machinery operators and drivers	14	18	27	6	40	18	16	11	**150**
Labourers	21	17	28	6	30	65	18	23	**208**
Inadequately described/ Not stated	3	3	0	0	3	0	0	7	**16**
Total	171	160	250	53	264	253	91	95	**1337**

5 Land use

Land use data from the study site was sourced from Queensland's land use mapping data. The study site lies on the boundary of the Condamine (Queensland Government, 2014) and Maranoa and Balonne (Queensland Government, 2015) catchments that have data to 2012 and 2013 respectively. The predominant land use in the study site is grazing from native vegetation, taking up over 70% of the area (Figure 20, Table 1Table 8). Forestry and agriculture make up a further 15% of land use. Agriculture is centred around the Condamine River. Residential areas are predominantly in Miles and the semirural developments to the south of the study site.

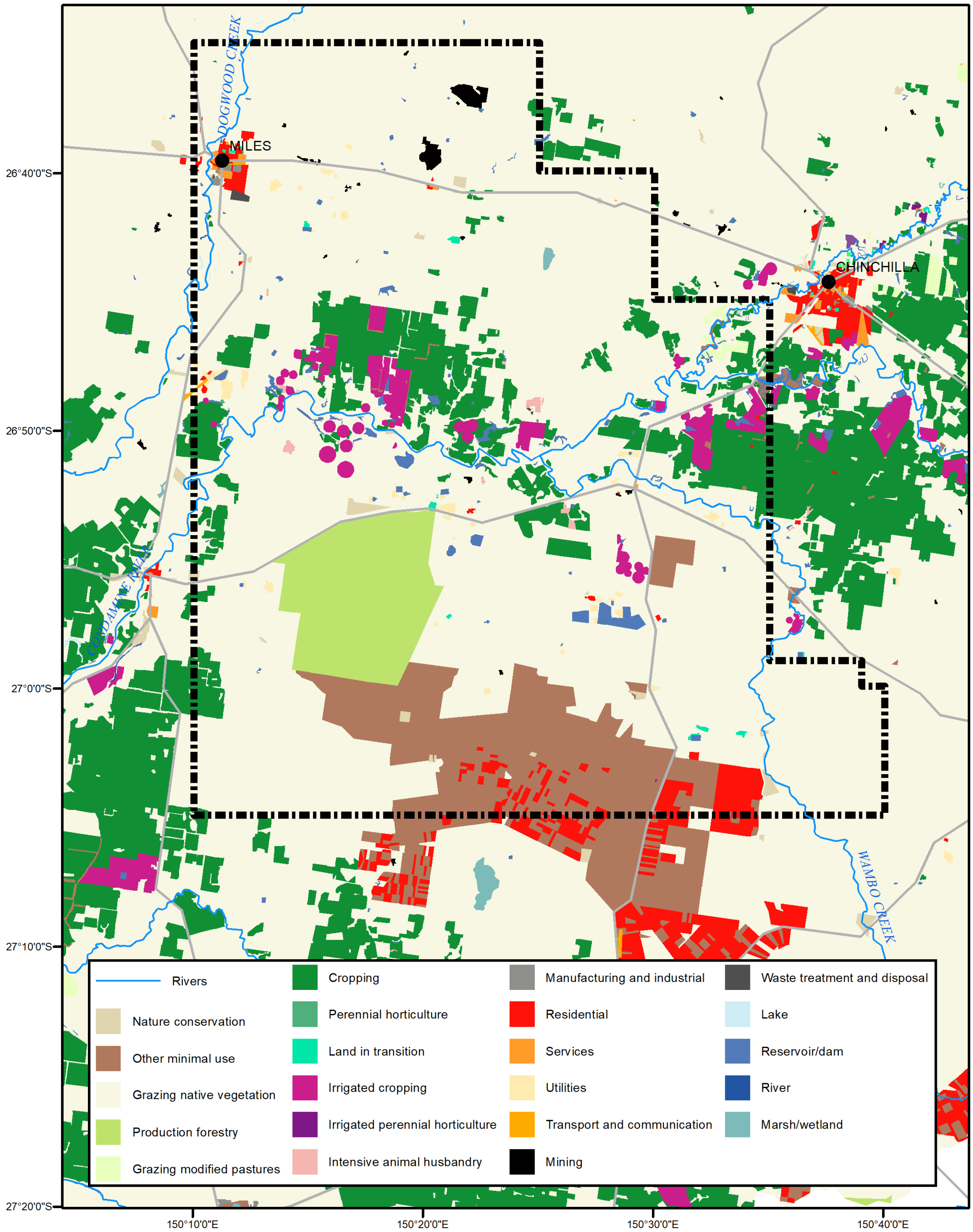


Figure 20: Land use in the study site (as of 2012 – 2013).

Data sourced from Queensland Government (2014, 2015).

Table 8: Land use data for the study site.

Data sourced from Queensland Government (2014, 2015).

Primary	km^2	%	Secondary	km^2	%	Tertiary	km^2	%
Conservation and natural environments	192.95	8.97	Nature conservation	6.87	0.32	Other conserved area	6.87	0.32
			Other minimal use area	186.07	8.65	Other minimal use	1.35	0.06
						Residual native cover	184.72	8.58
Production from Relatively Natural Environments	1656.48	76.97	Grazing native vegetation	1546.65	71.87	Grazing native vegetation	1546.65	71.87
			Production forestry	109.82	5.10	Production forestry	109.82	5.10
			Grazing modified pastures	3.49	0.16	Grazing modified pastures	3.49	0.16
Production from Dryland Agriculture and Plantations	185.66	8.63	Cropping	178.94	8.31	Cropping	178.94	8.31
			Cropping - Cotton	1.41	0.07	Cotton	1.41	0.07
			Perennial horticulture	0.06	0.00	Perennial horticulture	0.06	0.00
			Land in transition	1.79	0.08	Land in transition	1.78	0.08
Production from Irrigated Agriculture and Plantations	42.14	1.96	Intensive animal production	2.56	0.12	Aquaculture	0.11	0.01
						Cattle feedlots	2.42	0.11
						Dairy sheds & yards	0.03	0.00
			Irrigated cropping	41.87	1.95	Irrigated cropping	41.87	1.95
			Irrigated cropping - Cotton	0.24	0.01	Irrigated cotton	0.24	0.01
			Irrigated perennial horticulture	0.02	0.00	Irrigated vine fruits	0.02	0.00
Intensive uses	52.88	2.46	Residential	30.25	1.41	Urban residential	1.19	0.06
						Farm buildings/infrastructure	0.11	0.01
						Remote communities	1.2	0.06
						Rural living	27.75	1.29
			Services	1.71	0.08	Commercial services	0.11	0.01
						Airports/aerodromes	0.24	0.01
						Public services	0.28	0.01
						Recreation and culture	1.32	0.06
			Utilities	9.22	0.43	Electricity substations & transmission	0.19	0.01
						Gas treatment, storage and transmission	9.03	0.42
			Transport and communication	0.51	0.02	Transport and communication	0.28	0.01
			Manufacturing and industrial	1.12	0.05	Manufacturing and industrial	1.12	0.05
			Mining	6.57	0.31	Mining	5.49	0.26
						Quarries	0.89	0.04
						Extractive industry not in use	0.18	0.01
			Waste treatment and disposal	0.93	0.04	Effluent pond	0.07	0.00
						Solid garbage	0.04	0.00
						Sewage	0.81	0.04
						Evaporation basin	1.11	0.05
Water	20.09	0.93	Reservoir/dam	18.24	0.85	Reservoir/dam	17.13	0.80
			River	0.76	0.04	River	0.76	0.04
			Lake	0.17	0.01	Lake	0.17	0.01
			Marsh/wetland	0.93	0.04	Marsh/wetland	0.93	0.04

6 Geology

The study site incorporates the northern edge of the Surat Basin, and western margin of the underlying Bowen Basin. These basins are well studied for their rich reserves of coal, gas and oil. The location and key structural elements of the Surat Basin and the southern region of the Bowen Basin are shown in Figure 21.

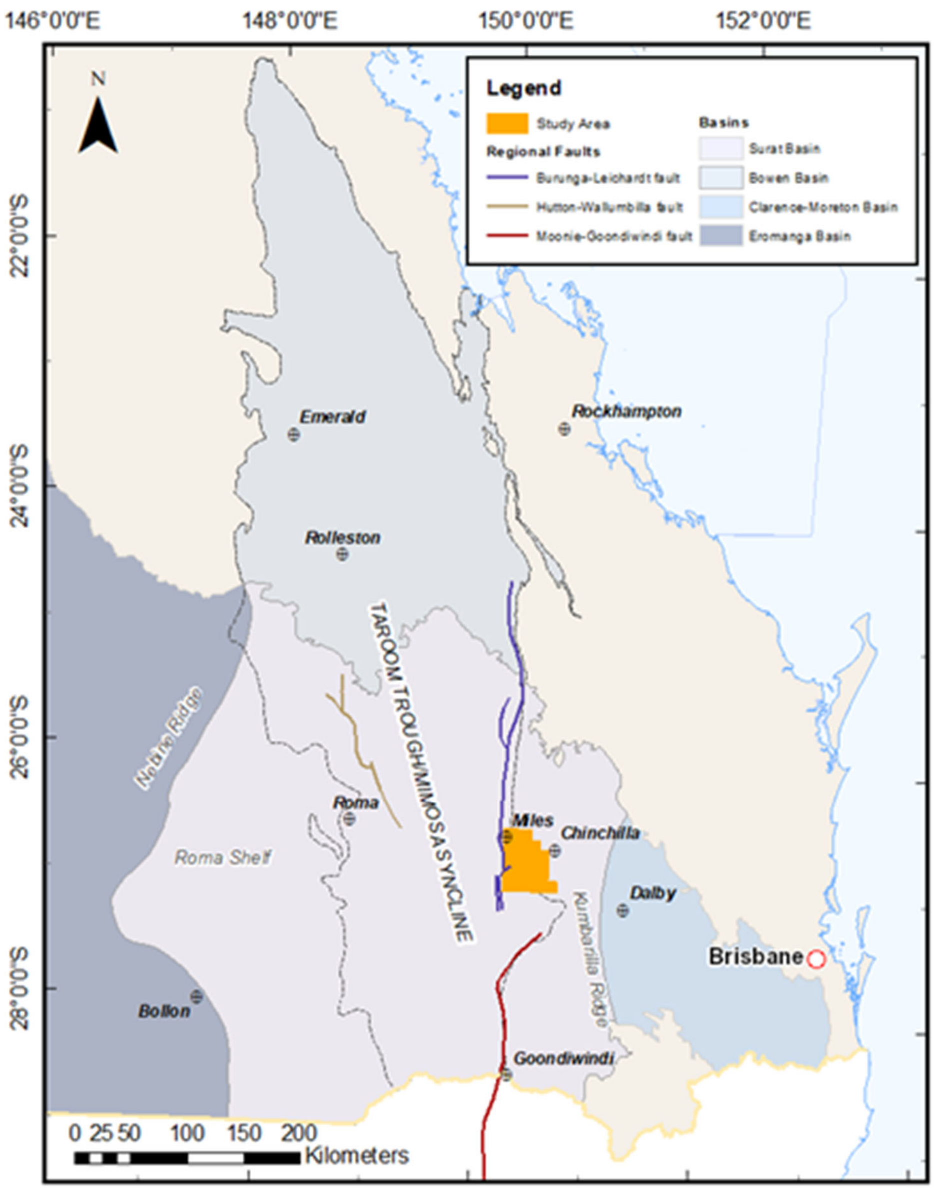


Figure 21: Location and structural elements of the Surat and Bowen Basins in context of the study site

6.1 The Bowen Basin

The Bowen Basin is the northern arm of the interconnected meridional Bowen-Gunnedah-Sydney basin system along the east coast of Australia. It is an elongate asymmetric basin approximately

600km long and 250km wide, extending from Collinsville in northern Queensland to Moree in northern New South Wales. Towards its southern extent, the sedimentary strata of the Bowen Basin are overlain by the younger strata of the Surat Basin.

The Bowen Basin sedimentary succession recorded several cycles of marine and terrestrial deposition during the Permian and Triassic periods, from approximately 300 to 240 Ma. Sedimentary accumulations up to 10km thick in the main depocentre of the Taroom Trough. The tectonic development of the Bowen Basin can be summarised into three major stages; mechanical extension with rapid subsidence in the early Permian, followed by thermal relaxation and reduced rates of subsidence through to the end of the early Permian, and finally entering a foreland basin phase throughout the remainder of the Permian and into the Triassic (Draper, 2013; Korsch & Totterdell, 2009; Korsch et al., 2009). During this time, the east coast of Australia was part of a collisional tectonic margin, with oceanic crust subducting underneath the Australia continent (Korsch et al., 2009). Basin deposition ceased with a compressive event that occurred during the mid Triassic, resulting in inversion along fault planes, folding and uplift and erosion of basin infill. Strata were eroded throughout the Triassic, before a new cycle of subsidence began to form the Surat Basin and introduced a new episode of deposition at the end of the Triassic, approximately 208 Ma.

6.2 The Surat Basin

The Surat Basin covers an area of approximately 300,000km^2 in southern Queensland and northern New South Wales (Exon, 1976). It is the third largest of the contiguous series of shallow intracontinental sag basins that formed during the Triassic to Cretaceous periods across inland Queensland, South Australia and the Northern Territory, and forms the eastern extent of the Great Artesian Basin (GAB). Several mechanisms driving the subsidence of the basin have been proposed, including thermal sag related to volcanic activity, extensional plate motion, and convection related to subduction along the eastern continental margin (A. C. Cook et al., 2013; Green, Hoffmann, et al., 1987). The western margin of the Surat Basin is defined by the Nebine Ridge, where sediments of the Eromanga and Surat Basins interfinger across a basement high (Cook & Draper, 2013). The eastern margin is contiguous with the Clarence-Moreton basin between uplifted basement blocks of the Auburn Province and northern New England Fold Belt (Cook & Draper, 2013; Exon, 1976). Between these blocks, the eastern margin of the basin is most commonly defined as the basement high of the Kumbarilla Ridge, but has been proposed to lie as far east as the Toowoomba Main range (Cook & Draper, 2013; Day et al., 2008). The southern margin of the basin in New South Wales is bounded by the Central West Fold Belt; the northern edge has been eroded considerably, with the deepest formations exposed at its most northern margin near Carnarvon Gorge.

The depositional history of the basin commenced with localised sedimentation during early basin development in the late Triassic (~208 Ma), with a defined hiatus before recommencing with fluvial-lacustrine deposition throughout the Jurassic and Cretaceous, terminating in the mid Cretaceous (~110 Ma) after a marine incursion and uplift (Cook & Draper, 2013). The main depocentre is a broad meridional fold towards the centre of the basin called the Mimosa Syncline, where the sedimentary succession is up to 2.5km thick. The location and orientation of this structure is controlled by the underlying Taroom Trough in the Bowen Basin. The strata of the

Surat Basin generally dip shallowly (<10°) towards the Mimosa Syncline, except where steep dips are encountered in the vicinity of fault systems. The eastern margin of the Mimosa Syncline is bounded by the Burunga-Leichhardt fault in the north and the Goondiwindi-Moonie fault in the south, both of which are meridionally oriented thrust systems. Reactivation along these fault systems throughout the Jurassic and Cretaceous are expressed through the Surat Basin succession, and throws of up to 200m in the Burunga-Leichhardt system and up to 100m in the Goondiwindi-Moonie system have been observed (Cook & Draper, 2013; Exon, 1976). The gentle rise between the fault systems and the Kumbarilla Ridge is the Chinchilla-Goondiwindi slope; this area is host to the majority of CSG developments within the basin. To the west, the Taroom Trough rises onto the St George Bollon slope and the fault-bonded Roma Shelf, which in turn rise towards the Nebine Ridge (Exon, 1976). The margins of the Surat Basin contain several significant anticlinal and synclinal structures, controlled by reactivation of Triassic and basement faults, and compressional deformation events which have important significance for CSG plays. The study site is on the eastern basin flank, to the east of the Goondiwindi-Moonie fault system. A key geological feature in the study site is the Undulla nose, an important anticlinal structure which shows a range of favourable characteristics for CSG deliverability, including enhanced permeability and high gas saturation (Ryan et al., 2012; Scott et al., 2004).

6.3 Stratigraphy of the study site

The stratigraphy of the Surat Basin has been examined in detail by several workers over decades (Cook & Draper, 2013; Elliott, 1989; Exon, 1976; Green, Carmichael, et al., 1987; Hamilton et al., 2014; Ryan et al., 2012; Scott et al., 2004; Swarbrick, 1973). The general stratigraphy of the Surat Basin and units of the CSG targets of the Walloon Subgroup are displayed in Figure 22. Cross-sections showing the succession and thickness of Surat Basin sedimentary strata across the study site is shown in Figure 23.

Triassic strata

Eddystone Beds/Taroom Beds: These beds are the oldest sediments within the Surat Basin, deposited in the late Triassic. They are unconformable with the underlying Permian strata and overlying Jurassic strata, and represent early deposition at the beginning of Surat Basin subsidence. They consist mostly of sandstone, transitioning to mudstone and coal in the upper part of the interval. The Eddystone and Taroom Beds are sparsely distributed and their extent within the study site is not well defined.

Jurassic starta

Precipice Sandstone: The Precipice Sandstone is a massive to thickly cross-bedded quartzose sandstone unit up to 106m thick, deposited in the early Jurassic. It unconformably overlies Eddystone and Taroom Beds and Bowen Basin strata, however, is not laterally present across the whole basin. Many of the commercial conventional oil and gas fields in the Surat Basin are hosted in the Precipice Sandstone near Moonie to the south of the study site (Elliott, 1989).

Evergreen Formation: The Evergreen formation is a siltstone and mudstone dominated unit consisting of upper and lower sections separated by the fine to coarse grained Boxvale Sandstone and Westgrove Ironstone members. It conformably overlies the Precipice Sandstone, and unconformably overlies the Bowen Basin where the Precipice Sandstone is absent. The main depocentre of the Evergreen Formation lies within the Mimosa Syncline, where it reaches up to 307m in thickness.

Hutton Sandstone: The Hutton Sandstone is a widespread sandstone unit, extending across the Eromanga, Surat and Clarence-Moreton Basins. It consists mostly of sublabile to quartzose sandstones, interbedded with siltstone and minor coal and mudstone. Thickness of this unit reaches up to 230m in the Mimosa Syncline, conformably overlying the Evergreen Formation.

Injune Creek Group: The Injune Creek Group consists of the Eurombah Formation, Walloon Coal Measures, Springbok Sandstone and Westbourne Formation.

Eurombah Formation: The Eurombah Formation is proposed as the basal unit of the Injune Creek Group, and consists of sublabile sandstones interbedded with siltstones, carbonaceous mudstones and conglomerate. It conformably overlies the Hutton Sandstone, however, this unit is restricted in its extent compared to surrounding formations. There is some debate over the definition of this formation in relation to overlying units, and is considered as part of the Walloon Subgroup by some workers (Arrow Energy, 2017; Green, Carmichael, et al., 1987). For the purposes of this study, the Eurombah Formation is considered as a separate formation to the Walloon Subgroup.

Walloon Subgroup: The Walloon Subgroup, also referred to as the Walloon Coal Measures, is generally recognised as consisting of 5 or 6 separate units, based on the initial lithostratigraphic divisions of Swarbrick (1973). The Walloon Subgroup has received much attention regarding its lithostratigraphic definition over several decades, and this has led to a number of interpretations on nomenclature.

The sixth and basal unit, the *Durabilla Formation*, was first described by Scott and others (2004) as constituting interbedded sandstones, siltstones, mudstones and carbonaceous bands, conformably overlying either the Eurombah Formation or the Hutton Sandstone where the former is not present. There is debate over the subdivision of this unit from the rest of the Walloon Subgroup, and as such is not consistently recognised by all workers or industry groups (Hamilton et al., 2014; Ryan et al., 2012; Scott et al., 2004, 2007).

The coal-bearing strata of the Walloon Subgroup are divided into the upper unit, the *Juandah Coal Measures* and the lower unit, the *Taroom Coal Measures*. These units are separated by the *Tangalooma Sandstone*. The Juandah Coal Measures are further divided into upper and lower units by the Juandah Sandstone. Coal seams are generally thin (<1m) and discontinuous, interbedded with low permeability interburden of labile sandstones, siltstone and mudstone with minor calcareous beds, ironstone and tuffs. The overall thickness of the Walloon Subgroup averages around 350m, with the thickest net coal, averaging between 30 - 35m, located along the northern and eastern basin margins.

Springbok Sandstone: The Springbok Sandstone represents a fining up sequence with a scoured erosional base unconformably overlying the Walloon Subgroup. It consists primarily of volcanolithic sandstone, pebbly towards the base of the unit, fining upwards with some minor interbedded siltstone, mudstone and coal towards the top of the unit. Its maximum thickness approaches 150m in the Mimosa Syncline.

Westbourne Formation: The Westbourne Formation is the uppermost unit of the Injune Creek Group, and conformably overlies the Springbok Sandstone. Its primary lithologies consist of interbedded shale, siltstone and quartzose sandstone, reaching up to 200m thick in its main depocentre along the eastern side of the Taroom Trough.

Gubberamunda Sandstone: The Gubberamunda Sandstone for the most part conformably overlies the Westbourne Formation. It consists predominantly of quartzose to sublabile sandstone, with lesser amounts of siltstone, mudstone and conglomerate. It reaches a maximum thickness of 298m in the Mimosa Syncline, thinning towards the basin margins.

Orallo Formation: The Orallo Formation consists of friable sublabile to labile sandstones interbedded with carbonaceous siltstones, mudstone, conglomerates and minor coals. It conformably overlies the Gubberamunda Sandstone, and reaches a maximum thickness of 306m.

Cretaceous strata

Cretaceous strata are largely eroded within the study site, but are mentioned here for completeness. Listed in stratigraphic order from oldest to youngest:

Mooga Sandstone: sublabile to quartzose sandstone with minor clayey sandstone, siltstone and mudstone.

Bungil Formation: fine grained lithic sandstone, siltstone and mudstone, with some marine fossils in the upper section.

Wallumbilla Formation: sequence of siltstone and mudstone with minor limestone, sandstone and conglomerate.

Surat Siltstone: thinly interbedded carbonaceous siltstones and mudstones, with lenses of fine to very fine grained labile sandstones.

Griman Creek Formation: fine to medium-grained labile sandstone, siltstone and mudstone, with minor conglomerate and coal.

6.4 The Surat Basin CSG play

The Bowen and Surat Basins have had a complex geological history and have generated significant amounts of hydrocarbon from coal and other organic-rich source rocks (Towler et al., 2016). Conventional gas resources have been developed since the late 1960s with a peak of production in the mid 1990s. CSG is produced from the Bowen and Surat Basins in Queensland, with production commencing in the Bowen Basin in the 1990s and the Surat Basin in 2006. Section 7 provides a brief summary of exploration and production in the Bowen and Surat Basins.

The majority of CSG production is now sourced from the coal-bearing measures of the Jurassic Walloon Subgroup, described in section 6.3. These coals have a low rank and gas contents of up to 15 m^3/t (Ryan et al., 2012). The gas in the coals of the Walloon Subgroup is derived mainly from later stage biogenic rather than thermogenic processes, however, there is a remnant thermogenic signature including the presence of ethane (Towler et al., 2016).

