Australian Government
Geoscience Australia

Groundwater hydrochemical characterisation —Surat Region and Laura Basin, Queensland

The coal seam gas (CSG) industry has expanded rapidly in Queensland over the last decade and is expected to expand CSG production in the future across many coal basins in eastern Australia. This has led to widespread community concern about the potential impacts to water resources from CSG extraction. Fundamental to better understanding these impacts is an understanding of groundwater systems and the processes that control them.

Groundwater hydrochemical analysis can significantly improve understanding of processes controlling groundwater movement, recharge mechanisms, the age of groundwater, inter-aquifer connectivity and the likely chemical compositions of aquifer materials. This Geoscience Australia desktop study, which was commissioned by the Department of the Environment, focused on using hydrochemical analysis to discriminate between groundwater in coal seams and adjacent aquifers in Queensland's Surat Region and Laura Basin.

This study collated and analysed existing groundwater chemistry data in the two areas, providing a hydrochemical characterisation of groundwater sources, and, potential hydrochemical signatures to distinguish between the various hydrogeological units.

The project also assessed the environmental values of groundwater in relation to ecological and human use, and has recommended possible groundwater quality monitoring strategies.

This report summarises the key findings of the study. Full details of the methodology and all findings of the study, including research limitations and assumptions, are provided in the companion technical report (Ransley et al., 2015).

Coal seam gas extraction

Methane is one of several naturally occurring gases associated with coal seams. Under natural conditions, these gases are held within coal seams by the pressure of groundwater and the overlying rocks. To extract the gas, the pressure of the groundwater in the coal seam must be lowered. This is usually done by pumping water from the coal seam to the ground surface through a production well.

Changes to aquifer pressures from pumping of coal seams may alter water pressure gradients between adjacent hydrogeological units (Figure 1). Such changes to pressure gradients may alter the direction and magnitude of groundwater flow within and between the coal seam and any surrounding aquifers. For example, during de-pressurisation of coal seams, groundwater may flow from surrounding aquifers towards the coal seams, if hydraulic connections exist. Once de-pressurisation ceases, water pressures in the coal seam is likely to rise again, resulting in flow away from the coal seam to adjacent aquifers. These processes may affect groundwater quality (where differences in water quality exist between aquifers) as well as groundwater pressure in connected aquifers.

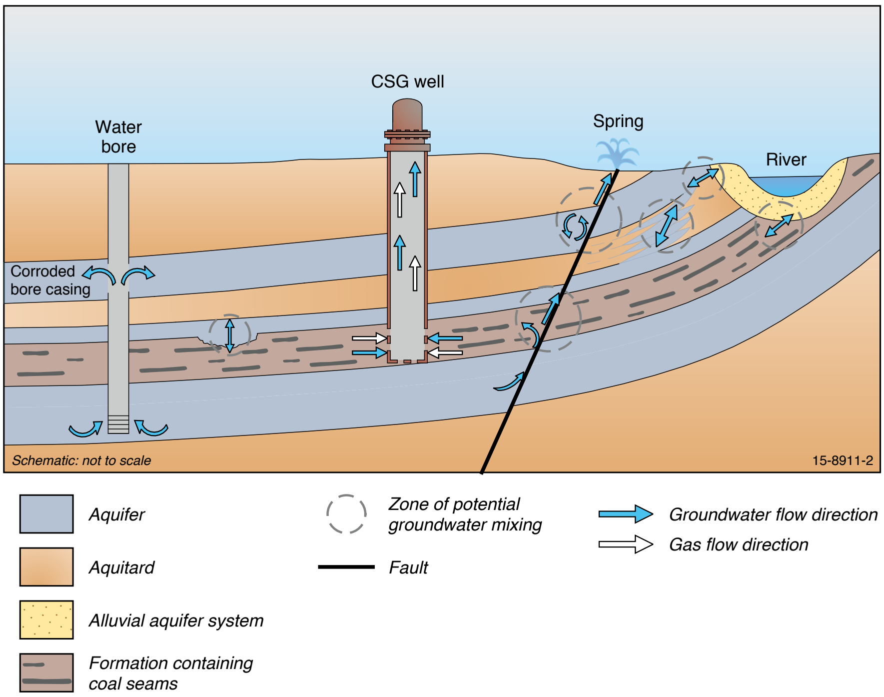

Figure 1: Mechanisms of potential inter-aquifer connection during operation of a coal seam gas well.