The Walloon Fairway is the most prospective CSG area within the Surat Basin and extends along the northern and north-eastern basin margin down dip of the Walloon subcrop, between Roma and Dalby (Figure 24). Many CSG fields are operated across this area, where several geological conditions favourable for production overlap (Ryan et al., 2012):

- High permeability - ranging from 0.1 mD to more than 2000 mD, generally decreasing with depth but enhanced around geological structures such as the Undulla Nose
- High net coal - between 30 and 35m over an average of a 350m thick section
- High gas content - ranging between 0.5 to 12 m^3/t, generally increasing with depth

The sedimentary package of the Walloon Subgroup is highly heterogeneous, and correlation of stratigraphy and reservoir properties between wells is challenging. Gas content and permeability are influenced by variations in the composition of the coals and the tectonic history, with permeability enhanced around certain geological structures (Ryan et al., 2012).

The Walloon Subgroup has a high water saturation and dewatering is required to allow gas to flow (Underschultz et al., 2018).

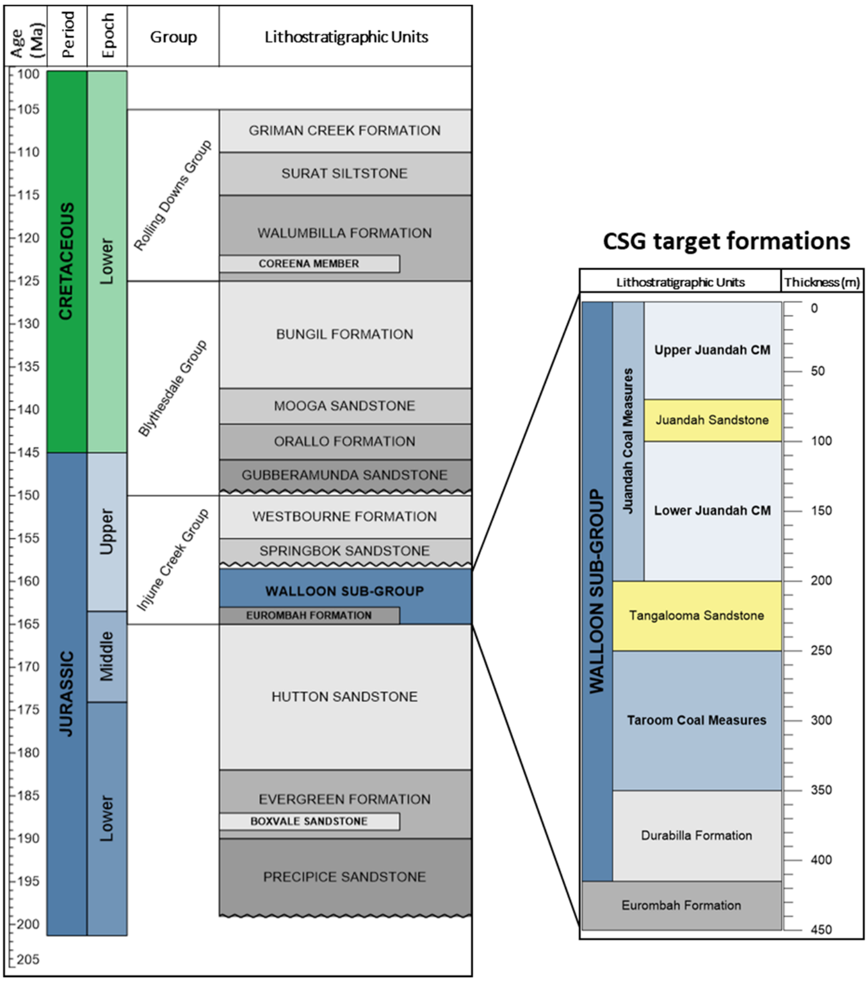


Figure 22: Stratigraphy of the Surat Basin and CSG targets of the Walloon Subgroup (coal-bearing formations highlighted in bold).

Source: adapted from Green, Carmichael, et al. (1987), Hamilton et al. (2014), and Scott et al. (2004).

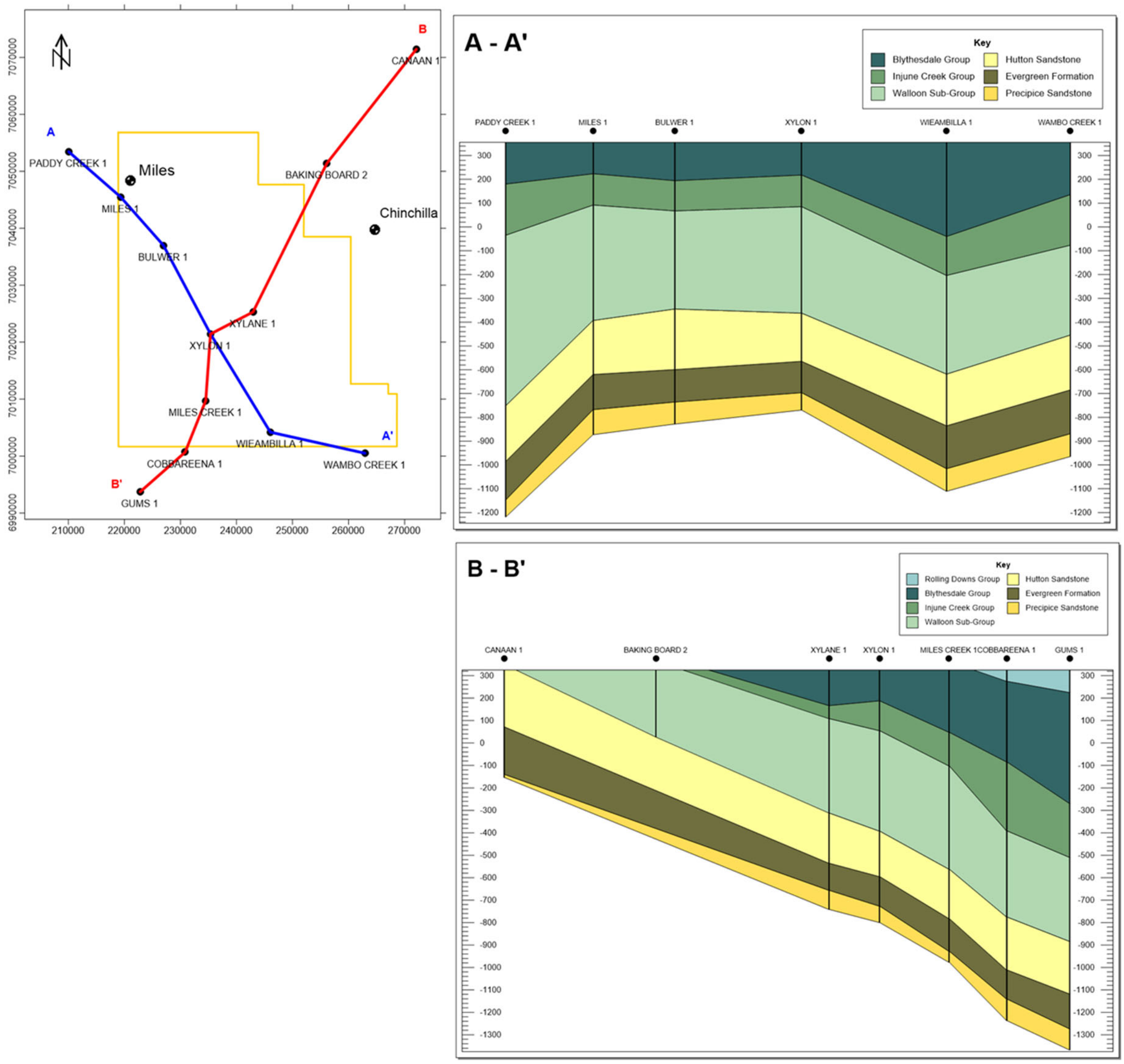


Figure 23: Cross-sections of Surat Basin Strata across the study site.

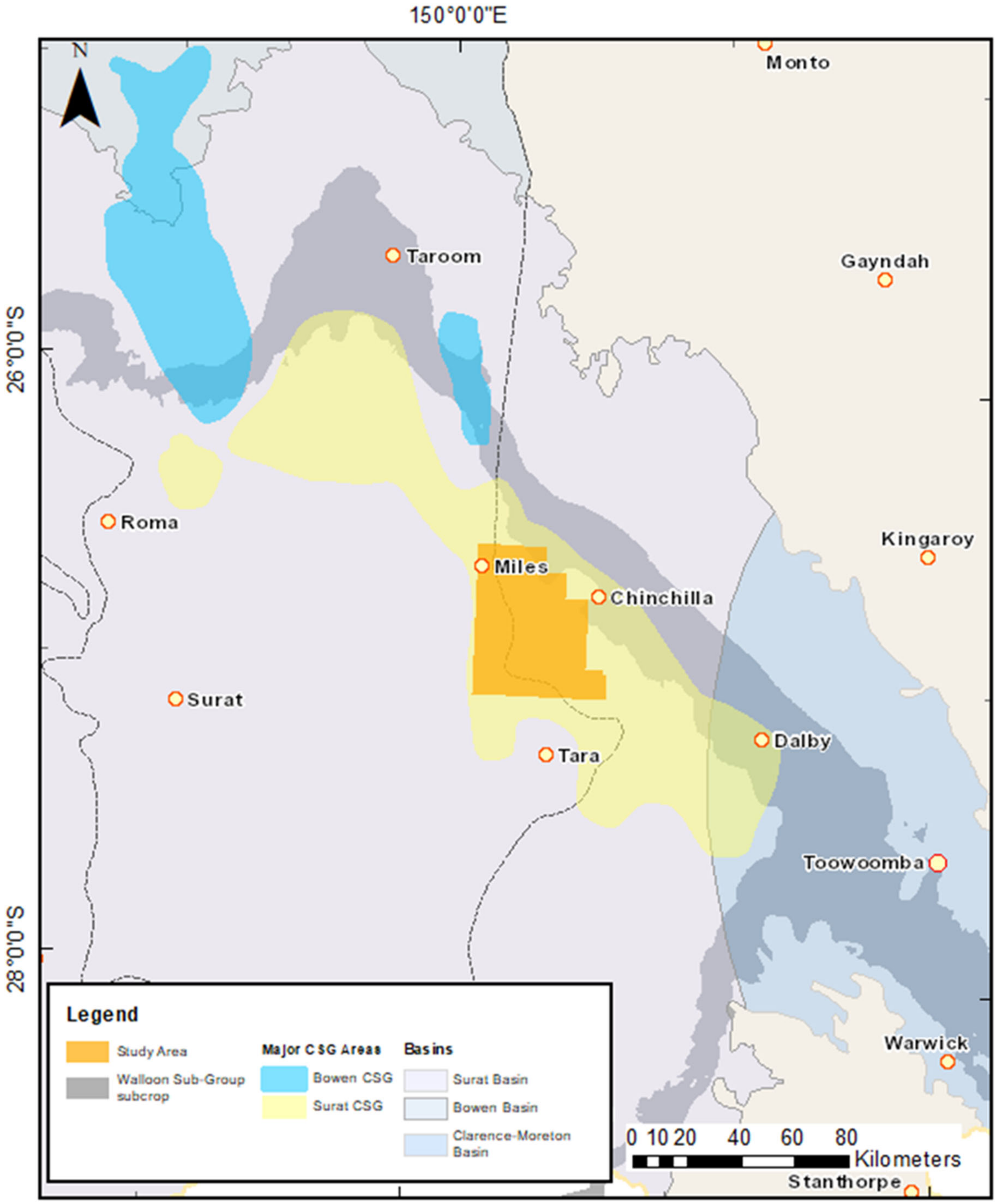


Figure 24: Location of Surat and Bowen Basin CSG fields and Walloon Subgroup outcrop in relation to the study site.

6.5 Hydrogeology

Groundwater is an important resource across much of arid and semiarid inland Australia and enables industrial, agricultural or domestic presence in areas where rainfall is infrequent and surface water is often non-existent.

Groundwater resources form when water seeps into the ground below lakes or rivers, or enters the ground from surface flow after rainfall, travelling through strata and fracture systems to accumulate in porous ground (for example sandstones and alluvium). With respect to groundwater potential, geological formations can be broadly categorised as aquifers, aquitards or aquicludes (Ransley et al., 2015):

- **An aquifer** is a permeable and porous unit with high hydraulic connectivity, that enables storage and subsurface flow of groundwater. Confined aquifers are overlain by low permeability rock strata acting as barriers to vertical movement; unconfined aquifers are near to the ground surface, such as deep gravel beds, and flow is not impeded by other rock strata.
- **An aquitard** has very low permeability and porosity with effectively no groundwater storage or hydraulic connectivity, and obstructs the flow of groundwater.
- **An aquiclude** behaves as an intermediate between an aquifer and an aquitard, with enough porosity to store groundwater, but permeability is too low to freely flow.

Aquifers can be indirectly recharged through seepage, or directly at the surface in areas where the formation is exposed at the surface through erosion. Water can be naturally discharged from aquifers in low-lying areas where the groundwater level is higher than that of the ground level, and is expressed at the surface as springs, lakes and rivers. Aquifers discharged by human extraction are typically accessed by drilling boreholes into the porous formation containing the groundwater. Groundwater may be extracted by pumping, or if the pressure conditions in the aquifer are right, water may rise to the surface on its own (under artesian flow).

Australia's groundwater deposits have accumulated over many millions of years, and are susceptible to overexploitation, therefore careful management of their use is required. The processes by which aquifers are recharged can be slow, depending on the permeability of the formation, and rely on adequate rainfall within key recharge catchments.

6.5.1 Hydrogeology of the Surat Basin

Key groundwater resources within the area of this study include the aquifers of the GAB, and a small section of the Upper Condamine alluvium.

Great Artesian Basin

Australia's most extensive groundwater resources are contained within the GAB. This vast hydrogeological system underlies approximately 1.7 million km^2 of inland Queensland, South Australia, New South Wales and the Northern Territory. Containing as much as 64 900 million megalitres of water, it is the largest groundwater basin in Australia (Ransley et al., 2015). The GAB is primarily contained within the Eromanga, Surat, Clarence-Moreton and Carpentaria basins (Figure 25). Key recharge areas for the GAB occur on the eastern margins of the Carpentaria, Eromanga and Surat basins in Queensland and New South Wales, and the western margin of the Eromanga Basin in South Australia, the Northern Territory and Queensland (Department of Agriculture, 2019). In Queensland, groundwater flow generally trends towards the south-southwest, away from the recharge zones along the eastern margin (Leach, 2013).

Primary industry relies heavily on artesian flow for irrigation of crops, grazing and feed lots. GAB aquifers also support natural spring systems, many of which have become severely degraded by draw-down from excessive extraction (Fensham & Fairfax, 2003).

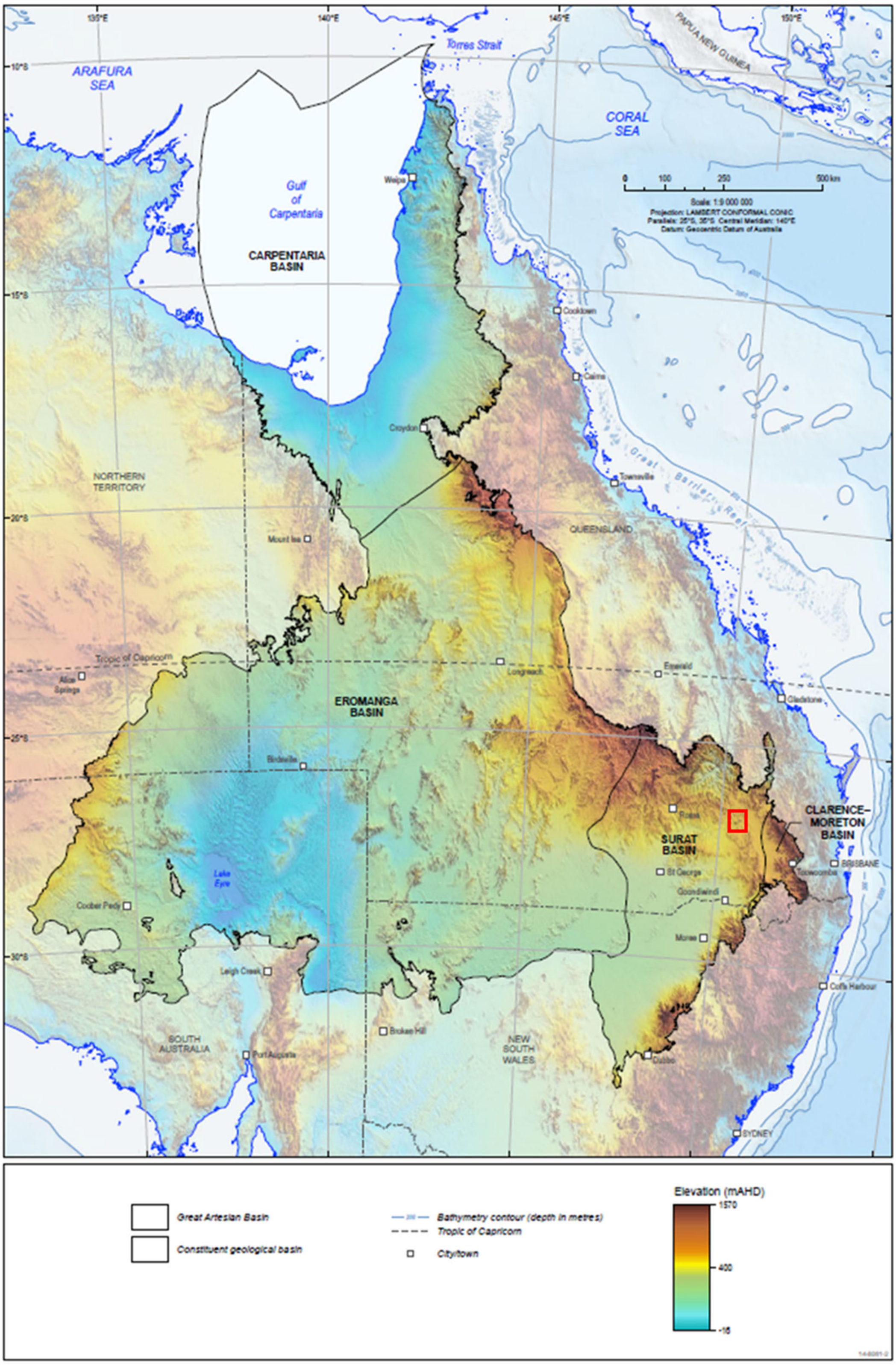


Figure 25: Extent of the Great Artesian Basin with divisions of constituent basins; study site is outlined in red.

Source: Ransley et al. (2015)

In the past, the groundwater resources of the GAB have been poorly managed, with recognition of inadequate controls and declining water pressure from uncontrolled artesian flow as far back as the early 1900s (Department of Agriculture, 2019). The Great Artesian Basin Strategic Management Plan was first implemented by the federal government in 2000 to provide a management framework regarding GAB resources for state governments, water users and other stakeholders, and was most recently revised in 2018. Given its economic, social and environmental importance, considerable effort has been made to understand key aspects of the hydrogeology of the GAB, and to identify and manage the impacts of extraction activities (de Rijke et al., 2016; Habermehl, 1980, 1982; Hennig, 2005; OGIA, 2021; Ransley et al., 2015).

Surat Basin GAB Hydrostratigraphy

The Surat Basin contains several important aquifers and aquitards of the GAB (Figure 26). Classifying the hydraulic properties of Surat Basin strata is challenging, as the geological heterogeneity within units creates local variability in hydraulic connectivity across the basin; therefore formations are classified according to a gradational system (Ransley et al., 2015). The Walloon Subgroup, the target for CSG extraction, is classified as a 'leaky aquitard' which has limited capacity for groundwater storage and minimal allowance for flow (Figure 26). Reported average permeability values of Surat Basin strata are between 100 and 1000 millidarcies (mD) for aquifers, and between 10 and 100 mD within aquitards; this equates to approximately 0.1 to 1 m/year and 1 cm/year of horizontal movement in aquifers and aquitards respectively (Smerdon et al., 2012). Although vertical permeability has been shown by some workers to be low (IESC, 2014; Smerdon et al., 2012), the potential impacts of a permeable connection between strata is of concern to regulators and industry alike. The Walloon Subgroup is flanked by partial aquifers of the Springbok and Hutton Sandstones; potential connectivity between these intervals may lead to aquifer degradation and reduction of water pressure, as well as reducing the efficacy of CSG extraction methods through recharging from adjacent aquifers . Regional groundwater monitoring has indicated some potential influence of CSG extraction on groundwater levels within the Springbok Sandstone; regional monitoring of the Hutton Sandstone has shown appreciable decline of water levels in recent years, however, there is as yet no evidence to support a direct link to CSG activities (OGIA, 2021).

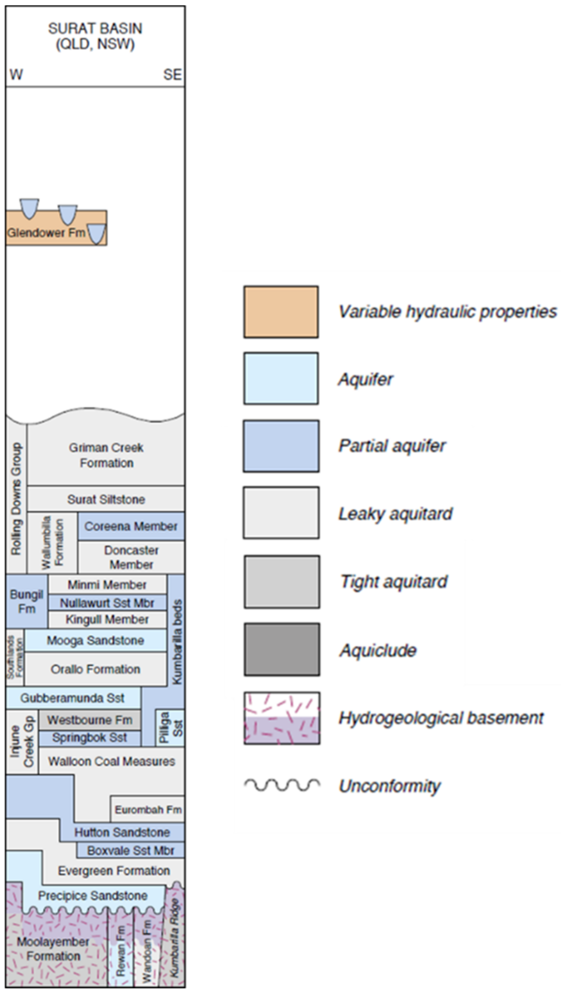


Figure 26: Hydraulic properties of Surat Basin strata.

Source: : Ransley et al. (2015)

6.5.2 Condamine Alluvium

The Condamine River headwaters originate in the Darling Downs east of Dalby, and flows northwest through Chinchilla, before turning to the south-west and becoming the Balonne River near Surat (Murray-Darling Basin Authority, 2018). The Upper Condamine alluvium consists of interbedded alluvial gravel, sand and clays deposited within the Balonne-Condamine river catchment. The alluvium reaches its maximum thickness of 150m within a broad north-west trending palaeochannel in the Central Condamine Alluvium (CCA) area around Dalby (Figure 27). (Queensland Department of Natural Resources and Mines, 2018). Groundwater is extracted from the CCA for irrigation, industrial and stock and domestic use, primarily in the area between Brookstead and Dalby. The aquifer is primarily recharged by percolation of rainfall, as well as lateral inflow from the surrounding topography and infiltration from streams (Leach, 2013). Tributaries to the Condamine Alluvium run throughout the study site, and have hydraulic connections with the underlying Walloon Subgroup (Hillier, 2010; OGIA, 2016).

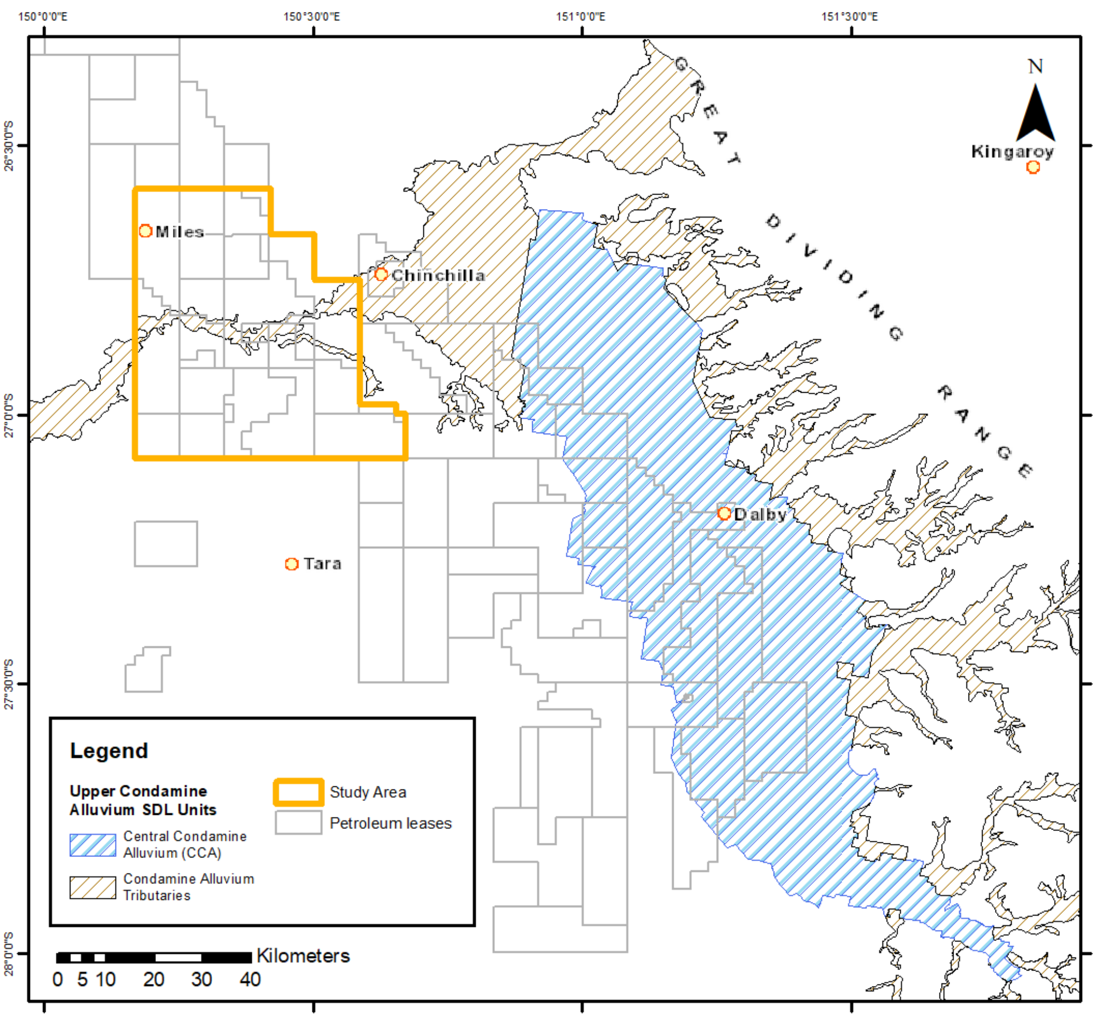


Figure 27: Condamine Alluvium Units in relation to the study site (Sustainable Diversion Limits (SDL) units).

Source: from Murray-Darling Basin Authority (2019)

6.5.3 Groundwater use, monitoring and management

In 2011, the Surat Cumulative Management Area (CMA) was established within Queensland by the Office of Groundwater Impact Assessment (OGIA), to enable a coordinated approach to groundwater management. OGIA assigns responsibilities to multiple overlapping development activities across the basin, as well as coordinating the implementation of a comprehensive regional monitoring network, which is executed and maintained by tenure holders. The current network consists of around 600 monitoring points from various types of installations, as show in Figure 28 (OGIA, 2021). Three main types of monitoring bores are used throughout the monitoring network, as described below (OGIA, 2021):

- Single aquifer piezometer – one of the simplest installations; groundwater pressure is recorded using a water level logger installed within the casing
- CSG completion – this completion is used where there is potential interaction between the CSG target and other formations; there are multiple monitoring points within a single bore, which measure groundwater pressure using water level loggers cemented outside the casing or suspended inside the casing.

- Cemented vibrating wire piezometer – typically installed in CSG exploration holes that have been repurposed as monitoring wells; groundwater pressure is monitored in multiple aquifers using a sensor called a vibrating wire piezometer that is cemented into the borehole.

Data gathered from bores must be reported back to OGIA by the tenure holders, where it is utilised to increase knowledge about baseline conditions, changing volumes, water chemistry and basin hydrology, and identify areas requiring attention. Data gathered from this network is publicly available from the Queensland Groundwater Database (GWDB) (Queensland Department of Natural Resources, 2020).

Findings from the analysis of groundwater data, recommendations and statutory responsibilities of tenure holders are presented in underground water impact reports (UWIR), prepared by OGIA. Four UWIRs have been released since the implementation of the Surat CMA, with the most recent report released in 2022 (OGIA, 2021).

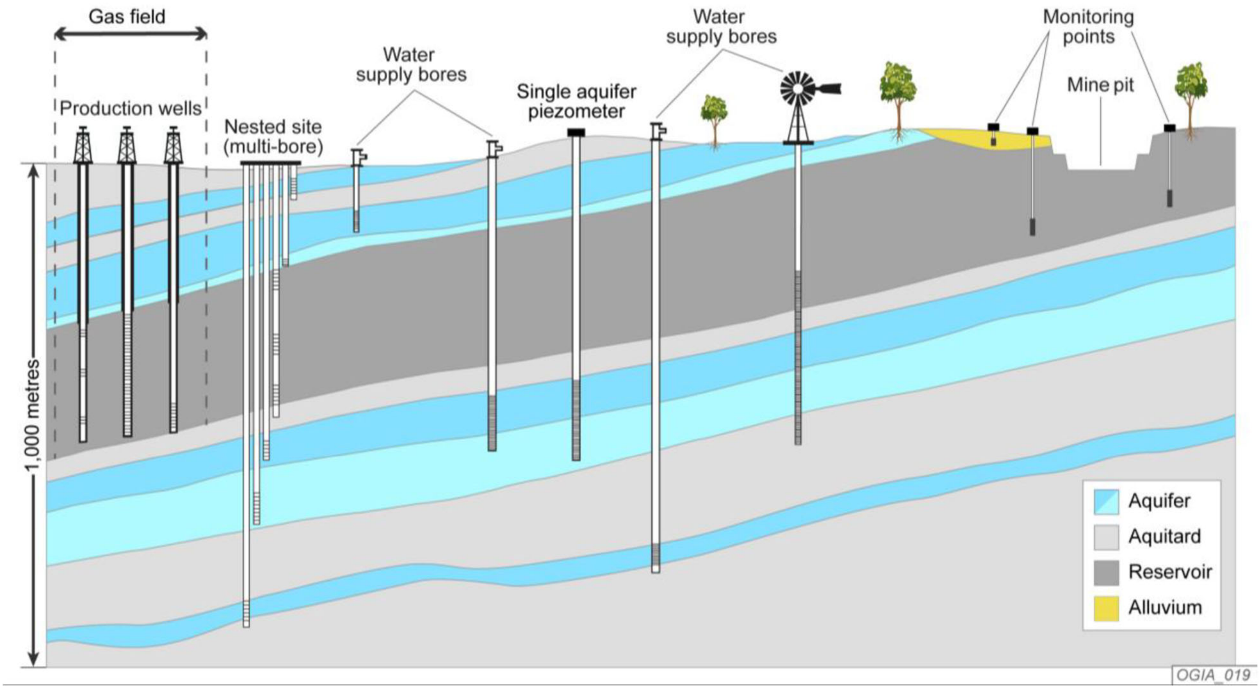


Figure 28: Range of groundwater monitoring installations within the Surat CMA

Source: from OGIA (2021).

Groundwater use

Groundwater is used for agricultural, irrigation, industrial, town water supply and stock and domestic (S&D) purposes in the Surat CMA. OGIA (2021) provides estimates of the total amount of water used in the Surat CMA, with a focus on an area of interest centred around CSG production areas (bores outside this area are unlikely to be impacted by CSG developments). Within this area of interest, OGIA estimates that there are approximately 8000 water bores. Around 4000 of these access aquifers in the GAB. Most of the groundwater extracted from GAB aquifers is utilised primarily for grazing, feedlot and domestic supply.

There is limited data available on actual volumes extracted for the majority of bores as metering is only required on a small proportion of bores. OGIA's estimates of groundwater use are based on a number of factors including any requirements in a water licence for a bore related to volumes, historical data on typical extraction volumes for the various end uses of groundwater, demand estimates for S&D bores, and metering where available. The estimated groundwater use in the Surat CMA area of interest presented by OGIA (2021) is:

- about 59 000 ML/year with 20 000 ML/year from the GAB
- 90% of groundwater use from the alluvium and basalt overlying the GAB is for non-S&D purposes (irrigation)
- two-thirds of the water used in the GAB is for non-S&D purposes

In the study site, most of the groundwater use is from the GAB with only small volumes from shallower alluvial aquifers. Groundwater bores typically extract water from the shallowest available aquifer with suitable volumes and water quality. Shallow alluvial aquifers are restricted to the vicinity of the Condamine alluvial tributaries (Figure 27) in the study site. Elsewhere in the study site, groundwater may be accessed from aquifers in the GAB including the Mooga Sandstone, Orallo Formation and Gubberamunda Sandstone. The water quality in these formations is not suitable for human drinking purposes but may be suitable for stock or irrigation (OGIA, 2019). The Hutton Sandstone is also used for non-S&D purposes in the study site.

Associated water (as a part of petroleum extraction) produced from CSG activities within the Surat CMA is estimated to be about 54 000 ML/year, after peaking at 67 000 ML/year in 2016 (OGIA, 2021). 45 000 ML/year comes from the Surat Basin with the remainder from the Bowen Basin. In 2020, a further 540 ML/year was extracted by CSG operators for other use (such as camp supplies and construction).

Part III CSG activities in the study site

7 History of oil and gas exploration and production in the Bowen and Surat Basins, Queensland

The depositional history of the Surat Basin, and the underlying Bowen Basin, have formed a range of unconventional and conventional petroleum deposits over their extent.

Petroleum was first reported in the Surat Basin with the discovery of gas in a water bore in 1900 at Hospital Hill near Roma; the first designated gas well was drilled in 1908, 75m from the original bore, and flowed 35 500 m^3/d from the Precipice Sandstone (Elliott, 1989). Small noncommercial discoveries were made again in the same region in 1927 and 1934, before gas was identified and commercialised from a geological structure in the original Hospital Hill area in 1954 (Wolfensohn & Marshall, 1964) (Wolfensohn & Marshall, 1964). Australia's first commercial oilfield was discovered near Moonie in 1961, hosted in Surat Basin strata and possibly sourced from underlying Bowen Basin sources (Wolfensohn & Marshall, 1964). Further exploration over the Roma Shelf identified over 30 conventional gas fields by 1968, prompting the construction of the Roma to Brisbane pipeline to connect Brisbane consumers; Surat Basin conventional fields peaked in production between 1994 to 1995, and were mostly depleted by 2002, driving exploration for a new discovery (Towler et al., 2016).

Indicators of gas resources in the Chinchilla region appeared as far back as the early 1900s, occurring as methane outbursts from water bores, documented in government drilling records and anecdotal accounts from landholders (Gray, 1967). CSG exploration in Queensland first began in the Bowen Basin in the 1970s, following international projects recognising CSG's potential as a stand-alone resource, rather than a nuisance and dangerous by-product of coal mining (Towler et al., 2016). It took several decades before CSG was able to be commercially produced from Bowen Basin Permian coals, first in the Dawson Valley in 1996, followed by Injune in 1998 and Moranbah in 2005 (Randall, 2013).

The first well drilled with the primary aim of exploring for CSG in the Surat Basin was Southeast Teatree CBM 1, drilled by Mosaic Oil in February 1995 (Scott et al., 2007). By 2006, the first commercial CSG from the Walloon Subgroup began production in the Kogan, Tipton West and Berwyndale fields around Chinchilla, overtaking CSG production from the Bowen Basin to become Queensland's primary supply of natural gas in 2011 (Towler et al., 2016). The gas found in these coal seams is interpreted to have predominantly biogenic origins, based on vitrinite reflectance measurements and isotopic compositions, but also contains some thermogenic influences from deeper Bowen Basin seams (Faiz & Hendry, 2006).

There are four major CSG developments operating in the Surat and Bowen basins in Queensland:

- Gladstone Liquified Natural Gas (GLNG). A joint venture operated by Santos, with LNG facilities on Curtis Island. Supplies gas for export and the domestic market.

- Australia Pacific Liquefied Natural Gas (APLNG). A joint venture with upstream activities operated by Origin and LNG facilities on Curtis Island operated by ConocoPhillips. Supplies gas for export and the domestic market.
- QGC venture (formerly Queensland Gas Company). Operated by Shell, with LNG facilities on Curtis Island (Queensland Curtis Liquefied Natural Gas or QCLNG). Supplies gas for export and the domestic market.
- Arrow Energy. Supplies gas to the domestic market. Commenced an expansion of production with the Surat Gas Project in 2020.

The GLNG, APLNG and QGC developments export most of their production through LNG facilities at Curtis Island. The total production of CSG in the 2018-2019 financial year was about 1440 PJ, with 1120 PJ from the Surat Basin and 320 PJ from the Bowen Basin (Queensland Government, 2022). By comparison, the total gas production in Australia for 2018-2019 was 5498 PJ, with 4094 PJ exported (Department of Industry, Science, Energy and Resources, 2020).

8 CSG activities in the study site

The study site covers activities by APLNG and QGC (Figure 29). Table 9 provides a list of production licences. There is an exploration tenement held by Arrow Energy in the north of the study site. Only two exploration wells have been drilled in this tenement and they were not included in this study. Table 9 provides a list of production licences and the associated field names. The first Production Leases were granted in 2004.

Table 9: Production Licences in the study site.

Lease	Operator	Field name(s)	Date granted	Area (ha)	Environmental Authority
PL 179	QGC	Argyle	29-Jun-05	5100	EPPG00878413
PL 180	QGC	Codie, Lauren, Kenya	1-May-09	13 500	EPPG00878413
PL 201	QGC	Berwyndale, Berwyndale South	24-Jun-04	6600	EPPG00652513
PL 211	QGC	Berwyndale	30-Jun-09	6600	EPPG00878413
PL 212	QGC	Berwyndale South	22-Nov-11	1800	EPPG00878413
PL 228	QGC	Kenya, Codie, Kate	29-Jun-05	15 000	EPPG00878413
PL 229	QGC	Argyle, Argyle East	29-Jun-05	2400	EPPG00878413
PL 247	QGC	Bellevue	30-Jun-09	7700	EPPG00611313
PL 257	QGC	Jammat	17-Feb-12	300	EPPG00889613
PL 263	QGC	Matilda-John, Lauren	3-Nov-11	8400	EPPG00878413
PL 278	QGC	Kenya East, Jammat, Margaret	9-Dec-11	22 200	EPPG00889613
PL 443	QGC	Owen	24-Dec-12	1200	EPPG00889613
PL 458	QGC	McNulty	18-Feb-13	6600	EPPG00932613
PL 459	QGC	McNulty	14-Feb-13	900	EPPG00932613
PL 461	QGC	Avon Downs	14-Feb-13	1500	EPPG00932613
PL 472	QGC	Avon Downs, McNulty	10-Feb-14	6200	EPPG00932613
PL 1018	APLNG	Riley	12-Jun-17	611	EPPG00968013
PL 1011	APLNG	Condabri Extension/ Alfredson	2-Aug-15	7500	EPPG03921216
PL1084	APLNG	Murrungama	9-Mar-20	1837	EPPG00968013
PL 215	APLNG	Orana	27-Apr-09	8400	EPPG00968013
PL 226	APLNG	Talinga/Orana North	16-Dec-04	19 800	EPPG00968013
PL 265	APLNG	Condabri	22-Aug-11	19 500	EPPG00968013
PL 266	APLNG	Condabri South	2-May-13	7500	EPPG00968013
PL 267	APLNG	Condabri North	10-Aug-11	18 000	EPPG00968013
PL 272	APLNG	Talinga/Orana North	2-Oct-13	22 500	EPPG00968013

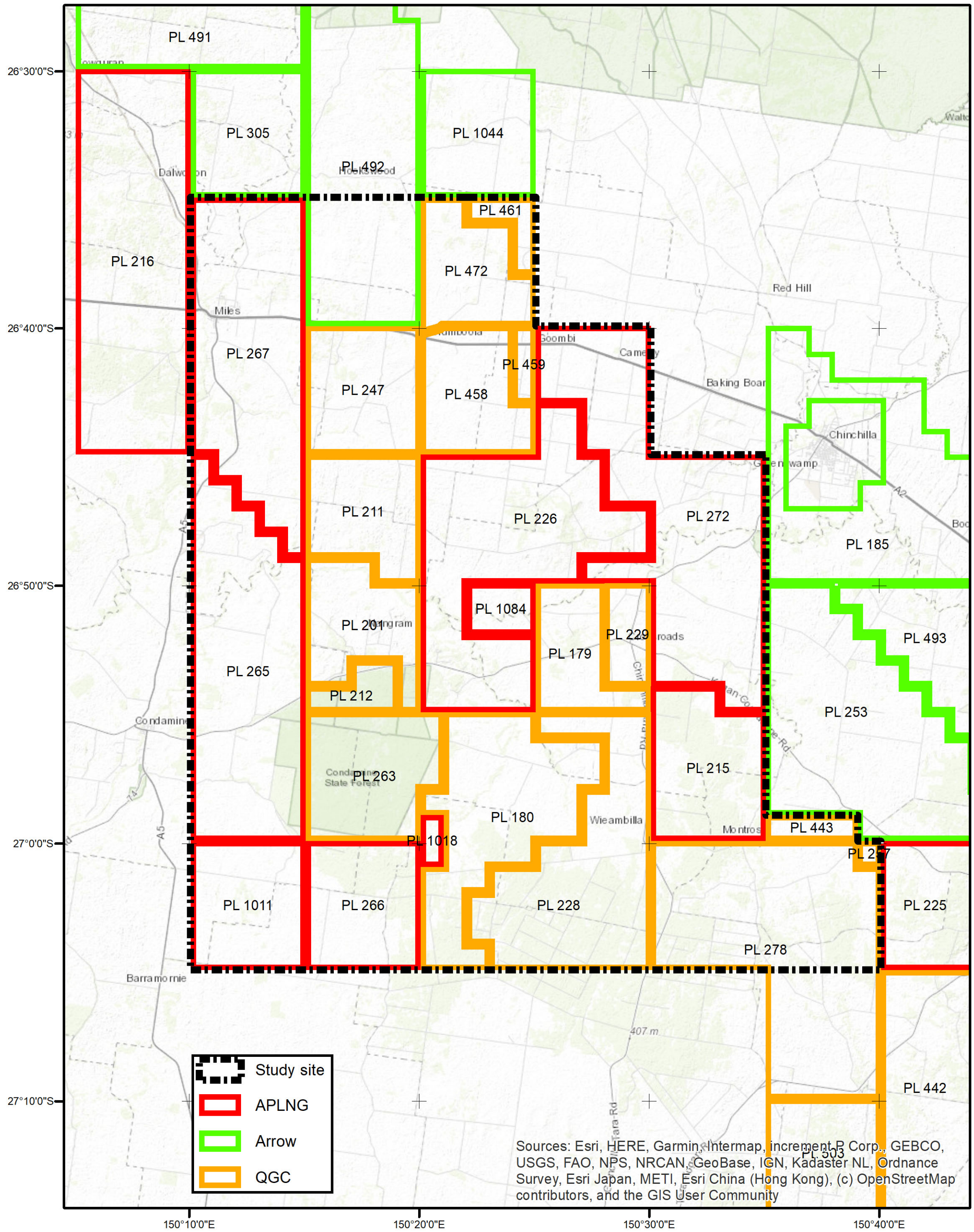


Figure 29: Petroleum Leases covered by the study site.

Prior to the granting of Production Leases activities were limited to a small number of wells for exploration. Extensive drilling activities did not commence until around 2006, primarily by QGC, with APLNG increasing activity from 2009 (Figure 30). Over half of the wells in the study site were drilled between 2012 and 2017. Drilling activity has significantly reduced in the last few years. QGC commenced production of gas in 2005, while APLNG commenced production in 2009 (Figure 31).

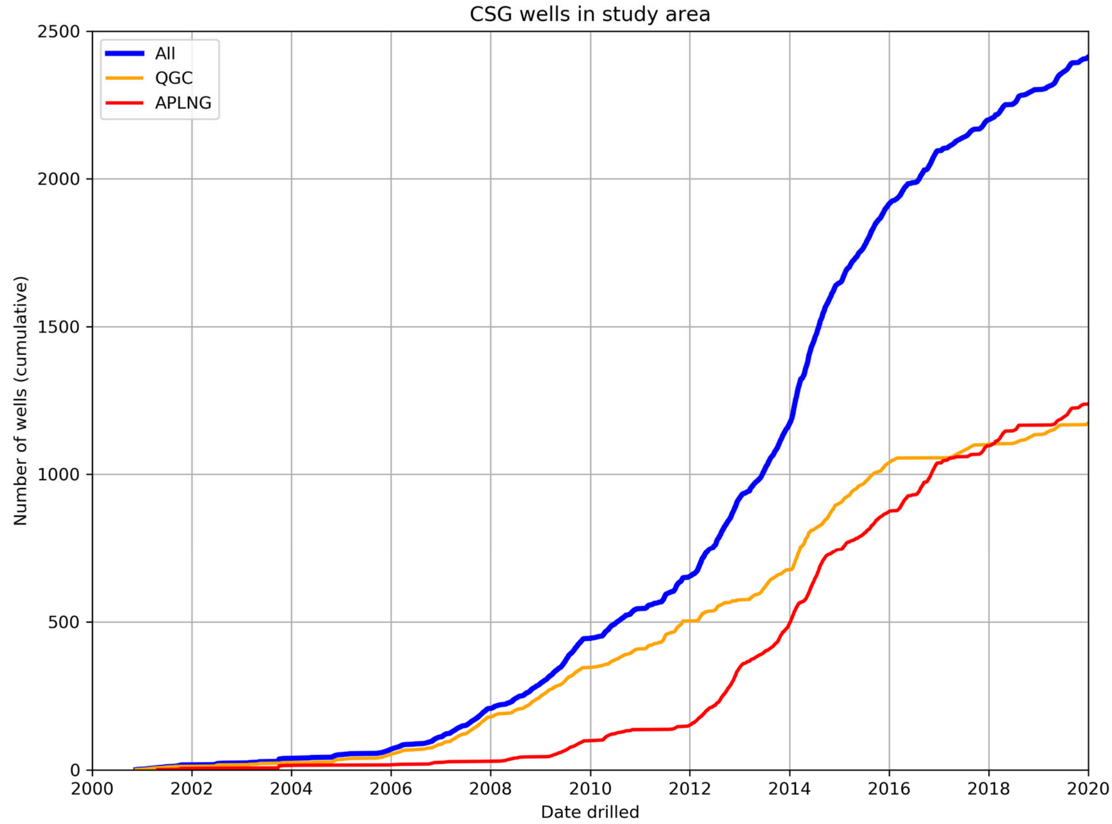


Figure 30: Count of CSG wells drilled in the study site to the end of 2020.