Case study areas

This study focussed on two coal bearing areas: the Queensland portion of the Surat Region and the Laura Basin (Figure 2). The two study areas contrast in the amount of hydrochemical data available and in the understanding of respective hydrogeological systems. The Surat Region has an extensive network of water bores and abundant chemistry data, providing a suitable test case for determining whether groundwater chemistry data can be used as a basis for discriminating between aquifers.

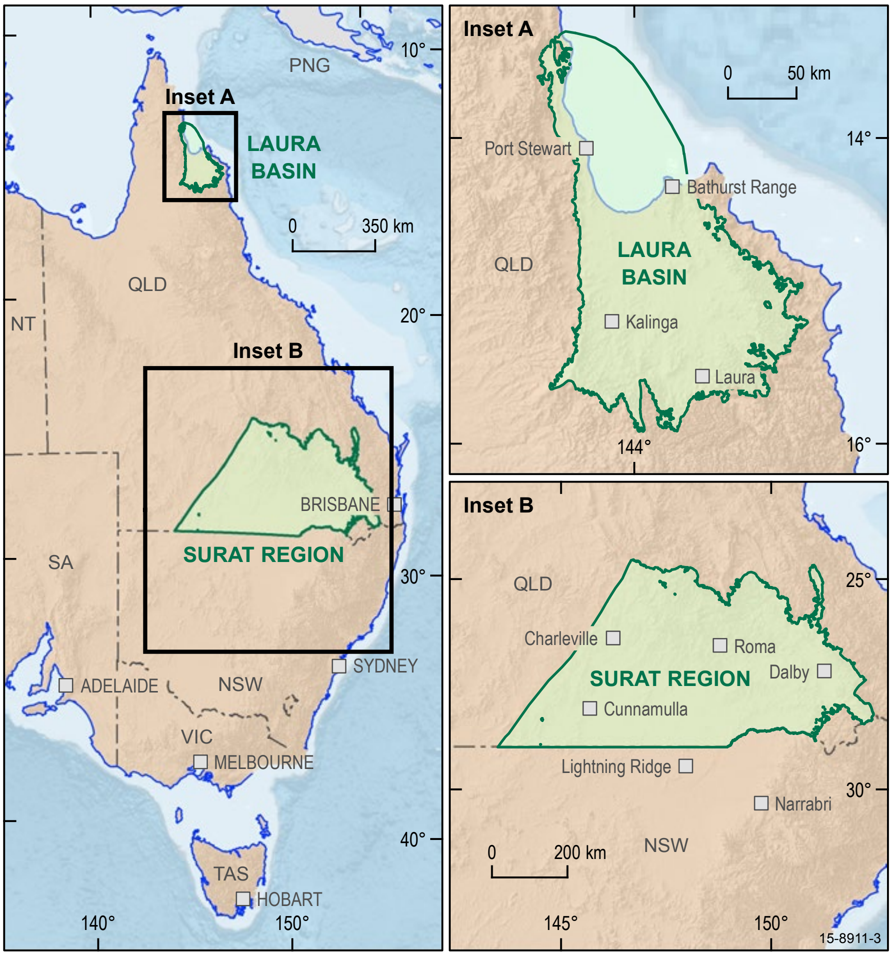

Figure 2: Location of Laura Basin and Surat Region study areas- Queensland.

In contrast, the Laura Basin is less well understood and has relatively few water bores and limited groundwater chemistry data. It was chosen to assess the limits to which hydrochemical characterisation studies can be usefully applied in data poor areas.