The early stages of production also require the water levels in the coal seams to be reduced. Figure 31 shows how water production peaked (2015) ahead of the peak in gas production (2017). In addition to construction of wells, the early stages of development includes the construction of associated infrastructure such as gathering lines, water treatment facilities, gas processing facilities and associated infrastructure, such as gathering lines, water treatment and gas processing facilities. This may require some gas to be flared or vented as production increases. This is a small proportion of the gas produced (Figure 31), and as infrastructure becomes available the need for flaring is reduced. Figure 32 shows that flaring has significantly decreased since 2018.

Figure 32 (dotted lines) also shows a difference in the amount of gas used in the field by QGC and APLNG. QGC use gas to drive most of their field compression stations and compressors in the gas processing facilities. APLNG use electricity to drive their compressors. Overall the proportion of gas used in the field, vented or flared is a small fraction of the overall volume of gas produced (Figure 31).

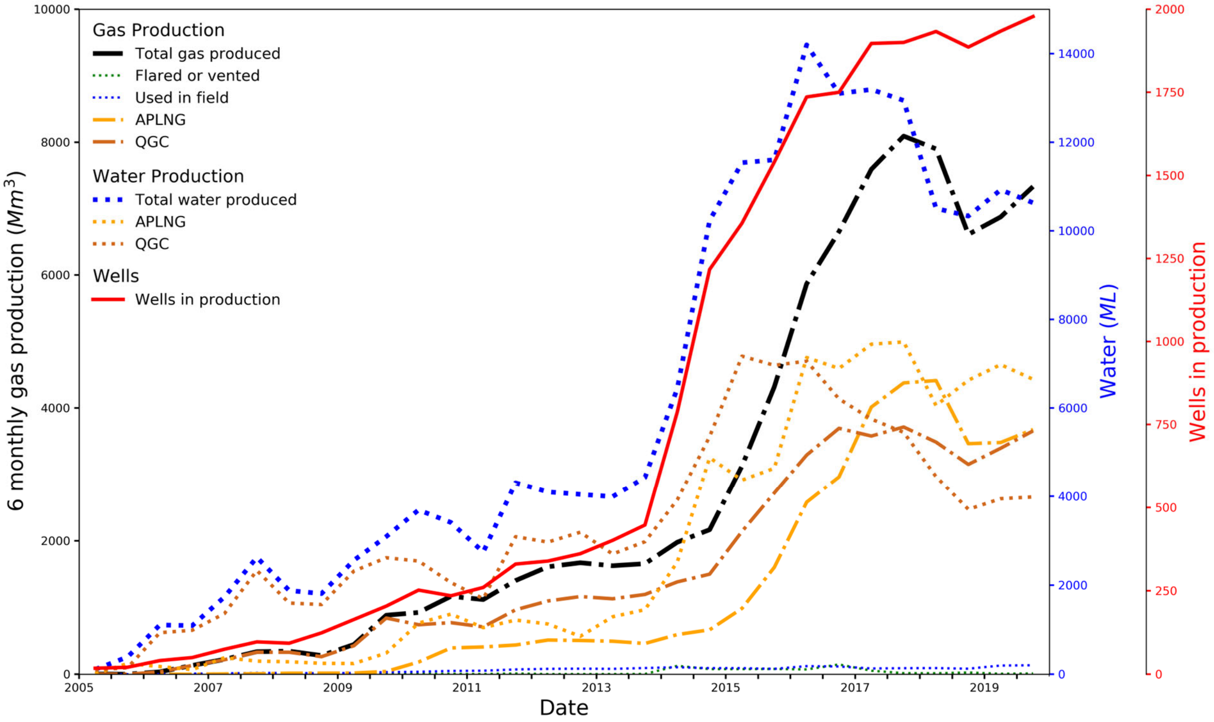


Figure 31: Gas and water production in the study site, along with the number of wells in production.

Source: Queensland Government (2022)

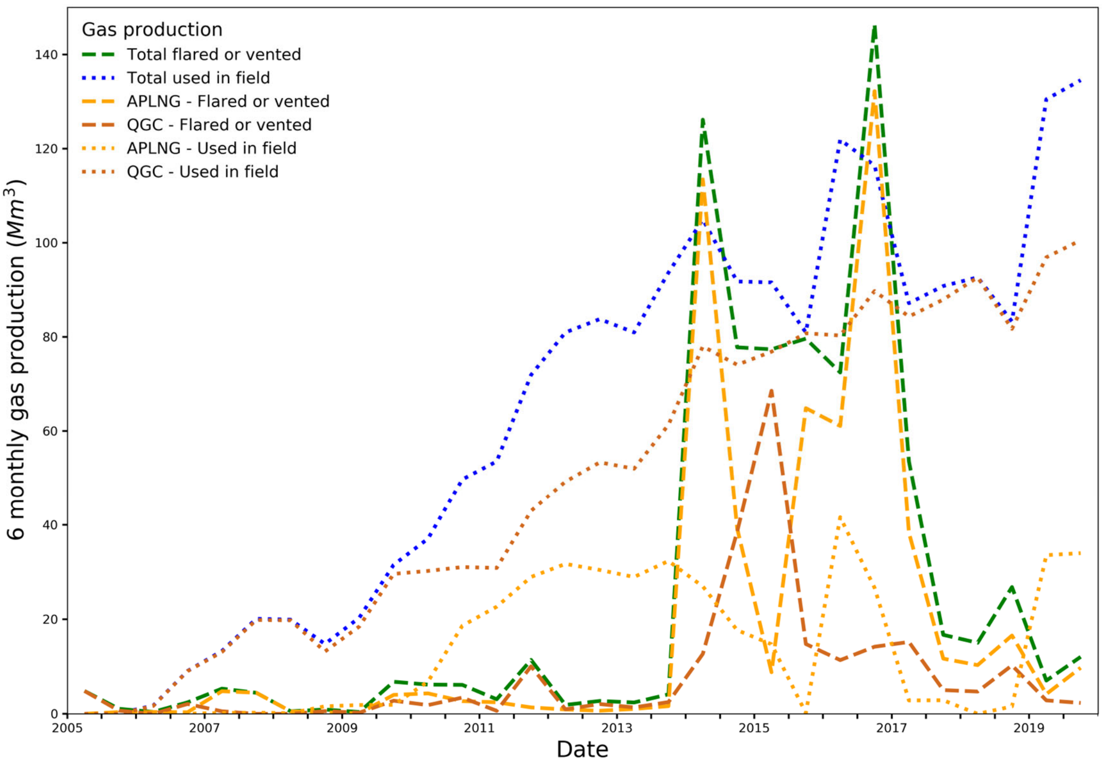


Figure 32: Gas used, vented or flared in the study site.

Source: Queensland Government (2022)

8.1 CSG infrastructure

APLNG and QGC operate wells, gathering lines, compression stations, gas processing facilities, water handling infrastructure (ponds and pump stations) and water treatment facilities in the study site, summarised in Table 10.

Origin Energy and Shell provided spatial data for CSG infrastructure within the study site for the APLNG and QGC projects respectively. These data consisted of locations for:

- wells
- gathering lines (gas and water)
- high point vents and low point drains
- gas pipelines
- gas compressors
- gas processing facilities
- flares
- water ponds
- water treatment facilities
- ancillary infrastructure.

The location of wells is shown in Figure 33, and of other infrastructure in Figure 34.

Table 10: Infrastructure in the study site (as of February 2020).

Category	APLNG	QGC
CSG Wells	1240	1184
Wells hydraulically fractured	43	24
Gathering pipelines (water and gas)	2286.7 km	2313.5 km
High point vents/Low point drains	1386/823	199/323
Water ponds	47 (2.4 km^2)	24 (6.01 km^2)
Water treatment facilities	2	2
Field compression stations	3	12
Gas processing plants	5	3
Flares	11	24

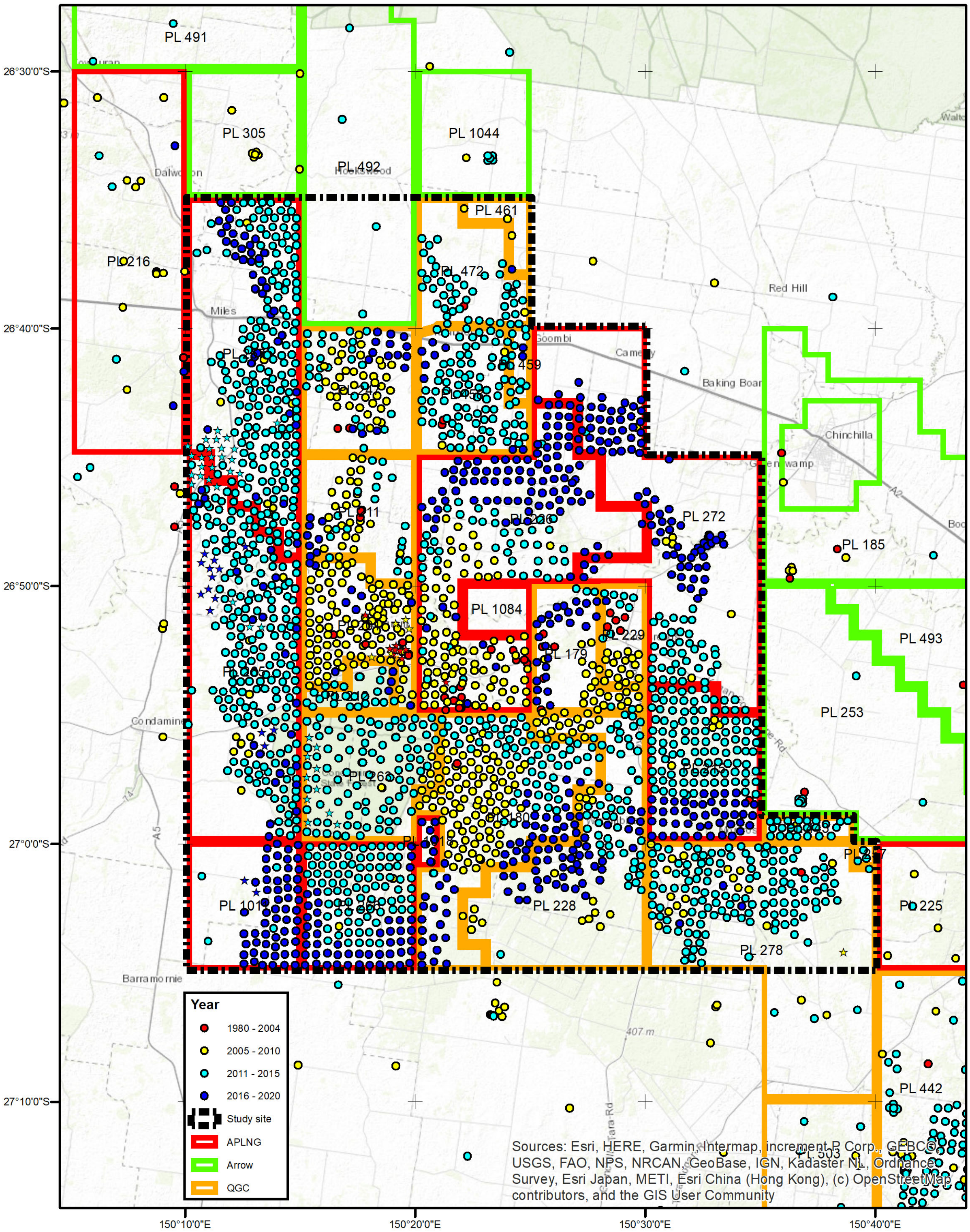


Figure 33: Well locations in the study site. Colours represent the year the well was drilled (based on rig-release date in (Geological Survey of Queensland)). Wells shown with a star symbol have been hydraulically fractured.

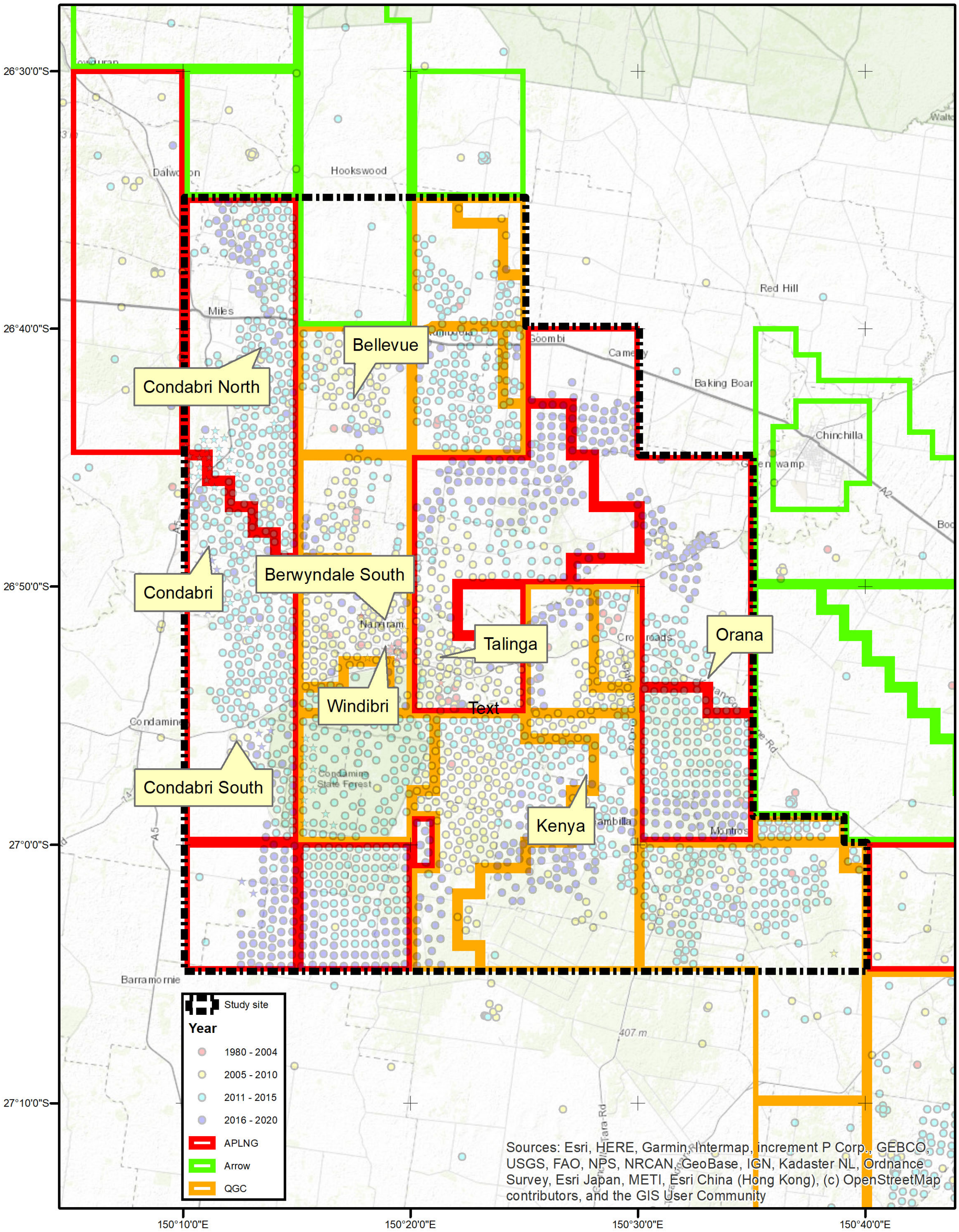


Figure 34: Locations of main CSG facilities in the study site. See text for further discussion.

8.1.1 APLNG

Origin Energy Upstream Operator Pty Ltd operates APLNG's natural gas resources and delivery of gas to feed the domestic market and the APLNG's LNG facility. Upstream operator obligations include drilling and completion of CSG wells and the operation and maintenance of all gas fields and gas transmission pipeline infrastructure.

APLNG's main facilities in the study site are at Condabri, near the township of Condamine, where they operate a gas processing facility and water treatment facility (Figure 34). They have smaller facilities at Talinga (gas processing and water treatment), Orana (gas processing), Condabri North (gas processing) and Condabri South (gas processing).

APLNG use RO in their treatment facilities at Talinga and Condabri. Treated water produced from the Talinga and Condabri water plant is utilised for beneficial use via the Fairymeadow Road Irrigation Pipeline scheme, near Miles.

8.1.2 QGC

Shell operates QGC's natural gas resources and delivery of gas to feed the domestic market and the QCLNG facility. Upstream operator obligations include drilling and completion of CSG wells and the operation and maintenance of all gas fields and gas transmission pipeline infrastructure.

The study site covers QGC's Central Gas Field APLNG's, with the main facilities at Kenya, where QGC operate a gas processing facility and water treatment facility (Figure 34). They have smaller facilities at Bellevue South (gas processing), Berwyndale South (gas processing) and Windibri (water treatment).

QGC operate RO at the Kenya and Windibri water treatment facilities. A brine concentrator is also used at the Kenya plant. Treated water produced from the Kenya water treatment facility is piped to the Chinchilla Weir where it is used in the Chinchilla Beneficial Use Scheme, mainly for irrigators.

9 Site specific data

9.1 Drilling and hydraulic fracturing additives

Site specific drilling and hydraulic fracturing data consists of the additives used during drilling or hydraulic fracturing of a well and the composition of the additives. An **additive** is a distinct product that is made up of one or more chemicals. For example, AMC Glute is a drilling additive that has the chemicals glutaraldehyde and water as its ingredients.

Data on the additives used by the CSG industry is held by the industry with some data reported to government. These data are collected for a variety of purposes, and not necessarily for an environmental health study. Regulatory requirements by government for data reporting have also changed through time.

9.1.1 Drilling additives

The drilling additives used in CSG wells are typically recorded for each well. This information is reported through well completion reports that industry must submit to the regulator 12 months after the completion of a well. Well completion reports are kept confidential for a period of five years from completion of production wells. Operators are required to list the additives used, however, they are not required to list the ingredients of these additives. CSG operators will also typically maintain their own database on drilling operations and chemical use.

For this project, additive use information was sourced from publicly available well completion reports, extracts of operator databases and well completion reports provided by operators for wells that are still within the confidentiality period. The quality of these data is variable, with data not recorded for some wells or generic terminology used. The quality of the data has improved through time.

The study looked at wells drilled up to February 2020, a total of 2424 CSG wells. The wells were identified from the Queensland Government's CSG well dataset (Geological Survey of Queensland, n.d.). From these 2424 wells:

- 121 wells had no record of whether drilling additives were used,
- 185 wells had records that stated that no drilling additives were used,
- three wells had records that were incomplete (partial list),
- 106 unique drilling additives were identified. Of these:
    - 82 had a uniquely identifiable name for an additive product (such as AMC Biocide G)
    - 24 were a generic name for a material used as an additive (such as KCl or bentonite)

There were an additional five descriptors used on some wells that were a generic name for a type of additive (such as biocide or loss control measure). A complete list of drilling additives identified for this project is provided in Appendix A.1.

The project team had limited access to data on the additives that are used during well workovers or the frequency of these activities.

9.1.2 Hydraulic fracturing additives

The hydraulic fracturing additives used in CSG wells are recorded for each well. This information is reported through hydraulic fracturing activities completion reports that industry must submit to the regulator six months after a well has been hydraulically fractured. These reports are kept confidential for a period of five years from the completion of hydraulic fracturing activities. Operators are required to list the additives used. Since regulatory changes in 2011, operators must also provide a hydraulic fracturing fluid statement that lists the additives used, their quantities, concentrations and the name of any chemical compound contained in the hydraulic fracture fluid.

For this project, additive use information was sourced from publicly available hydraulic fracturing reports and hydraulic fracturing reports provided by operators for wells that are still within the confidentiality period. 64 wells have been hydraulically fractured with the study site. Additive data was available for all 64 wells. 3 wells were treated with a method referred to as formation stabilisation, which is similar to hydraulic fracturing. 57 unique hydraulic fracturing additives were identified. A complete list of hydraulic fracturing additives identified for this project is provided in Appendix A.2.

9.1.3 Additive ingredients

The ingredients for drilling and hydraulic fracturing additives where primarily sourced from Safety data Sheets (SDS, previously known as a material safety data sheet) for the additives. The majority of these SDS are available on the operator's websites. Additional SDS were provided directly by the operators, accessed through chemical management databases (ChemWatch and ChemAlert), manufacturer websites or as included in other studies or assessments. Where multiple SDS were available for a particular additive and different or additional ingredients were listed, the additive was assumed to contain all of those ingredients for the purposes of this study.

The requirements for which products or chemicals require an SDS is regulated under state-based workplace health and safety legislation (these laws are part of nationally harmonised work health and safety laws). In Queensland, SDS requirements are in the *Work Health and Safety Regulation 2011*.

The regulations require an SDS when a manufacturer determines that a product or its ingredients are hazardous according to relevant criteria. This is currently the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), 3rd revised edition (United Nations, 2009), although this is being transitioned to the 7th edition (United Nations, 2017). The regulations also set requirements for whether ingredients need to be named with a unique chemical identity, and whether the exact concentration is required or a range of concentrations (for commercial in confidence products). Manufacturers are not required to have their SDS approved, but the regulator may review SDS to determine whether they are compliant with relevant regulations.

According to these regulations, SDS do not need to list ingredients that are determined to be non-hazardous, or to provide chemical identifiers in certain circumstances. As a result, SDS do not always contain a complete list of the ingredients of a product. This regulation applies to the majority of industrial chemicals in Australia, not just those used in the CSG sector.

For the purposes of this study only chemicals with a Chemical Abstracts Service Registration Number (CAS RN) were appraised. The CAS RN provides certainty about the identity of the chemical.

For the 110 drilling additives and 58 hydraulic fracturing additives and one additive used in both drilling and hydraulic fracturing, an SDS or ingredient list could be found for all except six of the drilling additives. Based on these data sources, 144 chemicals with a CAS RN were identified. The SDS or ingredients lists also contained entries that did not have a CAS RN.

A complete list of the ingredients of drilling and hydraulic fracturing additives identified for this project are provided in Appendices A.1 and A.2 respectively.