Methodology

Datasets were collected from a variety of sources to provide fit for purpose hydrochemical data for analysis. Queensland's Office of Groundwater Impact Assessment (OGIA) was instrumental in accessing industry data and contributed additional Surat Region groundwater datasets compiled by the former Department of Environment and Resource Management (DERM). A new hydrochemistry database including detailed quality assurance and quality control (QA/QC) information was developed as an important result of this study.

Analyses of the compiled hydrochemistry data used a variety of methods to characterise the groundwater chemistry in each study area. The methods included spatial mapping of groundwater chemistry variations, determining major hydrochemical water types (Piper diagrams), statistical data analyses (such as Principal Component Analysis) and interpretation of gas compositions and isotopes of gas and groundwater. The comparison of specific groundwater parameters against national water quality guidelines helped to assess the environmental values of groundwater.

Summary of results

Surat Region—geology and hydrogeology

The Surat Region encompasses the entire Surat geological basin and parts of the adjacent Eromanga and Clarence-Moreton basins. The region comprises Jurassic to Cretaceous aged aquifers and aquitards of the Great Artesian Basin (GAB), which includes the coal seam gas yielding sequence of the Walloon Coal Measures. Overlying the GAB sequence are the geologically younger Cenozoic alluvial and fractured rock aquifer systems. The main GAB aquifers in the region include the Precipice, Hutton, Adori-Springbok and Gubberamunda-Mooga sandstone aquifers and their equivalent stratigraphic units (Figure 3).

The main Cenozoic aged aquifers in the Queensland portion of the Surat Region include the Condamine Alluvium and the Main Range Volcanics. Both are significant local aquifer systems that are used extensively for irrigation, stock and domestic, and some town water supplies.

For the purpose of this study, emphasis has been given to assessing the hydrochemistry of groundwater in aquifers/partial aquifers adjacent to the Walloon Coal Measures (the coal bearing unit from which CSG is extracted). These include the