9.1.4 Ingredients without a CAS

The ingredients list for many of the additives included an ingredient with no CAS RN, or the listed ingredients did not total to 100% (suggesting the remaining ingredients are considered non-hazardous). 68 of the additives identified for the study site had at least one ingredient with no CAS RN. There may be additional additives for which the composition did not total 100%. The 47 ingredients identified without a CAS RN can broadly be grouped as follows:

- statement that the manufacturer's assessment is that the ingredient(s) are non-hazardous - one ingredient
- generic component (carrier, emulsifier, neutraliser, additives) six ingredients
- not disclosed (not available, proprietary) two ingredients
- unprocessed plant-based materials (nut shells, wood fibre) four ingredients
- chemicals with a non-unique name, 34 ingredients

It was not possible to appraise the hazard potential of these ingredients.

Some additives used have generic names that may be one of a number of products. For example, bentonite clay is a commonly used additive that is often recorded as simply 'bentonite' or 'gel.' There are several additives made by various manufacturers that contain bentonite, including AMC Aus-Ben, AMC Aus-Gel and MI Swaco M-I Gel. In addition, there are a range of manufacturers who have a product simply named bentonite. The SDS for these products have varying ingredients, although in the case of bentonite these tend to be limited to impurities present at very low concentrations (other silicate minerals).

In the majority of cases these generic additives are made up of a single ingredient. However, they may contain small amounts of impurities or ingredients that maintain the physical properties of the additive (such as an anticaking agent). These additives are:

- acetic acid
- barite
- bentonite
- caustic soda
- citric acid
- guar gum
- potassium chloride
- lactose
- lime
- limestone
- sodium chloride
- PAC (polyanionic cellulose)
- potassium acetate
- potassium carbonate
- potassium sulfite
- sand (proppant)
- soda ash
- sodium bicarbonate
- sodium formate
- sodium sulfite
- starch
- xanthan gum

Data cut-off

The list of drilling and hydraulic fracturing additives and their ingredient chemicals used for the appraisal detailed in Rigby et al. (2021) was based on the data collated before mid-2020. A subsequent review of data identified additional additives and additional information sources for additive ingredients. This new information was derived from a reappraisal of available data sets, data that was available but not discovered by mid-2020 and datasets made available after mid-2020.

From this review, an additional 29 additives were discovered. Most of these additives were used in drilling and generally had low usage rates. Ingredient information was found for six additives that had previously been identified without ingredient data. Additional ingredient information was found for 26 additives. The majority of this new information on additives and their ingredients overlapped with the chemical list identified in the pre-mid-2020 data. However, an additional 47 unique chemicals have been identified, and these have not been appraised as part of this study.

In summary, these chemicals include:

- six chemicals that are naturally occurring minerals that are impurities in bentonite (340 wells) or barite (29 wells)
- 22 chemicals that were components of 10 additives that were newly identified, one chemical was used in two additives across 38 wells and the remaining 21 were used in 14 wells or less
- 26 chemicals that were ingredients found in new information for 14 additives:
    - one chemical (calcium stearate, CAS RN 1592-23-0, an anticaking agent used in food) was a component of two additives and was used in 162 wells
    - two chemicals were an ingredient of one additive that was used in the drilling of 91 wells

- the remaining 23 chemicals were ingredients of eight additives used in drilling or hydraulic fracturing in a small number of wells (6 wells or less)

9.2 Water treatment and gas processing additives

Data on the use of chemicals used in water treatment facilities was derived from company reports on the operation of these facilities. A total of 19 unique chemicals with a CAS RN were identified for water treatment plants (Rigby et al., 2023). Six of these chemicals were also identified as chemical factors used in drilling and hydraulic fracturing additives, and two are known environmental degradation product of chemical factors used in drilling and hydraulic fracturing.

Only one unique chemical with a CAS RN was identified for gas processing facilities (Rigby et al., 2023). Gas processing facilities are primarily used to compress gas for pipeline transmission. Processing of the gas is limited to dehydration using triethylene glycol. There are other chemicals used, such us lubricants in gear boxes on compressors, which are outside of this project's scope.

9.3 Incident data

The pathways by which factors associated with CSG activities may be released to the environment may be intended or inadvertent. Factors may be released to the environment through normal operations, such as in additives used in drilling or hydraulic fracturing or combustion products from flaring natural gas. These pathways can be readily characterised as the activities that give rise to them are also well described and understood. Inadvertent or unintended events happen as a result of human error or a failure of engineering controls, such as spills of chemicals during transport or a release of water from a damaged pipe. While the potential for inadvertent events can be identified, there is uncertainty about their characteristics (frequency, duration, magnitude).

Historical data on inadvertent events provides a way in which to characterise them in the study site. There is no publicly accessible dataset of incidents.

The conditions of environmental authorities for CSG activities include reporting requirements related to spills and exceedances of environmental conditions. For example, the Streamlined model conditions for petroleum activities (Queensland Department of Environment and Heritage Protection, 2016), has the following notification requirements in condition General 12:

> *In addition to the requirements under Chapter 7, Part 1, Division 2 of the Environmental Protection Act 1994, the administering authority must be notified through the Pollution Hotline and in writing, as soon as possible, but within 48 hours of becoming aware of any of the following events:*
>
> *(a) any unauthorised significant disturbance to land*
>
> *(b) potential or actual loss of structural or hydraulic integrity of a dam*
>
> *(c) when the level of the contents of any regulated dam reaches the mandatory reporting level*
>
> *(d) when a regulated dam will not have available storage to meet the design storage allowance on 1 November of any year*
>
> *(e) potential or actual loss of well integrity*

(f) when the seepage trigger action response procedure required under condition (Water 14(g)) is or should be implemented

(g) unauthorised releases of any volume of prescribed contaminants to waters

(h) (h) unauthorised releases of volumes of contaminants, in any mixture, to land greater than:

i. 200 L of hydrocarbons; or

ii. 200 L of stimulation additives; or

iii. 500 L of stimulation fluids; or

iv. 1 000 L of brine; or v. 5 000 L of untreated coal seam gas water; or

v. 5 000 L of raw sewage; or

vi. 10 000 L of treated sewage effluent.

(i) the use of restricted stimulation fluids

(j) groundwater monitoring results from a landholder's active groundwater bore monitored under the stimulation impact monitoring program which is a 10% or greater increase from a previous baseline value for that bore and which renders the water unfit for its intended use

(k) monitoring results where two out of any five consecutive samples do not comply with the relevant limits in the environmental authority.

9.3.1 Incident data - industry

The environment authorities for the petroleum activities in the study site have the same or very similar conditions. The operators provided the following data for notifiable incidents in their permits. One operator provided data for the period from the granting of Production Leases to the end of 2019. The other operator provided data for the period from the start of 2018 to the end of 2020. In total there were 62 incidents. None of these incidents have been determined to have caused an environmental harm. The largest number of incidents are related to produced water leaks and spills, with the majority of those from well heads (14 of 30) and pipelines or vents/drains on pipelines (9 of 30). The incidents are summarised in Table 11.

Table 11: Summary of incident data provided by the two operators in the study site.

Description	Number of incidents	Volumes
Release of hydraulic fracturing fluid at a well site.	1	200 litres
Release of produced water from surface infrastructure. Primarily from wellheads (14) and gathering pipelines (9), with the remainder from stand pipes, truck rollovers and pond seepage.	30 (3 have no volume data)	500 to 100 000 litres Median volume: 10 000 litres
Drilling fluids (also known as drilling muds). The largest volume was during land spray while drilling operations.	3	10 litres 4800 litres and 10 000 litres
Diesel fuel or engine/gearbox/hydraulic oils#. Includes spills from storage tanks or from vehicles (acciidents or breakdowns).	11 (4 have no volume data)	5 to 1145 litres Median volume: 200 litres
Sewage from camps and administration facilities#. Including the release of effluent, or sewage.	7 (2 have no volume data)	50 to 10 200 litres Median volume 200 litres
Storm water, waste water from interceptor ponds or vehicle washdown water.	4 (3 have no volume data)	4700 litres
Odour from a waste water pond.	1	Not applicable
Release of diluted Vital Strike# and water during filling of a water truck. Vital Strike is a soil stabilising agent used during the reinstatement process, and is not used in drilling, hydraulic fracturing, water treatment or gas processing facilities.	1	300 Litres
Total	**62**	

#The scope of this study is for factors particular to drilling, hydraulic fracturing, wastewater treatment and gas processing. Fuels and oils used in vehicles or stationary plant and factors associated with camps or administration infrastructure (including sewage treatment) are out of scope. Products used in reinstatement (such as Vital Strike) are also out of scope.

The data provided by one of the operators also contained exceedance data for some parameters monitored in accordance with their environment authorities (Table 12).

Table 12: Summary of exceedance data provided by the two operators in the study site.

Description	Number of exceedances reported
Exceedances in water quality parameters. Inorganic compounds in produced water. All incidents in 2010-2011. Exceedances of reporting limits for calcium, magnesium, sodium, chloride or sulfate. Sampling location not disclosed.	7
Exceedances in water quality parameters from effluent water (sewrage) for E.coli or biochemical oxygen demand.	3

9.3.2 Incident data – Queensland Government

In addition to the data provided directly to CSIRO by industry, incident data was also obtained from the Queensland Government through a Right to Information request (RTI application 19-109). These data are reported to government by industry.

The scope of the RTI request was

> *"Documents relating to all relevant notifications and non-compliance reporting including any sensitive receptor reports for the Origin coal seam gas site at Condabri (EPPG00853013), including:*
>
> - *all notifiable spills (Condition K1h)*
> - *pond overtopping/integrity incidents (K1b)*
> - *well integrity reporting (K1e)*
> - *non-compliant releases of to land (K1h) surface water (K1g and K1k), and groundwater (K1j and K1k)*
> - *non-compliant releases to air, verification monitoring exceeds modelled concentrations (F6, F23 and F24)*
> - *groundwater changes (K1j)*
> - *seepage trigger action (K1f)*
> - *use of restricted fracturing fluids (K1i)*
> - *emergency environmental incidents (General 16)*
> - *drinking water standards non-compliance (B12 and B13)*
> - *odour notifications (F23)*
> - *dust exceedance notifications (F26, F23)*
> - *noise investigation notifications (E16 and E17)*
> - *sensitive receptor reports*
>
> *Excluding:*
>
> - *any personal information of landholders;*
> - *any personal information of employees, consultants and contractors of Origin, APLNG and others;*
> - *any property descriptions and names, GPS coordinates, photos and Google maps;*
> - *personal information of departmental officers;*
> - *duplicate documents; and*
> - *environmental authorities and permits that are publicly available.*
>
> *Time period: 1 January 2013 to 31 December 2017."*

The list of incidents reported by the operator whose activities were subject to the RTI request matched the data in the RTI request with the exception of two releases of sediment (erosion run-off) to waterways.

The RTI request also included information on

- a noise complaint during drilling operations at one well site
- a potential aquifer connectivity incident between the Hutton Sandstone and overlying Walloon Coal Measures
- investigation into potential impacts of landspray while drilling activities that determined the exceedances were related to natural variability in soil properties
- annual dam inspection reports
- gas gathering network pipeline pressure testing management plans
- water quality monitoring management plan production operations

These additional data are related to how the RTI request was interpreted by the Queensland Department of Environment and Science.

9.3.3 Incident data – enforcement actions

The Queensland Department of Environment and Science has a public register includes information and documentation required under sections 540 and 540A of the *Environmental Protection Act 1994*. The public register includes an online portal that provides access to enforcement actions which are issued by the department to an individual or company for non-compliance with a condition of an EA or the Environmental Protection Act 1994. The types of enforcement actions available are:

- accepted enforceable undertakings
- transitional environmental programs (TEPs)
- environmental protection orders
- environmental evaluations
- direction notices
- clean-up notices
- cost recovery notices.

For the petroleum licences in the study site, there is one enforcement action originally recorded in TEP MAN19660 and subsequent amendments (MAN19720 and MAN19760). This TEP relates to exceedances of noise limits at sensitive receptors. Monitoring at a residence approximately 5.5 km from QGC's Kenya Gas Processing Facility showed instances where noise levels were above the night time noise limit set out in Condition E7, Schedule E, Table 1 – Noise Limits at Sensitive Receptors (EPPG00878413). This limit is 28 dBA L_{Aeq} (L_{Aeq} = A-weighted equivalent continuous sound level) between 10:00 pm and 6:00 am. QGC installed an acoustic barrier that successful reduced the noise levels to below the stipulated limits. QGC subsequently purchased the property and the TEP was cancelled.

Appendix A Drilling and hydraulic fracturing additives and ingredients

The data in the following tables is a collation of data on drilling and hydraulic fracturing additives and their ingredients discovered throughout the CSIRO GISERA H.2 Project *Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland.* See section 9.1 for further information on how these data were compiled.

Column information abbreviations and styles used in the tables are:

Additive column: Name of the additive, either the name of a product or a generic material used as an additive.

(Blue highlight), data discovered (additive or ingredient) post 2020

Class column: Class of the additive to allow additives that are similar or that have similar usage to be grouped.

Type: *Specific* refers to an additive that is a specific product; *Generic material* refers to an additive that is a single material that may be sourced from a number of suppliers; Generic additive refers to additives that are recorded by their intended purpose without reference to the product or material.

Wells: The number of wells in the study site in which the additive was used.

Names as recorded: Additive names as recorded in well completion reports, hydraulic fracturing reports and drilling databases supplied by industry.

CAS RN: Chemical Abstract Service Registry Number, used to provide a unique, unmistakable identifier for chemical substances. Used to identify ingredients in an additive. Where a CAS RN was not available, NA-XXX and the name of the ingredient are used. Where no ingredient information could be found, NAC is used.

Name: Name of the chemical substance. Where a CAS RN was not available, NA-XXX and the name of the ingredient are used.

Ingredient source column: The source used to determine the ingredients of an additive. In some cases multiple sources with differing ingredients were discovered in which case all ingredients are listed.

Abbreviation	Definition
AS	SDS available on APLNG website (https://aplng.com.au/material-safety-data-sheets/) at time of study
SS	SDS on Shell (QGC) website (https://www.shell.com.au/about-us/projects-and-locations/qgc/about-onshore-natural-gas/hydraulic-fracturing-and-chemicals-used.html) when sourced
CW	SDS in ChemWatch (https://www.chemwatch.net/), University of Queensland
CA	SDS in ChemAlert (https://rmtglobal.com/solution/chemalert/), CSIRO
U	insufficient information to determine additive or ingredients
MB	supplier/manufacturer's information other than SDS
MS	SDS sourced from supplier/manufacturer
X	unable to source SDS or ingredient list
WA	ingredients listed in environment plan for drilling in Western Australia
G	generic ingredient readily identifiable

Note: ## (blue highlight)in the additive or source columns denotes data discovered (additive or ingredient) post 2020.

A.1 Drilling additives and chemicals

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Aldacide G	Biocide	Specific	183	ALDACIDE - BIO CIDE ALDACIDE G - BACTERICIDE ALDACIDE G - BIOCIDE BAROID ALDACIDE - BACTERICIDE	111-30-8	Pentanedial (Glutaraldehyde)	CW
					67-56-1	Methanol	CW
AMC Biocide##	Biocide	Generic additive	16	AMC BIOCIDE ()	NA-045	Biocide	U
AMC Biocide G	Biocide	Specific	132	AMC BIOCIDE G AMC BIOCIDE G - BIO CIDE AMC BIOCIDE G () AMC BIOCIDE G (BACTERICIDE) AMC BIOCIDE-G - BIO CIDE BIOCIDE G - BIO CIDE BIOCIDE G - INHIBITION BIOCIDE-G BIOCIDE-G - BACTERICIDE BIOCIDE-G - BIO CIDE BIOCIDE-G - BIOCIDE BIOCIDE-G (DISPLACEMENT) - BACTERICIDE BIOCIDE-G (DRILLING)	55566-30-8	Tetrakis (hydroxymethyl) phosphanium sulfate (THPS)	CW
					NA-037	Non-hazardous ingredients	CW
AMC Defoamer##	Defoamer	Specific	1	AMC DEFOAMER - DEFOAMER	7732-18-5	Water	CA
					NA-074	Polyglycol	CA
AMC EP Bit Lube##	Other	Specific	10	BIT LUBE () BIT LUBE (LUBRICANT) EP BIT LUBE () EP BIT LUBE (LUBRICANT)	102-71-6	2,2`,2"-nitrilotriethanol (triethanolamine)	CA
					34590-94-8	Dipropylene glycol monomethyl ether##	CW
					68584-25-8	(C10-16) alkylbenzenesulfonic acid, triethanolamine salt##	CW
					7757-82-6	Sodium sulfate##	CA
					NA-037	Non-hazardous ingredients	CA
					NA-046	alkenes, C11-C12, hydroformylation products, low boiling	CW
					NA-072	Vegetable oils	CA
AMC Glute	Biocide	Specific	105	AMC GLUTE 50 () Glute 50% GLUTE BIOCIDE (BIOCIDE)	111-30-8	Pentanedial (Glutaraldehyde)	CW
					7732-18-5	Water	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
AMC PAC##	PAC	Specific	252	AMC PAC L AMC PAC L - FILTRATION CONTROL AMC PAC L - FLUID LOSS AMC PAC L - POLYMER AMC PAC L - VISCOSIFIER AMC PAC R AMC PAC R - FLUID LOSS AMC PAC R - POLYMER AMC PAC R - VISCOSIFIER AMC PAC-R	9004-32-4	Sodium carboxymethylcellulose	CA
					NA-037	Non-hazardous ingredients	CA
AMC Resi-Drill	LCM	Specific	4	RESIDRILL ()	NA-056	Micronised cellulose & proprietary ingredients	MB
					NA-075	Vegetable extract	CA
					NA-076	Organic polymers	CA
					NA-077	Insoluble oxides	CA
AMC Shalehib NC	Other	Specific	5	SHALEHIBNC - SHALE INHIBITOR	NAC	No ingredients available	X
Ancor1##	Other	Specific	1	Ancor 1 - Corrosion inhibitor 20LT	102-71-6	2,2`,2"-nitrilotriethanol (triethanolamine)	MS
					NA-037	Non-hazardous ingredients	MS
Aqucar THPS	Biocide	Specific	43	AQUCAR, THPS BIOCIDE - BIOCIDE	55566-30-8	Tetrakis (hydroxymethyl) phosphanium sulfate (THPS)	MB
					NA-037	Non-hazardous ingredients	MB
Aus-Ben	Bentonite	Specific	72	AUS BEN - GEL/WATER AUS-BEN AUS-BEN - BENTONITE AUS-BEN (AUST) - BENTONITE AUS-BEN (AUST) - VISCOSIFIER	1302-78-9	Bentonite	CA
					14808-60-7	Crystalline silica-quartz	CA
Aus-Det##	Surfactant	Specific	66	AMC AUSDET XTRA - DETERGENT AUS-DET - BIT BALLING AUS-DET - DETERGENT	NA-003	Alkaline salts	CA
					NA-037	Non-hazardous ingredients	CA
					NA-045	Biocide	CA
					NA-078	Non-ionic surfactants	CA
Aus-Det-Xtra	Surfactant	Specific	88	AUS DET EXTRA - DETERGENT AUS DET XTRA AUS DET XTRA - DETERGENT AUS-DET XTRA AUS-DET XTRA - DETERGENT AUSDET XTRA - DETERGENT AUS-DET XTRA () AUS-DET XTRA (INHIBITER)	7732-18-5	Water	CW
					NA-003	Alkaline salts	CW
					NA-037	Non-hazardous ingredients	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Aus-Dex	Starch	Specific	168	AMC DEX AUS - DEX () AUS DEX AUS DEX - POLYMER AUS DEX () AUS DEX (LOSS CONTROL) AUS-DEX - DETERGENT AUS-DEX - POLYMER AUS-DEX - STARCH AUSDEX (FILTRATE CONTROL) AUS-DEX (FILTRATE REDUCER)	9005-25-8	Starch (Thyodene; Amylodextrin)	CW
					NA-031	Not available	CW
Aus-Gel	Bentonite	Specific	116	AUS GEL - BENTONITE AUS GEL - GEL/WATER AUS GEL () AUSGEL AUS-GEL AUSGEL - BENTONITE AUS-GEL - GEL AUSGEL - GEL/CHEM AUSGEL - GEL/WATER AUSGEL - VISCOSIFIER	1302-78-9	Bentonite	CW
					14808-60-7	Crystalline silica-quartz	CW
					497-19-8	Sodium carbonate	CW
					9003-05-8	Acrylamide homopolymer	CW
Aus-Plug##	Other	Specific	1	Ausplug	25608-12-2	Potassium polyacrylate##	CA
Baracarb	Salt	Specific	3	BARACARB 50 - LOST CIRCULATION MAT BARACARB 600 - LOST CIRCULATION MAT	1317-65-3	Limestone	CA
					14808-60-7	Crystalline silica-quartz	CA
Barazan	Xanthan Gum	Specific	297	BARAZAN - VISCOSIFIER BARAZAN D - VISCOSIFIER	11138-66-2	Xanthan gum	CA
Barite	Salt	Generic material	29	BARITE BARITE - WEIGHT MATERIAL BARITE - WEIGHTING AGENT BARITE - WEIGHTING MATERIAL BARITE 4.2 SG (SACK) - LOCAL	12001-26-2	Mica##	CA
					1310-14-1	Goethite##	CA
					13397-26-7	Calcite##	CA
					14476-16-5	Siderite##	CA
					14808-60-7	Crystalline silica-quartz	CW
					7727-43-7	Barium sulfate	CW
Barofibre	LCM	Specific	13	BAROFIBRE - LOST CIRCULATION MAT BAROFIBRE - SEEPAGE LOSS CONTROL	NA-037	Non-hazardous ingredients	CA
					NA-050	Nut hulls	CA
Barra Defoam HP	Defoamer	Specific	6	BARA-DEFOAM HP - DEFOAMER	25322-69-4	Polypropylene glycol##	WA
					53637-25-5	Methyloxirane polymer with oxirane, ether with 1,2-propanediol##	WA
					9082-00-2	Methyloxirane polymer with oxirane, ether with 1,2,3-propanetriol##	WA

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
					NA-037	Non-hazardous ingredients	MS
Bentonite	Bentonite	Generic material	206	BENTONITE BENTONITE - BENTONITE BENTONITE - VISCOSIFIER BENTONITE () BENTONITE (GEL) (VISCOSIFIER) BENTONITE (VISCOSIFIER) gel GEL () GEL (VISCOSIFIER) GEL 25KG SX ()	12001-26-2	Mica[##]	CA
					1302-78-9	Bentonite	CA
					1318-74-7	Kaolinite	CA
					1318-93-0	Montmorillonite[##]	CA
					1340-69-8	Smectite[##]	CA
					14464-46-1	Cristobalite	CA
					14808-60-7	Crystalline silica-quartz	CA
					15468-32-3	Crystalline silica, tridymite	CA
					471-34-1	Calcium carbonate	CA
					68476-25-5	Feldspar	CA
Biocide	Biocide	Generic additive	122	BACTERICIDE (BACTERICIDE) BIOCIDE BIOCIDE - BACTERICIDE BIOCIDE - BIOCIDE BIOCIDE (DRILLING) - BACTERICIDE BIOCIDE () BIOCIDE (BACTERICIDE) BIOCIDE (CEMENTING) - BACTERICIDE BIOCIDE (DISPLACEMENT) - BACTERICIDE BIOCIDE (DRILLING) - BACTERICIDE BIOCIDE (INHIBITER)	NA-045	Biocide	U
Bore-Hib	Other	Specific	39	BAROID BORE - HIB - SHALE INHIBITOR BORE-HIB - CLAY INHIBITOR	1312-76-1	Potassium silicate	CA
					NA-037	Non-hazardous ingredients	CA
CaCl2	Salt	Generic material	2	CALCIUM CHLORIDE CALCIUM CHLORIDE (SALINITY CONTROL)	10043-52-4	Calcium chloride	G
Calcium Carbonate	Salt	Generic material	67	CALCARB M - LOST CIRCULATION MAT CALCIUM CARB F, M, C (LCM) CALCIUM CARBONATE (LCM) CALCIUM CARBONATE (LIMESTONE, MEDIUM/FINE) (LCM) CALCIUM CARBONATE COARSE - LOST CIRCULATION MAT CALCIUM CARBONATE MEDIUM - LOST CIRCULATION MAT CIRCAL 1000 - CACO3 COARSE CIRCAL 60/16 - CACO3 MEDIUM CIRCAL Y CIRCAL Y - CACO3 COARSE STONEDUST - LOST CIRCULATION MAT	14808-60-7	Crystalline silica-quartz	AS
					471-34-1	Calcium carbonate	
Caustic Soda	Base	Generic material	3	Caustic 31.5% Caustic CAUSTIC () Caustic Soda	1310-73-2	Sodium hydroxide	G

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Cement##	Other	Generic additive	4	CEMENT CEMENT () CEMENT (CEMENT) CEMENT (SEALENT)	14808-60-7	Crystalline silica-quartz	G
					65997-15-1	Portland cement##	G
Citric Acid	Acid	Generic material	717	AMC CITRIC ACID - PH CONTROL BAROID CITRIC ACID - ALKALINITY CONTROL BAROID CITRIC ACID - POLYMER CITIRC ACID CITRIC ACID CITRIC ACID - ALKALINITY CONTROL CITRIC ACID - CITRIC ACID CITRIC ACID - LOW PH/DRISPAC CITRIC ACID - PH CONTROL CITRIC ACID - PH CONTROLLER CITRIC ACID (ALCALINE) CITRIX ACID - PH CONTROL	77-92-9	Citric Acid	G
Con Det	Surfactant	Specific	91	CON DET CON DET - DETERGENT	1300-72-7	Sodium xylene sulphonate##	CA
					1310-58-3	Potassium hydroxide	CA
					67-63-0	2-Propanol (isopropanol)	CA
					68603-42-9	Cocamide diethanolamine##	CA
					7320-34-5	Tetrapotassium diphosphate	CA
					NA-021	Additives	CA
CR 650	Other	Specific	3	CR 650 (VISCOSIFIER) CR650 CR-650	25987-30-8	Acrylic acid/ acrylamide copolymer, sodium salt##	CA
					NA-037	Non-hazardous ingredients	CA
CRP	Other	Specific	9	CRP () CRP (VISCOSIFIER) CRP POLYMER (VISCOSIFIER) Tuff C.R.P (CR 650 Core recovery Polymer) TUFF CRP (VISCOSIFIER)	NA-037	Non-hazardous ingredients	CA
					NA-062	Anionic polyacrylamide	CA
D-D Drilling Detergent	Surfactant	Specific	1	D-D - DRILLING DETERGENT	67-63-0	2-Propanol (isopropanol)	AS
					68155-07-7	Amides, C8-18 (even numbered) and C18-unsatd., N, N-bis(hydroxyethyl)	AS
Defoam A	Defoamer	Specific	82	DEFOAM A - ALCOHOL BASED DEFOAMER	144-19-4	2,2,4-trimethylpentane - 1,3-diol	AS
Defoam Ns##	Defoamer	Specific	5	DEFOAM NS - LIQUID DEFOAMER	55965-84-9	CMIT / MIT	CA
					NA-037	Non-hazardous ingredients	CA
					NA-085	Polyol	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Defoam-AP 400##	Defoamer	Specific	11	DEFOAM AP400 Defoamer AP400 25LT	123-96-6	Octan-2-ol##	MS
					25322-68-3	Polyethylene glycol##	MS
Defoamer	Defoamer	Generic additive	9	DEFOAMER - FOAMING AGENT DEFOAMER (DEFOAMER)	NA-063	Defoamer	U
Defoamer S	Surfactant	Specific	6	DEFOAMER S () DEFOAMER-S	NA-001	Silicone based emulsion neutralised polyacrylic based stabiliser	CA
					NA-037	Non-hazardous ingredients	CA
Dextrid LTE	Starch	Specific	2	DEXTRID LTE - FLUID LOSS REDUCER	1310-73-2	Sodium hydroxide	WA
					533-74-4	Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione (Dazomet) ##	WA
					9005-25-8	Starch (Thyodene; Amylodextrin)	WA
					NA-037	Non-hazardous ingredients	CW
Diaseal	LCM	Specific	1	DIASEAL M LCM (LCM)	1305-62-0	Calcium hydroxide (Ca(OH)2)	CA
					14808-60-7	Crystalline silica-quartz	CA
					61790-53-2	Silica amorphous, diatomaceous earth	CA
					9004-34-6	Cellulose	CA
					NA-037	Non-hazardous ingredients	CA
Drispac	PAC	Specific	261	AMC DRISPAC R - POLYMER DRIS PAC SUPER LO - POLYMER DRISPAC - DRISPAC SUPER LO DRISPAC PLUS REGULAR DRISPAC- R - DRISPAC R - POLYANIONIC CELLULOSE DRISPAC REGULAR - POLYMER DRISPAC REGULAR - VISCOSIFIER DRISPAC REGULAR PLUS - POLYMER DRISPAC SUPER LOW - VIS POLYMMER PACR - DRISPAC- R -	9004-32-4	Sodium carboxymethylcellulose	CA
Drispac Plus	PAC	Specific	124	AMC DRISPAC REGULAR PLUS - POLYMER AMC DRISPAC SUPA LO PLUS - POLYMER DRISPAC PLUS - REG DRISPAC PLUS SUPER LOW - POLYMER DRISPAC PLUS SUPER LOW (PACK L) - POLYMER DRISPAC-PLUS	1592-23-0	Calcium stearate##	CA
					2836-32-0	Sodium glycolate	CW
					7647-14-5	Sodium chloride	CW
					7732-18-5	Water	CW
					9004-32-4	Sodium carboxymethylcellulose	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Duo-Squeeze	LCM	Specific	1	DUO-SQUEEZE H - LOST CIRCULATION MAT	7631-86-9	Non-crystalline silica (impurity, Silica amorphous))	CW
					NA-037	Non-hazardous ingredients	CW
Duo-Vis	Xanthan Gum	Specific	212	DUO-VIS - XANTHAN GUM	107-22-2	Glyoxal	AS
					11138-66-2	Xanthan gum	WA
					NA-037	Non-hazardous ingredients	CA
Econolite##	Other	Specific	7	ECONOLITE	1344-09-8	Sodium metasilicate	CW
					6834-92-0	Sodium metasilicate anhydrous##	CA
					7732-18-5	Water	CW
Enerseal	Other	Specific	14	ENERSEAL C (LCM) ENERSEAL F (LCM) ENERSEAL M (LCM)	NA-049	vegetable matter (oat offal)	CW
Enviro Thin	Other	Specific	19	ENVIRO-THIN - THINNER	39331-38-9	Iron lignosulfonate	CW
					NA-037	Non-hazardous ingredients	CW
Extra Sweep	LCM	Specific	25	X-tra Sweep XTRA SWEEP () XTRA SWEEP (LCM) Xtra-Sweep XTRA-SWEEP - LOST CIRCULATION MAT	9003-07-0	Polypropylene	CA
					NA-021	Additives	CA
Flowzan	Xanthan Gum	Specific	30	FLOWZAN - POLYMER	11138-66-2	Xanthan gum	WA
					1592-23-0	Calcium stearate##	WA
					NA-037	Non-hazardous ingredients	CA
					NA-064	Carboxylic acid, calcium salt	CA
					NA-065	Proprietary ingredients	AS
Frac Seal	LCM	Specific	2	FRAC SEAL MEDIUM - LOST CIRCULATION MAT FRACSEAL M (LCM)	9004-34-6	Cellulose	CW
Guar Gum	Guar Gum	Generic material	11	GUAR GUM - VISCOSIFIER	9000-30-0	Guar gum-carbohydrate polymer	CA
Hydro 327##	Other	Specific	38	Hydro 327	112-34-5	Diethylene glycol monobutyl ether##	CA
					61791-39-7	Imidazoline##	CA
					NA-065	Proprietary ingredients	CA
Hydroxyethylcellulose	Other	Specific	1	HEC - FLUID LOSS	9004-62-0	Hydroxyethylcellulose	CW
Idcide-20	Biocide	Specific	3	BIOCIDE (COMPLETIONS AND WORKOVERS) (IDCIDE 20) Biocide 20LT (Idcide20)	55566-30-8	Tetrakis (hydroxymethyl) phosphanium sulfate (THPS)	SS
					7732-18-5	Water	SS
IDP-404	Surfactant	Specific	97	BAROID IDP - 404 IDP-404 - DETERGENT	1344-09-8	Sodium metasilicate	CW
					9016-45-9	Nonylphenol, ethoxylated	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
					NA-037	Non-hazardous ingredients	CA
Inhibitor	Salt	Generic additive	2	INHIBITOR (INHIBITOR)	NA-066	Inhibitor	G
KCl	Salt	Generic material	1287	KCL KCL () KCL (INHIBITER) KCL (SALT) KCL (WEIGHT) KCL POTASSIUM CHLORIDA - BRINE KCL POTASSIUM CHLORIDE - BRINE POTASSAIM CHLORIDE (INHIBITER) POTASSAIM CHLORIDE (KCL) POTASSAIM CHLORIDE KCL (INHIBITER) POTASSIUM CHLORIDA - KCL POTASSIUM CHLORIDA - SHALE INHIBITOR POTASSIUM CHLORIDA (KCL) POTASSIUM CHLORIDE POTASSIUM CHLORIDE - BRINE POTASSIUM CHLORIDE - CLAY INHIBITOR POTASSIUM CHLORIDE - KCL POTASSIUM CHLORIDE - PH CONTROLLER POTASSIUM CHLORIDE - SHALE INHIBITOR POTASSIUM CHLORIDE (INHIBITER) POTASSIUM CHLORIDE (KCL) POTASSIUM CHLORIDE (SALINITY CONTROL) SALT (ALCALINE)	7447-40-7	Potassium chloride	G
KLA-Stop	Other	Specific	7	KLA-STOP - POLYAMINE SHALE INHIBITOR	9046-10-0	Polyether amine (polyoxypropylenediamine)	AS
					NA-067	Polyether amine	CA
					NA-079	Polyether amine acetate	AS
Kwikseal	LCM	Specific	201	KWICKSEAL C () KWICKSEAL M () KWICKSEAL MEDIUM (LCM) KWIK SEAL COARSE - LOST CIRCULATION MAT Kwikseal C KWIKSEAL C - LOST CIRCULATION MAT KWIKSEAL COARSE (LCM) KWIK-SEAL COARSE (LOST CIRCULATION MAT) Kwikseal F KWIKSEAL F - LOST CIRCULATION MAT KWIKSEAL F ()	9004-34-6	Cellulose	CA
					9005-81-6	Cellophane[##]	CW
					NA-008	Vegetable and polymer fibres, flakes and granules	CA
					NA-037	Non-hazardous ingredients	CA
					NA-050	Nut hulls	AS
					NA-051	Wood fibre	AS
					NA-068	Synthetic fibres	AS
					NA-069	Synthetic flakes	AS

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
				KWIKSEAL F, M & C - FIBROUS CELLULOSIC MATERIAL F, M & C KWIKSEAL FINE () KWIKSEAL FINE (LCM) Kwikseal M KWIKSEAL M - LOST CIRCULATION MAT KWIK-SEAL MEDIUM (LOST CIRCULATION MAT)			
LCM	LCM	Generic additive	74	COARSE LCM (LOSS CONTROL) COURSE LCM (LOSS CONTROL) FINE LCM (LOSS CONTROL FINE LCM (LOSS CONTROL) LCM - Coarse LCM - Fine LCM - FINE (LCM) LCM - Medium LCM () Lost circulation material MEDIUM LCM (LOSS CONTROL)	NA-070	LCM	G
Lignite	LCM	Specific	1	LIGNITE / HUMALITE	129521-66-0	Lignite[##]	MS
Lime	Base	Generic material	1	LIME - PH CONTROL	1305-62-0	Calcium hydroxide (Ca(OH)2) [##]	AS
Limestone	Base	Generic material	2	LIMESTONE T ()	14808-60-7	Crystalline silica-quartz	AS
					471-34-1	Calcium carbonate	G
					546-93-0	Magnesium carbonate	G
Liquipol	Other	Specific	5	Liqui Pol Liquid Polymer Liquipol LIQUIPOL - VISCOSIFIER	7732-18-5	Water	CA
					NA-080	Anionic polymer	CA
					NA-081	Carrier fluid	CA
					NA-082	Activator(s)	CA
					NA-083	Emulsifier(s)	CA
					NA-084	Neutraliser(s)	CA
M-I Gel	Bentonite	Specific	5	M-I GEL - BENTONITE API (SACK)	1302-78-9	Bentonite	CA
					14808-60-7	Crystalline silica-quartz	AS
M-I-X II	LCM	Specific	11	MIX II F, M & C - FIBROUS CELLULOSIC MATERIAL F, M & C	14808-60-7	Crystalline silica-quartz	MS
					9004-34-6	Cellulose	MS
NaCl	Salt	Generic material	337	FLOSSY SALT FLOSSY SALT () FLOSSY SALT (INHIBITER) FLOSSY SALT (NACL) - DISPLACEMENT BRINE FLOSSY SALT (NACL) - SODIUM CHLORIDE NACL FLOSSY SALT (NACL) - WEIGHT AND INHIBITIO	7647-14-5	Sodium chloride	G

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
				NaCl NACL (SALT) NACL (SALT) - WEIGHTING AGENT SALT SALT - WEIGHT AND INHIBITIO SODIUM CHLORIDE SODIUM CHLORIDE () SODIUM CHLORIDE (BIG BAG) SODIUM CHLORIDE (FLOSSY SALT) - WEIGHTING AGENT SODIUM CHLORIDE (SALT) - WEIGHTING AGENT			
NDFT 341##	Other	Specific	1	NDFT 341	NAC	No ingredients available	X
NDFT 376##	LCM	Specific	3	NDFT 376	65996-61-4	Cellulose pulp##	CA
					9004-34-6	Cellulose	MS
NDFT 377##	LCM	Specific	3	NDFT 377	65996-61-4	Cellulose pulp##	CA
NewPac LV##	PAC	Specific	74	NEWPAC LV	2836-32-0	Sodium glycolate	MS
					7647-14-5	Sodium chloride	MS
					7732-18-5	Water	MS
					9004-32-4	Sodium carboxymethylcellulose	MS
NewXan D	Xanthan Gum	Specific	74	NEWZAN D	11138-66-2	Xanthan gum	MS
					7732-18-5	Water	MS
Nutplug	LCM	Specific	204	AMC NUT PLUG F - BIT BALLING NUT PLUG NUT PLUG - BIT BALLING NUT PLUG - LCM NUT PLUG - LOST CIRCULATION MAT Nut Plug F NUT PLUG FINE - LOST CIRCULATION MAT NUTPLUG F, M & C - GROUND WALL NUT HULLS NUTPLUG MEDIUM - LOST CIRCULATION MAT	14808-60-7	Crystalline silica-quartz	AS
					NA-037	Non-hazardous ingredients	CA
PAC	PAC	Generic material	344	BAROID PAC L - POLYMER PAC - L PAC - L - POLYMER PAC L - FLUID LOSS PAC L - LOW VIS POLYMER PAC L - SEEPAGE LOSS CONTROL PAC R PAC R - PAC PAC-L PAC-L - POLYMER PAC-L - POLYMER/FILTRATE LOS	9004-32-4	Sodium carboxymethylcellulose	AS
					NA-037	Non-hazardous ingredients	AS

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
				PAC-R PACR - VISCOSIFIER PAC-R (FILTRATION CONTROL A) PAC-RE - POLYMER PAC-RE - POLYMER/FILTRATE LOS			
Penetrol Excel##	Other	Specific	2	PENETROL EXCEL ()	NA-071	Polyol ester	CA
PHPA##	Other	Generic material	14	PHPA	25085-02-3	Sodium acrylate/acrylamide polymer##	CW
					NA-031	Not available	CW
					NA-086	Acrylamide	CW
Platinum D-D Drilling Detergent	Surfactant	Specific	3	PLATINUM D-D - DRILLING DETERGENT	25155-30-0	Sodium dodecylbenzenesulfonate	AS
					68585-34-2	Alcohols, C10-16, ethoxylated, sulfates, sodium salts	AS
					7320-34-5	Tetrapotassium diphosphate	AS
					7732-18-5	Water	AS
Platinum PAC	PAC	Specific	104	PLATINUM PAC - POLYANIONIC CELLULOSE PLATINUM PAC UL PLATINUM PAC UL - POLYANIONIC CELLULOSE	9004-32-4	Sodium carboxymethylcellulose	MS
					NA-037	Non-hazardous ingredients	AS
Platinum Rodease	Other	Specific	1	PLATINUM RODEASE - LUBRICANT	NA-021	Additives	CA
					NA-072	Vegetable oils	CA
Poly PAC##	PAC	Specific	253	POLYPAC R - HIGH MOLECULAR WT. POLYANIONIC CELLULOSE POLYPAC UL - POLYANIONIC CELLULOSE Polypac-R	NA-037	Non-hazardous ingredients	AS
					9004-32-4	Sodium carboxymethylcellulose	CA
Poly-xan	Xanthan Gum	Specific	2	POLY-XAN / MILLZAN D	11138-66-2	Xanthan gum	MS
Potassium Acetate	Salt	Generic material	221	50% POTASSIUM ACCETATE SOIN - KCL AMC POTASSIUM ACETATE - INHIBITION POTASSIUM ACETATE POTASSIUM ACETATE - CLAY INHIBITOR POTASSIUM ACETATE - INHIBITION POTASSIUM ACETATE - KCL POTASSIUM ACETATE - SHALE INHIBITOR POTASSIUM ACETATE (INHIBITER) POTASSIUM ACETATE (PA) - INHIBITION POTASSIUM ACITATE - KCL	127-08-2	Potassium acetate	G
Potassium Carbonate	Salt	Generic material	59	POTASSIUM CARBONATE	584-08-7	Potassium carbonate	G

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Potassium Sulfate	Salt	Generic material	12	K2SO4 POTASSIUM SULPHATE - SHALE INHIBITOR POTASIUM SULPHATE POTASSIUM SULPHATE POTASSIUM SULPHATE - K2SO4	7778-80-5	Potassium sulphate	G
Quickseal	LCM	Specific	55	QUICK SEAL C (LCM) QUICK SEAL COARSE (LCM) QUICK SEAL COARSE (LCM) QUICK SEAL COURSE (LCM) QUICK SEAL F (LCM) QUICK SEAL M (LCM) QUICK SEAL MEDIUM (LCM) QUICKSEAL ( ) QUICKSEAL (COARSE) (LCM) QUICKSEAL C QUICKSEAL C (LCM) QUICKSEAL COARSE (LCM) QUICKSEAL COARSE (LCM) QUICKSEAL COURSE (LCM) QUICKSEAL F (LCM) QUICKSEAL FINE (LCM) Quickseal M QUICKSEAL M (LCM) QUICKSEAL MEDIUM (LCM)	9004-34-6	Cellulose	SS
					NA-037	Non-hazardous ingredients	CA
Quik-Free##	Surfactant	Specific	1	QUIK-FREE - Spotting Agent	10024-47-2	Fatty acid ester##	WA
					111-76-2	Ethylene glycol monobutyl ether##	WA
					112-34-5	Diethylene glycol monobutyl ether##	WA
					135800-57-2	Fatty acids ester##	WA
					14808-60-7	Crystalline silca-quartz	WA
					56-81-5	Glycerol / Glycerine	WA
					61788-63-4	Quarternary ammonium compounds##	WA
					61790-12-3	Mixture of dimer and trimer fatty acids of indefinite composition derived from tall oil##	WA
					67-63-0	2-Propanol (isopropanol)	WA
					71011-24-0	Modified bentonite##	WA
					7732-18-5	Water	WA

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
					8001-22-7	Soybean oil##	WA
					8002-43-5	Lecithins##	WA
					NA-037	Non-hazardous ingredients	WA
Radiagreen EME Salt##	Other	Specific	1	RADIAGREEN EME SALT - LUBRICANT	NA-089	Fatty esters	MS
					NA-090	Specialties	MS
Safe-Cide	Biocide	Specific	169	SAFE-CIDE - BIOCIDE	141-43-5	Monoethanolamine (2-aminoethanol)	AS
					4719-04-4	2,2'''',2"-(hexahydro-1, 3,5-triazine-1,3,5-triyl)triethanol	AS
					64-02-8	Tetrasodium ethylenediaminetetra acetate	AS
SAPP	Other	Specific	49	SAAP (FILTRATE REDUCER) SAPP SAPP - BIT BALLING SAPP - DISPERSANT SAPP - PIPE FREEING SPOTING SAPP - THINNER/DISPERSANT SAPP (DISPERSANT)	7758-16-9	Sodium acid pyrophosphate	CW
Soda Ash	Salt	Generic material	603	BAROID SODA ASH - POLYMER SODA ASH SODA ASH - ALKALINITY CONTROL SODA ASH - CALCIUM REMOVER SODA ASH - FILTRATION CONTROL SODA ASH - PH CONTROL SODA ASH - PHPA SODA ASH - SODIUM CARBONATE SODA ASH () SODA ASH (ALCALINE) SODA ASH (CONDITIONER) Soda Ash 25KG	497-19-8	Sodium carbonate	AS
Sodium Bicarbonate	Salt	Generic material	419	AMC SODIUM BICARB - CALCIUM REMOVER SODIUM BICARB SODIUM BICARB - CALCIUM REMOVER SODIUM BICARB - TREAT CEMENT SODIUM BICARBONATE SODIUM BICARBONATE - ALKALINITY CONTROL SODIUM BICARBONATE - PH CONTROL SODIUM BI-CARBONATE ()	144-55-8	Sodium bicarbonate	AS