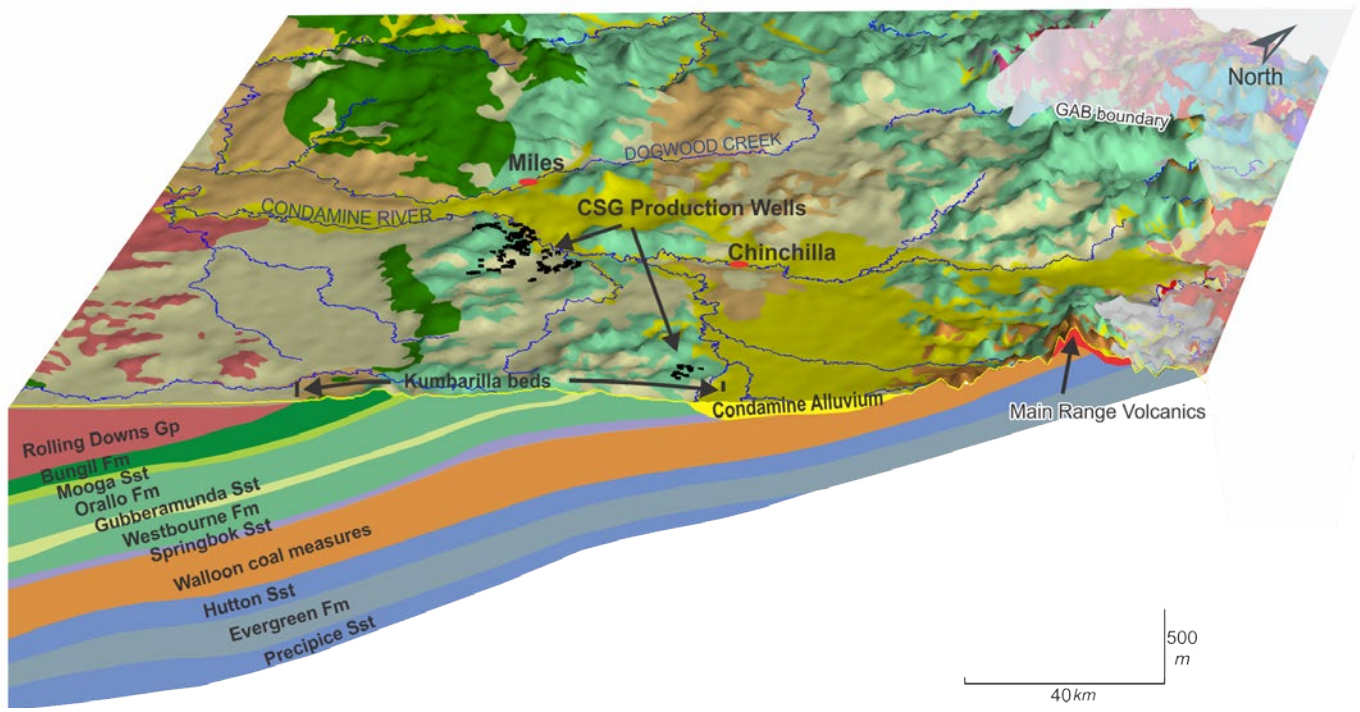

Figure 3: Schematic cross section through the coal seam gas production area in the north-east of the Surat Region illustrating surface and sub-surface geology.

Gubberamunda Sandstone, Kumbarilla Beds, Adori Sandstone (and its lateral equivalent the Springbok Sandstone) and the Hutton Sandstone and its equivalent in the Clarence-Moreton Basin—the Marburg Subgroup. Preliminary hydrochemical assessment of groundwater in the Condamine River Alluvium, which in part overlies sub-cropping areas of the Walloon Coal Measures, was also completed.

Groundwater chemistry

At a regional scale, there is considerable spatial variation in groundwater chemistry within the six target aquifers. Compared to other aquifers, groundwater in the Walloon Coal Measures has elevated salinity, alkalinity, sodium, chloride, sodium adsorption ratio (SAR), pH and low sulfate concentrations (Figure 4). The median sulfate concentration in the Walloon Coal Measures is 2 mg/L but is highly variable with a maximum of 2000 mg/L in the intake beds, situated along the north-eastern and eastern boundary of the region.

Locally in the main area of CSG production, there are some differences in groundwater chemistry within the Walloon Coal Measures between the deeper CSG production areas and the shallow areas tapped by water bores. Interestingly, sulfate concentrations are consistently low in all active CSG production wells in the north-east of the Surat Region. This phenomenon can be explained by the process of methanogenesis (conversion of carbon dioxide to methane) which occurs only after sulfate has first been reduced to sulfides.

Although there is considerable spatial variability in the hydrochemistry data, regional compositions of groundwater in all six target aquifers is dominated by sodium, chloride and alkalinity (as bicarbonate). The relative proportions of chloride and alkalinity vary considerably across the Surat Region and locally other ions (principally calcium, magnesium and sulfate) may form increased proportions of the total dissolved solids (TDS) concentrations. There is a general pattern within the Hutton Sandstone/Marburg Subgroup of decreasing chloride and TDS concentrations from the groundwater recharge areas in the north-east along the groundwater flow path toward the west and south-west of the basin.

Gas compositions and isotopes

Methane is naturally present in most of the groundwater in the GAB. Migration of additional methane from coal seams into overlying potable groundwater aquifers could adversely impact water quality and is a potential indicator of inter-aquifer connectivity. The origin of the methane in groundwater can be identified by measuring the isotopes of carbon within methane molecules.