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Sodium Formate	Salt	Generic material	2	SODIUM FORMATE	141-53-7	Sodium formate	CA
Sodium Sulfite	Salt	Generic material	39	Sodium Sulphite	7446-09-5	Sulfur dioxide	CA
					7757-83-7	Sodium sulfite	CA
Starch##	Starch	Generic material	2	STARCH (CAKE BUILDER)	9005-25-8	Starch (Thyodene; Amylodextrin)	G
Starglide	Other	Specific	1	STARGLIDE - ESTER BASED LUBRICANT	9004-77-7	Poly(oxy-1,2-ethanediyl), a-butyl-w-hydroxy-	AS
					NA-012	Aliphatic hydrocarbon	AS
Steelseal##	LCM	Specific	1	STEELSEAL 1000 - LOST CIRCULATION MAT	64743-05-01	Petroleum coke (calcined) ##	MS
Stopleak	LCM	Specific	2	STOP LEAK #4 - LOST CIRCULATION MAT	NAC	No ingredients available	X
Stoppit	LCM	Specific	47	BAROID STOPPIT - POLYMER STOPPIT - LOST CIRCULATION MAT	14808-60-7	Crystalline silica-quartz	CW
					471-34-1	Calcium carbonate	CW
					NA-037	Non-hazardous ingredients	CW
Sugar	Sugar	Generic material	67	SUCROSE SUGAR WHITE GRANULATED CEMENT CURING RETARDER 25KG BAG SUGAR SUGAR 25KG	57-50-1	Sucrose	G
Super Foam##	Surfactant	Specific	1	SUPER FOAM	NA-037	Non-hazardous ingredients	CA
					NA-087	Lauryl sulfate sodium salt	CA
					NA-088	glycol ethers	CA
Tiger Bullets	LCM	Specific	1	TIGER BULLETS - TREATED FIBER PLUGGING AGENT LCM/LPM	471-34-1	Calcium carbonate	AS
					NA-015	Wood and cellulosic fiber	AS
Torque Seal	LCM	Specific	1	TORQUE-SEAL - LOST CIRCULATION MAT	NA-037	Non-hazardous ingredients	MS
Troll##	Other	Specific	1	Troll	NAC	No ingredients available	X
Trugel 13A	Bentonite	Specific	11	TRUE-GEL 13A TRUGEL 13A - BENTONITE API (SACK) - LOCAL	12199-37-0	Magnesium aluminosilicate (smectite)	AS
					1318-74-7	Kaolinite	AS
					14464-46-1	Cristobalite	CA
					14808-60-7	Crystalline silca-quartz	AS
					68476-25-5	Feldspar	AS
					NA-073	Plagioclase	AS
Tuff-Trol	PAC	Specific	1	Tuff trol/PAC-R (High mw PAC)	NAC	No ingredients available	X
Wildkat 420	Other	Specific	3	WILD CAT 420 WILD CAT 4-20	107-21-1	1,2-Ethanediol (Ethylene Glycol)	CW
					NA-018	Organic acid amine	CW
					NA-019	Aliphatic solvent	CW
					NA-020	Glycol package	CW
					NA-021	Additives	CW

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
Wildkat 555	Biocide	Specific	128	BIOCIDE 555 - BACTERICIDE BIOCIDE 555 - CORROSION INHIBITOR WILDCAT 555 - BACTERICIDE WILDCAT 555 - BIO CIDE WILDCAT 555 - BIOCIDE (20L DRUMS) WILDKAT 555 - BIO CIDE WILDKAT 555 - BIOCIDE WILKAT 555 - BIO CIDE	55566-30-8	Tetrakis (hydroxymethyl) phosphanium sulfate (THPS)	AS
					NA-037	Non-hazardous ingredients	AS
Xan Bore	Xanthan Gum	Specific	94	AMC XAN BORE () AMC XAN BORE (VISCOSIFIER) Xan Bore XANBORE () XANBORE (VISCOSIFIER) XANBORE/FLOWZAN - VISCOSIFIER	11138-66-2	Xanthan gum	CW
Xantemp SD##	Xanthan Gum	Specific	7	Xantemp SD	NAC	No ingredients available	X
Xanthan Gum	Xanthan Gam	Generic material	126	XAN GUM (VISCOSIFIER) XANTHAM GUM (VISCOSIFIER) Xanthan Gum D XANTHAN GUM D (VISCOSIFIER) Xanthan Gum D1 XANTHUM GUM XANTHUM GUM - POLYMER	11138-66-2	Xanthan gum	G

A.2 Hydraulic fracturing additives and ingredients

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
2,3,4,5-TTFBA chemical tracer(10%v/v)	Tracer	Specific	6	2,3,4,5-TTFBA chemical tracer(10%v/v)	1201-31-6	2,3,4,5-tetrafluorobenzoic acid	AS
					7732-18-5	Water	AS
2,3,4-TFBA chemical tracer(10%v/v)	Tracer	Specific	2	2,3,4-TFBA chemical tracer(10%v/v)	61079-72-9	2,3,4-trifluorobenzoic acid	AS
					7732-18-5	Water	AS
2,3-DFBA chemical tracer(10%v/v)	Tracer	Specific	4	2,3-DFBA chemical tracer(10%v/v)	4519-39-5	2,3-difluorobenzoic acid	AS
					7732-18-5	Water	AS
2,4,5-TFBA chemical tracer(10%v/v)	Tracer	Specific	2	2,4,5-TFBA chemical tracer(10%v/v)	446-17-3	2,4,5-trifluorobenzoic acid	AS
					7732-18-5	Water	AS
2,4-DFBA chemical tracer(10%v/v)	Tracer	Specific	5	2,4-DFBA chemical tracer(10%v/v)	1583-58-0	2,4-difluorobenzoic acid	AS
					7732-18-5	Water	AS
2,5-DFBA chemical tracer(10%v/v)	Tracer	Specific	7	2,5-DFBA chemical tracer(10%v/v)	2991-28-8	2,5-difluorobenzoic acid	AS
					7732-18-5	Water	AS
2,6-DFBA chemical tracer(10%v/v)	Tracer	Specific	7	2,6-DFBA chemical tracer(10%v/v)	385-00-2	2,6-difluorobenzoic acid	AS
					7732-18-5	Water	AS
2-FBA chemical tracer(10%v/v)	Tracer	Specific	7	2-FBA chemical tracer(10%v/v)	445-29-4	2-fluorobenzoic acid	AS
					7732-18-5	Water	AS
2-TFMBA chemical tracer(10%v/v)	Tracer	Specific	2	2-TFMBA chemical tracer(10%v/v)	433-97-6	2-(trifluoromethyl) benzoic acid	AS
					7732-18-5	Water	AS
3,4,5-TFBA chemical tracer(10%v/v)	Tracer	Specific	1	3,4,5-TFBA chemical tracer(10%v/v)	121602-93-5	3,4,5-trifluorobenzoic acid	AS
					7732-18-5	Water	AS
3,4-DFBA chemical tracer(10%v/v)	Tracer	Specific	6	3,4-DFBA chemical tracer(10%v/v)	455-86-7	3,4-difluorobenzoic acid	AS
					7732-18-5	Water	AS
3,5-DFBA chemical tracer(10%v/v)	Tracer	Specific	6	3,5-DFBA chemical tracer(10%v/v)	455-40-3	3,5-difluorobenzoic acid	AS
					7732-18-5	Water	AS
3-FBA chemical tracer(10%v/v)	Tracer	Specific	8	3-FBA chemical tracer(10%v/v)	455-38-9	3-fluorobenzoic acid	AS
					7732-18-5	Water	AS
3-TFMBA chemical tracer(10%v/v)	Tracer	Specific	3	3-TFMBA chemical tracer(10%v/v)	454-92-2	3-(trifluoromethyl)benzoic acid	AS
					7732-18-5	Water	AS
4-FBA chemical tracer(10%v/v)	Tracer	Specific	8	4-FBA chemical tracer(10%v/v)	456-22-4	4-fluorobenzoic acid	AS
					7732-18-5	Water	AS
4-TFMBA chemical tracer(10%v/v)	Tracer	Specific	3	4-TFMBA chemical tracer(10%v/v)	455-24-3	4-(trifluoromethyl)benzoic acid	AS
					7732-18-5	Water	AS
Acetic Acid	Acid		1	Acetic acid	64-19-7	Acetic acid	SS

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
		Generic material			7732-18-5	Water	SS
Acetic Acid 60%##	Acid	Generic material	1	Acetic Acid 60%	64-19-7	Acetic acid	AS
Acetic acid 80%	Acid	Generic material	10	Acetic acid 80%	64-19-7	Acetic acid	AS
B499 Corrosion inhibitor	Other	Specific	22	B499 B499 Corrosion inhibitor	9000-70-8	Gelatine	AS
BC-140C crosslinker	Viscosifier	Specific	8	BC 140C crosslinker	10377-81-8	Monoethanolamine borate	MS
					NA-037	Non-hazardous ingredients	AS
BE-6	Biocide	Specific	1	BE-6	52-51-7	2-Bromo-2-nitro-1,3-propanediol (bronopol)	SS
BE-7 biocide	Biocide	Specific	8	BE-7/CAT-1	1310-73-2	Sodium hydroxide	AS
					7681-52-9	Sodium hypochlorite	AS
BE-9 biocide	Biocide	Specific	14	BE-9 biocide	81741-28-8	Tributyltetradecylphosphonium chloride (TTPC)	AS
Cat-1 Bacteria Kill	Biocide	Specific	1	Cat-1 Bacteria Kill	1310-73-2	Sodium hydroxide	MB
					7681-52-9	Sodium hypochlorite	MB
Caustic 31.5%	Base	Specific	8	Caustic 31.5%	1310-73-2	Sodium hydroxide	MS
CI-25	Other	Specific	5	CI-25	107-19-7	Propargyl alcohol##	MS
					26027-38-3	Ethoxylated 4-nonylphenol##	MS
					64742-94-5	Heavy aromatic naptha##	MS
					67-56-1	Methanol	MS
					67-63-0	2-Propanol (isopropanol) ##	MS
					75-12-7	Formanide##	MS
					8002-09-3	Pine oil##	MS
					91-20-3	Naphthalene##	MS
					94266-47-4	Citrus extract##	MS
					NA-093	Haloakyl heteropolycycle salt##	MS
					NA-094	Substituted alcohol##	MS
DCA-17004 corrosion inhibitor	Other	Specific	9	DCA-17004 corrosion inhibitor	84650-00-0	Coffee extract	MS
					NA-037	Non-hazardous ingredients	AS
DCA-25005 Guar	Viscosifier	Specific	13	DCA-25005 Guar	9000-30-0	Guar gum-carbohydrate polymer	MS
					NA-037	Non-hazardous ingredients	AS
FE-1A Acidizing composition	Acid	Specific	7	FE-1A FE-1A Acidizing composotion	108-24-7	Acetic anhydride	SS
					64-19-7	Acetic acid	SS
FP-9L	Other	Specific	2	FP-9L	27458-94-2	Isononanol	CA

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
FR-28LC	Other	Specific	1	FR-28LC	64742-47-8	Hydrotreated light petroleum distillate[##]	SS
					93-83-4	9-Octadecenamide, n,n-bis-2(hydroxy-ethyl)-,(Z)	SS
					NA-091	Acrylamide copolymer	SS
GasPerm 1000	Surfactant	Specific	1	GasPerm 1000	67-63-0	2-Propanol (isopropanol)	CA
					68647-72-3	Terpenes and Terpenoids, sweet orange oil[##]	CA
					94266-47-4	Citrus, extract[##]	CA
GBW-12CD	Breaker	Specific	5	GBW-12CD	9025-56-3	Hemicellulase Enzyme concentrate	MS
GBW-30 Breaker	Breaker	Specific	15	GBW-30 GBW-30 Breaker	9012-54-8	Hemicellulase enzyme	SS
Gel-STA	Other	Specific	1	Gel-STA	7772-98-7	Sodium thiosulphate	SS
GW-38	Viscosifier	Specific	5	GW-38 GW-38 (CMHPG)	68130-15-4	Gum guar, carboxymethyl 2-hydroxypropyl ether, sodium salt	SS
HCL 15% H015	Acid	Specific	28	H015 HCL 15% H015	7647-01-0	Hydrochloric acid	AS
HCl 32% H032	Acid	Specific	14	H032 HCL 32% HCl 32% H032	7647-01-0	Hydrochloric acid	AS
HCl BTEX Free	Acid	Specific	9	HCl BTEX Free	7647-01-0	Hydrochloric acid	G
J134	Breaker	Specific	1	J134	9025-56-3	Hemicellulase Enzyme concentrate	SS
					NA-037	Non-hazardous ingredients	SS
J218 Live Breaker	Breaker	Specific	38	J218 J218 Live Breaker	7727-54-0	Diammonium peroxidisulphate (Ammonium persulphate)	AS
J318 Low temperature Breaker Aid	Breaker	Specific	38	J318 J318 Low temp. breaker aid J318 Low temperature Breaker Aid	102-71-6	2,2`,2"-nitrilotriethanol (triethanolamine)	AS
J479 Encapsulated breaker (EB Clean)	Breaker	Specific	38	J479 J479 Encapsulated breaker (EB Clean)	7727-54-0	Diammonium peroxidisulphate (Ammonium persulphate)	AS
J580 Water gelling Agent	Viscosifier	Specific	40	J580 J580 Water gelling Agent	9000-30-0	Guar gum-carbohydrate polymer	AS
J604 Crosslinker	Viscosifier	Specific	20	J604 J604 Crosslinker	107-21-1	1,2-Ethanediol (Ethylene Glycol)	AS
					110-17-8	Fumaric acid (2-Butenedioic acid, E-)	AS

Additive	Class	Type	Wells	Names as Recorded	CAS RN	Name	Source
					1303-96-4	Sodium Tetraborate Decahydrate	AS
J610 Crosslinker	Viscosifier	Specific	4	J610 Crosslinker	1310-58-3	Potassium hydroxide	AS
					NA-027	Aliphatic polyol	AS
K-35	Buffer	Specific	1	K-35	497-19-8	Sodium carbonate	SS
KCl	Salt	Generic material	3	KCl	7447-40-7	Potassium chloride	G
Lactose	Other	Generic material	11	Lactose	63-42-3	Lactose	G
Lite Prop##	Proppant	Specific	6	Lite Prop	NA-037	Non-hazardous ingredients	MS
M091 Bleach	Other	Specific	1	M091 Bleach	1310-73-2	Sodium hydroxide	SS
					7681-52-9	Sodium hypochlorite	SS
M117 KCL Clay control	Salt	Specific	49	M117 M117 KCl M117 KCL Clay control	7447-40-7	Potassium chloride	AS
M275 Biocide BPA68915	Biocide	Specific	38	M275 M275 Biocide M275 Biocide BPA68915	55965-84-9	CMIT / MIT	AS
					NA-037	Non-hazardous ingredients	AS
M575 Magnacide	Biocide	Specific	6	M575 Magnacide Magnacide	55566-30-8	Tetrakis (hydroxymethyl) phosphanium sulfate (THPS)	SS
Rock Salt##	Salt	Generic material	7	Rock Salt	7647-14-5	Sodium chloride	G
Sand (Proppant)	Proppant	Generic material	66	Sand (Proppant)	14808-60-7	Crystalline silica-quartz	G
Stock Salt	Salt	Generic material	7	Stock Salt	7647-14-5	Sodium chloride	G
WG-17	Viscosifier	Specific	1	WG-17	NA-092	Cellulose derivative	SS

A.3 Summary tables of ingredients with no CAS RN and additives with no ingredients

A.3.1 Additives with no ingredients

Additive	Class	Wells	Names as recorded	Most likely use
AMC Shalehib NC	Other	5	SHALEHIBNC - SHALE INHIBITOR	Clay stabiliser, possibly salt based (e.g. KCl)
NDFT 341##	Other	1	NDFT 341	Drilling fluid viscosity modifier (Thinner/Dispersant)
Stopleak	LCM	2	STOP LEAK #4 - LOST CIRCULATION MAT	Loss control measure
Troll##	Other	1	Troll	Lubricant for core drilling
Tuff-Trol##	PAC	1	Tuff trol/PAC-R (High mw PAC)	Lubricant for core drilling
Xantemp SD##	Xanthan Gum	7	Xantemp SD	Xanthem gum, viscosity modifier

A.3.2 Ingredients named with no CAS RN

Drilling Additives

Identifier	Name	Additive	Class	Type	Wells	Source
NA-001	Silicone based emulsion neutralised polyacrylic based stabiliser	Defoamer S	Surfactant	Specific	6	CA
NA-003	Alkaline salts	Aus-Det##	Surfactant	Specific	66	CA
		Aus-Det-Xtra	Surfactant	Specific	88	CW
NA-008	Vegetable and polymer fibres, flakes and granules	Kwikseal	LCM	Specific	201	CA
NA-012	Aliphatic hydrocarbon	Starglide	Other	Specific	1	AS
NA-015	Wood and cellulosic fiber	Tiger Bullets	LCM	Specific	1	AS
NA-018	Organic acid amine	Wildkat 420	Other	Specific	3	CW
NA-019	Aliphatic solvent	Wildkat 420	Other	Specific	3	CW
NA-020	Glycol package	Wildkat 420	Other	Specific	3	CW
NA-046	alkenes, C11-C12, hydroformylation products, low boiling	AMC EP Bit Lube##	Other	Specific	10	CW
NA-049	vegetable matter (oat offal)	Enerseal	Other	Specific	14	CW
NA-050	Nut hulls	Barofibre	LCM	Specific	13	CA
		Kwikseal	LCM	Specific	201	AS
NA-051	Wood fibre	Kwikseal	LCM	Specific	201	AS
NA-056	Micronised cellulose & proprietary ingredients	AMC Resi-Drill	LCM	Specific	4	MB
NA-062	Anionic polyacrylamide	CRP	Other	Specific	9	CA
NA-064	Carboxylic acid, calcium salt	Flowzan	Xanthan Gum	Specific	30	CA

Identifier	Name	Additive	Class	Type	Wells	Source
NA-067	Polyether amine	KLA-Stop	Other	Specific	7	CA
NA-068	Synthetic fibres	Kwikseal	LCM	Specific	201	AS
NA-069	Synthetic flakes	Kwikseal	LCM	Specific	201	AS
NA-071	Polyol ester	Penetrol Excel##	Other	Specific	2	CA
NA-072	Vegetable oils	AMC EP Bit Lube##	Other	Specific	10	CA
NA-073	Plagioclase	Trugel 13A	Bentonite	Specific	11	AS
NA-074	Polyglycol	AMC Defoamer##	Defoamer	Specific	1	CA
NA-075	Vegetable extract	AMC Resi-Drill	LCM	Specific	4	CA
NA-076	Organic polymers	AMC Resi-Drill	LCM	Specific	4	CA
NA-077	Insoluble oxides	AMC Resi-Drill	LCM	Specific	4	CA
NA-078	Non-ionic surfactants	Aus-Det##	Surfactant	Specific	66	CA
NA-079	Polyether amine acetate	KLA-Stop	Other	Specific	7	AS
NA-080	Anionic polymer	Liquipol	Other	Specific	5	CA
NA-085	Polyol	Defoam Ns##	Defoamer	Specific	5	CW
NA-086	Acrylamide	PHPA##	Other	Generic material	14	CW
NA-087	Lauryl sulfate sodium salt	Super Foam##	Surfactant	Specific	1	CA
NA-088	Glycol ethers	Super Foam##	Surfactant	Specific	1	CA
NA-089	Fatty esters	Radiagreen EME Salt##	Other	Specific	1	MS

Hydraulic Fracturing

Identifier	Name	Additive	Class	Type	Wells	Source
NA-027	Aliphatic polyol	J610 Crosslinker	Viscosifier	Specific	4	AS
NA-091	Acrylamide copolymer	FR-28LC	Other	Specific	1	AS
NA-092	Cellulose derivative	WG-17	Viscosifier	Specific	1	MS
NA-093	Haloakyl heteropolycycle salt##	CI-25	Other	Specific	5	AS
NA-094	Substituted alcohol##	CI-25	Other	Specific	5	SS

A.3.3 Ingredients with generic name

Drilling

Identifier	Name	Additive	Class	Type	Wells	Source
NA-021	Additives	Con Det	Surfactant	Specific	91	CA
		Extra Sweep	LCM	Specific	25	CA
		Wildkat 420	Other	Specific	3	CW
NA-031	Not available	Aus-Dex	Starch	Specific	168	CW
		PHPA##	Other	Generic material	14	CW
NA-037	Non-hazardous ingredients	AMC Biocide G	Biocide	Specific	132	CW
		AMC EP Bit Lube##	Other	Specific	10	CA
		AMC PAC##	PAC	Specific	252	CA
		Ancor1##	Other	Specific	1	MS
		Aqucar THPS	Biocide	Specific	43	MB
		Aus-Det##	Surfactant	Specific	66	CA
		Aus-Det-Xtra	Surfactant	Specific	88	CW
		Barofibre	LCM	Specific	13	CA
		Barra Defoam HP	Defoamer	Specific	6	MS
		Bore-Hib	Other	Specific	39	CA
		CR 650	Other	Specific	3	CA
		CRP	Other	Specific	9	CA
		Defoam Ns##	Defoamer	Specific	5	CA
		Defoamer S	Surfactant	Specific	6	CA
		Dextrid LTE	Starch	Specific	2	CW
		Diaseal	LCM	Specific	1	CA
		Duo-Squeeze	LCM	Specific	1	CW
		Duo-Vis	Xanthan Gum	Specific	212	CA
		Enviro Thin	Other	Specific	19	CW
		Flowzan	Xanthan Gum	Specific	30	CA
		IDP-404	Surfactant	Specific	97	CA
		Kwikseal	LCM	Specific	201	CA
		Nutplug	LCM	Specific	204	CA
		PAC	PAC	Generic material	344	AS
		Platinum PAC	PAC	Specific	104	AS
		Poly PAC##	PAC	Specific	253	AS
		Quickseal	LCM	Specific	55	CA
		Quik-Free##	Surfactant	Specific	1	WA

Identifier	Name	Additive	Class	Type	Wells	Source
		Stoppit	LCM	Specific	47	CW
		Super Foam##	Surfactant	Specific	1	CA
		Torque Seal	LCM	Specific	1	MS
		Wildkat 555	Biocide	Specific	128	AS
NA-045	Biocide	AMC Biocide##	Biocide	Generic additive	16	U
		Aus-Det##	Surfactant	Specific	66	CA
		Biocide	Biocide	Generic additive	122	U
NA-063	Defoamer	Defoamer	Defoamer	Generic additive	9	U
NA-065	Proprietary ingredients	Flowzan	Xanthan Gum	Specific	30	AS
		Hydro 327##	Other	Specific	38	CA
NA-066	Inhibitor	Inhibitor	Salt	Generic additive	2	G
NA-070	LCM	LCM	LCM	Generic additive	74	G
NA-081	Carrier fluid	Liquipol	Other	Specific	5	CA
NA-082	Activator(s)	Liquipol	Other	Specific	5	CA
NA-083	Emulsifier(s)	Liquipol	Other	Specific	5	CA
NA-084	Neutraliser(s)	Liquipol	Other	Specific	5	CA
NA-090	Specialties	Radiagreen EME Salt##	Other	Specific	1	MS

Hydraulic Fracturing

Identifier	Name	Additive	Class	Type	Wells	Source
NA-037	Non-hazardous ingredients	BC-140C crosslinker	Viscosifier	Specific	8	MS
		DCA-17004 corrosion inhibitor	Other	Specific	9	MS
		DCA-25005 Guar	Viscosifier	Specific	13	AS
		J134	Breaker	Specific	1	AS
		Lite Prop##	Proppant	Specific	6	SS
		M275 Biocide BPA68915	Biocide	Specific	38	SS

Appendix B Hydraulically fractured wells

The table below lists wells that were:

- hydraulically fractured (64 wells, including one well that was hydraulically fractured twice, purple highlight).
- treated with a technique similar to hydraulic fracturing (Diagnostic Fracture Injection Test (DFIT), formation stabilisation (3 wells, blue highlight)).
- flagged to have been hydraulically fractured in the Queensland Government's CSG well location dataset (Geological Survey of Queensland, n.d.) that were not hydraulically fractured (3 wells, grey highlight). Since midway through 2010, this dataset records wells where the operator notified the regulator of the intention to hydraulically fracture a well regardless of whether the well is actually hydraulically fractured.