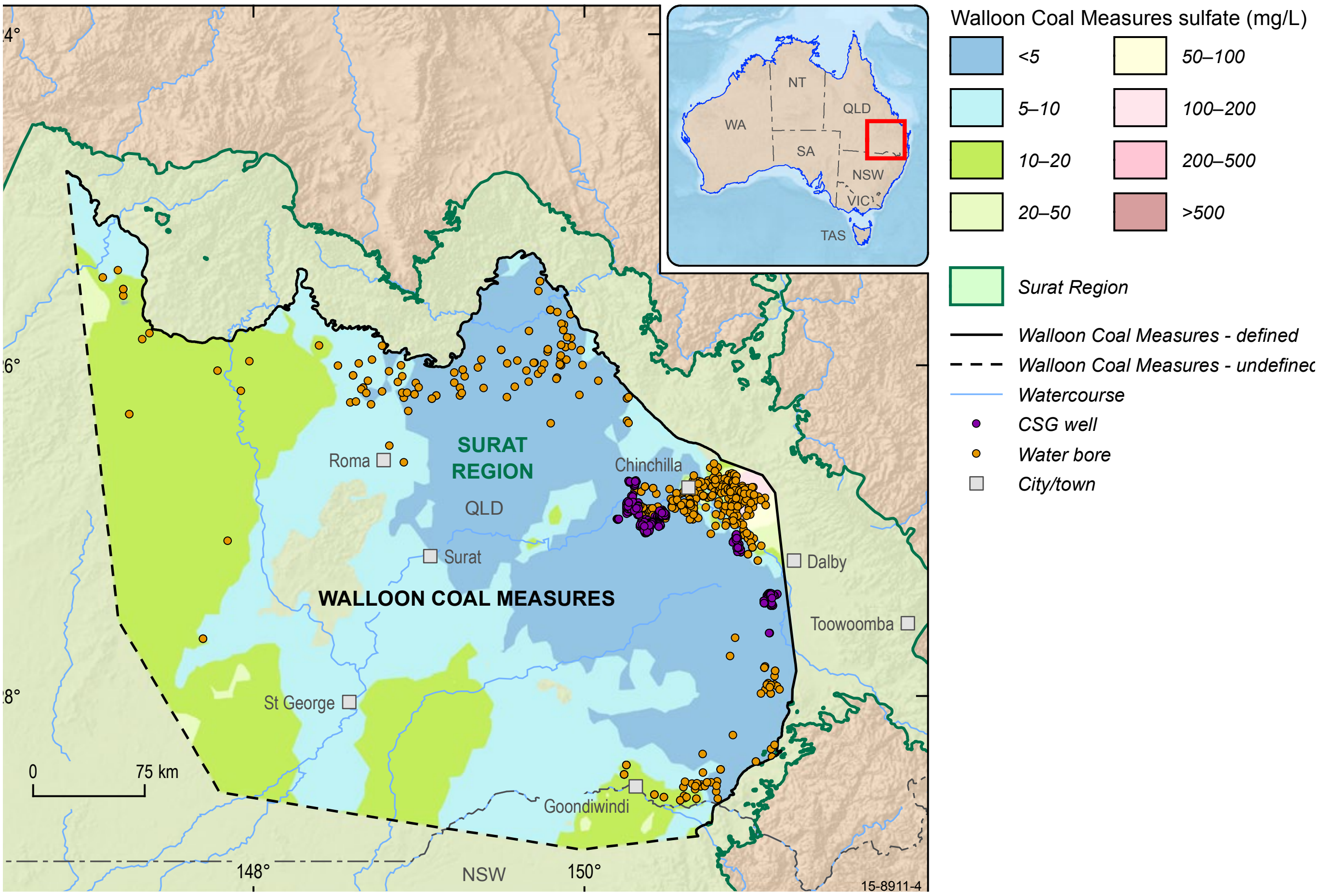

Figure 4: Spatial distribution of sulfate in the Walloon Coal Measures in the Surat Region and sample locations.