Additive usage was available for all 67 wells that were hydraulically fractured or treated using a similar technique.

Well name	Frac flag	Date	Total Volume injected (Litres)	Comment
Condabri North 211	Y	14/06/2017	752 537	
Condabri North 212	Y	14/08/2017	470 069	
Condabri North 215	Y	Not stimulated	0	This well was planned to be fracture stimulated, however, the fracture stimulation was not performed (cement bond log showed insufficient isolation to perform the intended fracture stimulation).
Condabri North 216	Y	6/07/2017	659 575	
Condabri North 218	Y	8/07/2017	747 734	
Condabri North 78	Y	22/01/2019	223 722	This well was treated with a Halliburton formation stabilisation treatment was performed rather than a traditional fracture stimulation job.
Condabri South 195	Y	21/06/2019	503 400	
Condabri South 207	Y	23/06/2019	548 360	
Talinga 7	N	22/02/2004	1 404 471	

Well name	Frac flag	Date	Total Volume injected (Litres)	Comment
Berwyndale South 3	N	21/08/2002	2 384 805	
Berwyndale South 5	N	28/08/2002	1 271 896	
Berwyndale South 2	N	29/08/2002	1 367 288	
Berwyndale South 1	N	31/08/2002	969 821	
Berwyndale South 4	N	31/08/2002	2 543 792	
Berwyndale South 12	N	29/10/2003	794 935	
Berwyndale South 11	N	29/09/2009	31 797	DFIT at multiple intervals.
Berwyndale South 32	N	20/12/2009	4 292 649	
Berwyndale South 62	N	4/04/2010	3 815 688	
Berwyndale South 8	N	7/04/2010	3 974 675	
Berwyndale South 21	N	4/04/2010	4 292 649	
Berwyndale South 22	N	7/04/2010	3 815 688	
Berwyndale South 28	N	10/04/2010	3 974 675	
Jammat 4	N	13/04/2010	874 429	Well stimulated twice.
Jammat 4	N	15/04/2010	3 815 688	Well stimulated twice.
Matilda-John 190	Y	16/07/2010	367 713	
Matilda-John 211	Y	5/08/2015	113 581	
Matilda-John 214	Y	9/08/2015	349 716	
Matilda-John 202	Y	20/08/2015	395 869	
Condabri 273	Y	9/04/2020	723 661	
Condabri 275	Y	31/03/2020	1 058 670	
Condabri 276	Y	7/04/2020	885 790	
Condabri 277	Y	11/03/2020	128 862	
Condabri 280	Y	16/03/2020	1 126 680	
Condabri 283	Y	20/03/2020	1 070 335	
Condabri 285	Y	24/03/2020	1 245 936	

Well name	Frac flag	Date	Total Volume injected (Litres)	Comment
Condabri 286	Y	20/04/2020	613 887	
Condabri 289	Y	26/03/2020	546 294	
Condabri 379	Y	21/11/2016	1 003 250	
Condabri 381	Y	26/11/2016	371 508	
Condabri 382	Y	21/07/2017	358 414	
Condabri 383	Y	Not stimulated	0	This well was planned to be fracture stimulated, however, the fracture stimulation was not performed (cement bond log showed insufficient isolation to perform the intended fracture stimulation).
Condabri 384	Y	19/06/2017	304 340	
Condabri 385	Y	24/05/2017	602 601	
Condabri 386	Y	9/08/2017	444 765	
Condabri 387	Y	11/08/2017	575 574	
Condabri 393	Y	6/04/2020	1 055 490	
Condabri 411	Y	5/06/2018	850 760	
Condabri 412	Y	3/06/2018	356 204	
Condabri 413	Y	11/06/2015	531 773	
Condabri 414	Y	13/06/2018	484 911	
Condabri 58	Y	8/01/2019	634 232	This well was treated with a Halliburton formation stabilisation treatment rather than a fracture stimulation job.
Condabri 66	Y	13/01/2019	634 202	
Condabri 68	Y	15/01/2019	773 394	This well was treated with a Halliburton formation stabilisation treatment was performed rather than a fracture stimulation job.
Condabri North 186	Y	12/11/2016	836 227	
Condabri North 191	Y	28/11/2016	650 680	
Condabri North 192	Y	18/11/2016	862 853	

Well name	Frac flag	Date	Total Volume injected (Litres)	Comment
Condabri North 200	Y	2/12/2016	985 208	
Condabri North 202	Y	Not stimulated	0	This well was not fracture stimulated. Perforating guns were used which contained propellant (named “Stimgun”)..
Condabri North 203	Y	25/06/2017	313 973	
Condabri North 204	Y	25/07/2017	343 999	
Condabri North 205	Y	1/07/2017	826 223	
Condabri North 206	Y	11/06/2017	596 710	
Condabri North 207	Y	3/07/2017	411 946	
Condabri North 209	Y	21/07/2017	513 387	
Condabri North 210	Y	23/07/2017	172 719	
Matilda-John 181	Y	22/08/2015	296 730	
Matilda-John 161	Y	23/08/2015	154 557	
Matilda-John 141	Y	25/08/2015	354 528	
Matilda-John 121	Y	26/08/2015	278 537	
Matilda-John 133	Y	30/08/2015	277,115	
Matilda-John 152	Y	2/09/2015	183,153	

References

Aecom Australia Pty Ltd. (2017). APLNG Project Hydraulic Fracturing Risk Assessment. In (pp. 156-156).

Ahmed, A. J., Johnston, S., Boyer, C., Lambert, S. W., Bustos, O. A., Pashin, J. C., & Wray, A. (2009). Coalbed methane: Clean energy for the world. *Oilfield Review, 21*(2), 4-13.

API. (2009). Hydraulic Fracturing Operations - Well Construction and Integrity Guidelines. *API, First Edition, Washington October*.

APLNG. (2017). APLNG Project Hydraulic Fracturing Risk Assessment.

APPEA. (2015). Water from coal. Retrieved from http://www.appea.com.au/tech-drill/water-from-coal/

Arrow Energy. (2010). Environmental Impact Statement, Surat Gas Project. Retrieved from https://www.arrowenergy.com.au/environment/project-assessment-eis/surat-gas-project-eis

Arrow Energy. (2017). Stratheden 43 well completion report. Retrieved from https://qdexguest.dnrm.qld.gov.au/portal/site/qdex/template.PAGE/search/?javax.portlet.tpst=c59371e644a51ca46a5e5410866d10a0&javax.portlet.prp_c59371e644a51ca46a5e5410866d10a0=action%3DdoReportDisplay%26id%3D100980&javax.portlet.begCacheTok=com.vignette.c

Arthur, D. J., Bohm, B., Coughlin, B. J., & Layne, M. (2009). Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs. *Proceedings of SPE Americas EP Environmental and Safety Conference*(March), 1-21. doi:10.2118/121038-MS

Australian Bureau of Statistics. (2017). 2016 Census of Population and Housing, General Community Profile (Catalogue number 2001.0). Retrieved from https://www.abs.gov.au/census/find-census-data/datapacks?release=2016&product=GCP&geography=ALL&header=S

Australian Bureau of Statistics. (2018). 033.0.55.001 - Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia, 2016. Retrieved from https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/2033.0.55.001Main+Features12016?OpenDocument

Australian Bureau of Statistics. (2021). 1410.0 - Data by Region, 2014-19, Population and People, ASGS and LGA, 2011, 2014-2019 Retrieved from https://www.abs.gov.au/AUSSTATS/subscriber.nsf/log?openagent&14100do0001_2014-19.xlsx&1410.0&Data%20Cubes&F907BB15254B8D37CA2586290010ADCD&0&2014-19&24.11.2020&Latest

Australian Government. (2019). Australian Energy Statistics. Retrieved from https://www.energy.gov.au/sites/default/files/australian_energy_statistics_2019_energy_update_report_september.pdf

Beckwith, R. (2010). Hydraulic Fracturing: The Fuss, The Facts, The Future. *Journal of Petroleum Technology, 62*(12). doi:10.2118/1210-0034-JPT

Bennett, T., & others. (2012). *Innovation of coal seam gas well-construction process in Australia: lessons learned, successful practices, areas of improvement.* Paper presented at the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition.

Cook, A. C., Bryan, S. E., & Draper, J. J. (2013). Post-orogenic Mesozoic basins and magmatism. In P. A. Jell (Ed.), *Geology of Queensland* (pp. 515-575). Brisbane: Geological Survey of Queensland.

Cook, A. C., & Draper, J. J. (2013). Surat Basin. In P. A. Jell (Ed.), *Geology of Queensland* (pp. 533-539): Geological Survey of Queensland.

Cook, P., Beck, V., Brereton, D., Clark, R., Fisher, B., Kentish, S., . . . Williams, J. (2013). Engineering Energy: Unconventional Gas Production - A study of shale gas in Australia. (978 0 9875798 1 2). Retrieved from www.acola.org.au

Council of Canadian Academies. (2014). Environmental Impacts of Shale Gas Extraction in Canada. Retrieved from https://cca-reports.ca/reports/environmental-impacts-of-shale-gas-extraction-in-canada/

Day, R. W., Bubendorfer, P. J., & Pinder, B. J. (2008). Petroleum potential of the easternmost Surat Basin in Queensland. In *Petroleum Exploration Society of Australia Special Publication* (Vol. 2008, pp. 191-199). Sydney, N.S.W.: Sydney, N.S.W., Australia: Petroleum Exploration Society of Australia.

de Rijke, K., Munro, P., & Zurita, M. d. L. M. (2016). The Great Artesian Basin: A Contested Resource Environment of Subterranean Water and Coal Seam Gas in Australia. *Society and Natural Resources, 29*(6), 696-710. doi:10.1080/08941920.2015.1122133

Department of Agriculture. (2019). Great Artesian Basin Strategic Management Plan. Retrieved from https://www.dcceew.gov.au/water/policy/national/great-artesian-basin/strategic-management-plan

Department of Industry, Science, Energy and Resources,. (2020). *Australian Energy Update 2020, Australian Energy Statistics*. Canberra Retrieved from https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

Draper, J. J. (2013). Bowen Basin. In P. A. Jell (Ed.), *Geology of Queensland* (pp. 371-384): Queensland Geological Survey.

Elliott, L. (1989). The Surat and Bowen Basins. In *APEA Journal* (Vol. 29, pp. 398-416).

Exon, N. F. (1976). *Geology of the Surat Basin in Queensland*. Canberra: Australian Government Publishing Service.

Faiz, M., & Hendry, P. (2006). Significance of microbial activity in Australian coal bed methane reservoirs - A review. *Bulletin of Canadian Petroleum Geology, 54*(3), 261-272. doi:10.2113/gscpgbull.54.3.261

Fensham, R. J., & Fairfax, R. J. (2003). Spring wetlands of the Great Artesian Basin, Queensland, Australia. *Wetlands Ecology and Management, 11*, 343-362.

Flores, R. M. (2014). Chapter 4 - Coalification, Gasification, and Gas Storage. In *Coal and Coalbed Gas* (pp. 167-233). Boston: Elsevier.

Gaurav, K., Husen, A., Saada, T., & Kumar, S. (2012). Performance analysis in coal seam gas. *Society of Petroleum Engineers - SPETT Energy Conference and Exhibition 2012, c*(June), 119-133.

Geological Survey of Queensland. (n.d.). Coal seam gas well locations - Queensland. Retrieved from https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={C45038EB-BB83-4B16-9231-1905ED753D77}

Gray, A. R. G. (1967). Natural gas occurrence in the Brigalow area, March, 1967. *Queensland Government Mining Journal, 68*(791), 394-394.

Green, P. M., Carmichael, D. C., Brain, T. J., Murray, C. G., McKellar, J. L., Beeston, J. W., & Gray, A. R. G. (1987). Lithostratigraphic Units in the Bowen and Surat Basins, Queensland. In P. M. Green (Ed.), *The Surat and Bowen Basins, south-east Queensland.* (pp. 41-108): Queensland Department of Mines and Energy.

Green, P. M., Hoffmann, K. L., Brain, T. J., & Gray, A. R. G. (1987). Project aims and activities, exploration history and geological investigations in the Bowen and overlying Surat Basins.

In P. M. Green (Ed.), *The Surat and Bowen Basins, south-east Queensland.* (pp. 1-12): Queensland Department of Mines and Energy.
Habermehl, M. A. (1980). The Great Artesian Basin, Australia. *BMR Journal of Australian Geology & Geophysics, 5*(1), 9-38.
Habermehl, M. A. (1982). Springs in the Great Artesian Basin, Australia: their origin and nature.
Hamilton, S. K., Esterle, J. S., & Sliwa, R. (2014). Stratigraphic and depositional framework of the Walloon Subgroup, eastern Surat Basin, Queensland. *Australian Journal of Earth Sciences, 61*(8), 1061-1080. doi:10.1080/08120099.2014.960000
Hennig, A. (2005). A summary of the Southern Eromanga and Surat Basins of the Great Artesian Basin. CO2CRC RPT05-0024.
Hillier, J. R. (2010). Groundwater connections between the Walloon Coal Measures and the Alluvium of the Condamine River. A Report for the Central Downs Irrigators Limited. Retrieved from https://www.aph.gov.au/DocumentStore.ashx?id=c8589d7a-a9da-480f-b5a7-bfd31f102795
Holditch, S. A., Ely, J. W., Semmelbeck, M. E., Carter, R. H., Hinkel, J., & Jeffrey, R. G. (1988). Enhanced recovery of coalbed methane through hydraulic fracturing. *In SPE annual technical conference and exhibition. Society of Petroleum Engineers*.
Huddlestone-Holmes, C. R., Measham, T. G., Jeanneret, T., & Kear, J. (2018). *Decommissioning coal seam gas wells*.
Huddlestone-Holmes, C. R., Wu, B., Kear, J., & Pandurangan, R. (2017). Report into the shale gas well life cycle and well integrity. (December), 77-168. doi:10.4225/08/5a3802273ed86
IESC. (2014). Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins. Retrieved from http://www.environment.gov.au/system/files/resources/004450a8-cf4f-4666-96b2-7be88a10add3/files/background-review-aquifer-connectivity_0.pdf
Jeffrey, R., Zhang, X., Chen, Z., Wu, B., Kear, J., & Kasperczyk, D. (2017). Literature review for coal seam gas hydraulic fracture growth and well integrity, report prepared by the Commonwealth Scientific and Industrial Research Organisation. Retrieved from https://www.dcceew.gov.au/sites/default/files/documents/technical-report-number-04-lit-rev-hydraulic-fracture-growth.pdf
Keywood, M., Grant, S., Walton, A., Aylward, L., Rifkin, W., Witt, K., . . . Williams, M. (2018). Human Health Effects of Coal Seam Gas Activities - A Study Design Framework. (9781486309672). Retrieved from https://gisera.csiro.au/wp-content/uploads/2018/06/Health-1-Final-Report.pdf
Korsch, R. J., & Totterdell, J. M. (2009). Evolution of the Bowen, Gunnedah and Surat Basins, eastern Australia. *Australian Journal of Earth Sciences, 56*(3), 271-272. doi:10.1080/08120090802695733
Korsch, R. J., Totterdell, J. M., Fomin, T., & Nicoll, M. G. (2009). Contractional structures and deformational events in the Bowen, Gunnedah and Surat Basins, eastern Australia. *Australian Journal of Earth Sciences, 56*(3), 477-499. doi:10.1080/08120090802698745
Leach, L. M. (2013). Groundwater resources. In P. A. Jell (Ed.), *Geology of Queensland* (pp. 787-804): Queensland Geological Survey.
Magoon, L. B., & Dow, W. G. (1994). The petroleum system. *AAPG Memoir, 60*, 3-24.
Millar, G. J., Couperthwaite, S. J., & Moodliar, C. D. (2016). Strategies for the management and treatment of coal seam gas associated water. *Renewable & Sustainable Energy Reviews, 57*, 669-691. doi:10.1016/j.rser.2015.12.087
Moore, T. A. (2012). Coalbed methane: A review. *International Journal of Coal Geology, 101*, 36-81. doi:10.1016/j.coal.2012.05.011

Murray-Darling Basin Authority. (2018). Condamine–Balonne catchment. Retrieved from https://www.mdba.gov.au/discover-basin/catchments/condamine-balonne

Murray-Darling Basin Authority. (2019). Groundwater SDL Resource Units. Retrieved from https://data.gov.au/data/dataset/66e3efa7-fb5c-4bd7-9478-74adb6277955

O'Keefe, J. M. K., Bechtel, A., Christanis, K., Dai, S., DiMichele, W. A., Eble, C. F., . . . Hower, J. C. (2013). On the fundamental difference between coal rank and coal type. *International Journal of Coal Geology, 118*, 58-87. doi:10.1016/j.coal.2013.08.007

OGIA. (2016). Groundwater Connectivity Between the Condamine Alluvium and the Walloon Coal Measures. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0019/403282/condamine-report-hydrogeological-investigation.pdf

OGIA. (2019). Underground Water Impact Report for the Surat Cumulative Management Area. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0019/1461241/uwir-full-report.pdf

OGIA. (2021). Underground Water Impact Report for the Surat Cumulative Management Area. Retrieved from https://www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/surat-cma/uwir

Origin Energy. (2017). Spring Gully North-West and North-East — Drilling Mud and Cement Additive.

Oyewole, P. O., Lea, J. F., & others. (2008). *Artificial-lift selection strategy for the life of a gas well with some liquid production.* Paper presented at the SPE Annual Technical Conference and Exhibition.

Palmer, I. D. (1992). Review of coalbed methane well stimulation. *In International Meeting on Petroleum Engineering. Society of Petroleum Engineers*, 679-703.

QGC. (2014). 14.0 - Associated water management. In QGC (Ed.), *Stage 3 Water Monitoring and Management Plan*.

Queensland Department of Environment and Heritage Protection. (2012). Coal Seam Gas Water Management Policy 2012. *Department of Environment and Heritage Protection Government, Brisbane*.

Queensland Department of Environment and Heritage Protection. (2014a). General Beneficial Use Approval — Associated Water (including coal seam gas water). Retrieved from https://www.ehp.qld.gov.au/management/non-mining/csg-water.html

Queensland Department of Environment and Heritage Protection. (2014b). General Beneficial Use Approval — Irrigation of Associated Water (including coal seam gas water). Retrieved from https://www.ehp.qld.gov.au/management/non-mining/csg-water.html

Queensland Department of Environment and Heritage Protection. (2016). Streamlined model conditions for petroleum activities guideline Version 2.01 - ESR/2016/1989. Retrieved from https://www.ehp.qld.gov.au/management/non-mining/environmental-authority.html

Queensland Department of Natural Resources, Mines and Energy. (2019). Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland Petroleum, Version 2. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0006/1461093/code-of-practice-petroleum-wells-bores.pdf

Queensland Department of Natural Resources, Mines and Energy. (2020). Groundwater Database - Queensland. Retrieved from https://www.data.qld.gov.au/dataset/groundwater-database-queensland

Queensland Department of Natural Resources and Mines. (2018). Upper Condamine Alluvium Central Condamine Alluvium Groundwater Background Paper. Retrieved from https://www.mdba.gov.au/sites/default/files/pubs/qld-central-condamine-alluvium-%28GS64a%29-groundwater-background-paper-2018_1.pdf

Queensland Government. (2014). *Land use mapping - 1999 to 2012 - Condamine NRM*. Retrieved from: http://www.qld.gov.au/environment/land/vegetation/mapping/qlump

Queensland Government. (2015). *Land use mapping - 1999 to 2013 - Maranoa and Balonne*. Retrieved from: http://www.qld.gov.au/environment/land/vegetation/mapping/qlump

Queensland Government. (2022). *Petroleum and gas production statistics (December 2020)*. Retrieved from: https://www.data.qld.gov.au/dataset/eab09d04-05a8-41c0-92bf-02255e4d7db8/resource/9746212a-e0c6-484d-95ad-b2be1c46027d/download/pg_production_from-dec-2014-till-dec2020.xlsx

Randall, R. E. (2013). Coal Seam Gas. In P. A. Jell (Ed.), *Geology of Queensland*. Brisbane: Geological Survey of Queensland.

Ransley, T. R., Radke, B., Feitz, A. J., Kellett, J. R., Owens, R., Bell, J., . . . Carey, H. (2015). Hydrogeological atlas of the Great Artesian Basin. Retrieved from http://dx.dpi.org/10.11636/9781925124668

Rigby, S. F., Mackie, R., Van Niekierk, S., Li, J., Grant, S., & Thomas, K. V. (2023). Hazard identification of Coal Seam Gas (CSG) drilling and hydraulic fracturing additives with potential for community human health impacts.

Ryan, D., Hall, A., Erriah, L., & Wilson, P. (2012). The Walloon coal seam gas play, Surat Basin, Queensland. *The APPEA Journal, 52*(1), 273-273. doi:10.1071/aj11020

Scott, S., Anderson, B., Crosdale, P., Dingwall, J., & Leblang, G. (2004). Revised geology and coal seam gas characteristics of the Walloon Subgroup – Surat Basin, Queensland. *PESA Eastren Australasian Basins Symposium II*(March), 19-22.

Scott, S., Anderson, B., Crosdale, P., Dingwall, J., & Leblang, G. (2007). Coal petrology and coal seam gas contents of the Walloon Subgroup - Surat Basin, Queensland, Australia. *International Journal of Coal Geology, 70*(1-3 SPEC. ISS.), 209-222. doi:10.1016/j.coal.2006.04.010

Smerdon, B. D., Marston, F. M., & Ransley, T. R. (2012). Water resource assessment for the Surat region: A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. EP132680. Retrieved from https://doi.org/10.4225/08/584c45479659a

Swarbrick, C. F. J. (1973). Stratigraphy and economic potential of the Injune Creek Group in the Surat Basin. *Report - Geological Survey of Queensland, 79*.

Thakur, P., Schatzel, S., & Aminian, K. (2014). *Coal Bed Methane: From Prospect to Pipeline*.

The Ground Water Protection Council. (2016). Frac Focus. Retrieved from http://fracfocus.org/

Thomas, L. (2012). Coal Geology. In. Chichester, UK: Chichester, UK: John Wiley & Sons, Ltd.

Towler, B., Firouzi, M., Underschultz, J., Rifkin, W., Garnett, A., Schultz, H., . . . Witt, K. (2016). An overview of the coal seam gas developments in Queensland. *Journal of Natural Gas Science and Engineering, 31*(2016), 249-271. doi:10.1016/j.jngse.2016.02.040

Underschultz, J. R., Vink, S., & Garnett, A. (2018). Coal seam gas associated water production in Queensland: Actual vs predicted. *Journal of Natural Gas Science and Engineering, 52*, 410-422. doi:10.1016/J.JNGSE.2018.02.010

Wolfensohn, J. D., & Marshall, E. (1964). Oil and Gas in Australia. *Financial Analysts Journal, 20*(5), 151-158. doi:10.2469/faj.v20.n5.151

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