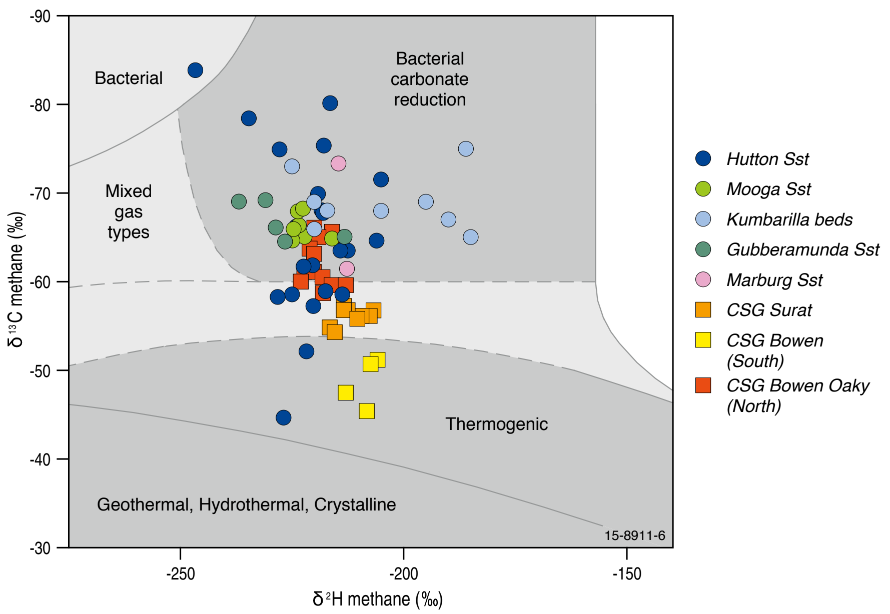

Figure 5: Isotope plot of methane from coal seam gas wells and groundwater wells. Bowen Oaky data from Golding et al. (2013).

There are two principal origins of methane in groundwater: *biogenic methane* forms from bacterial reduction of organic matter and *thermogenic methane* forms by breaking down higher mass hydrocarbons at elevated temperatures. Limited isotopic measurements of the carbon-13 ($\delta^{13}C$) and deuterium ($\delta^{2}H$) content of methane in the Walloon Coal Measures suggests that it comprises a mixture of thermogenic and biogenic sources (Figure 5). However, analysis of gas samples in the Bowen Basin[1] indicates that different CSG production fields can have different isotopic signatures for methane depending on the ratio of thermogenic and biogenic methane. For example, methane from the southern Bowen Basin has a strong thermogenic signature, whereas the northern Bowen Basin has a strong biogenic signature (Figure 5).

1 The Bowen Basin is an older geological basin containing CSG which underlies the Surat Basin.

Importantly, coal seam methane can have a different isotopic signature to methane in groundwater contained in overlying aquifers, which has a purely biogenic signature.

In the Walloon Coal Measures, sufficient differences in gas and isotope chemistry enable discrimination between methane and water from coal seams and overlying aquifers. For example, groundwater from the overlying Kumbarilla Beds show low dissolved methane compared to the Walloon Coal Measures, the $\delta^{13}C$ of the methane is purely biogenic, and the $\delta^{13}C$ of the dissolved inorganic carbon (DIC) is not consistent with typical CSG production water (Figure 5).

Laura Basin—geology and hydrogeology

The principal aquifers of the Laura Basin are hosted in the Gilbert River Formation and the underlying Dalrymple Sandstone (Figure 6). The Gilbert River Formation outcrops around the basin margins and receives direct recharge by rainfall. Elsewhere, the aquifer is confined by the Wallumbilla Formation of the Rolling Downs Group, with the exception of the north-east corner of the basin, where they are absent. In this area, the Normanton Formation (a sand rich facies of the Rolling Downs Group) directly overlies the Gilbert River Formation and the aquifer is not regionally confined. The Normanton Formation acts as an aquifer in this area and may be locally important for spring discharge.

The Gilbert River Formation and the Dalrymple Sandstone are considered to be a single hydrostratigraphic unit as there is no evidence for a contiguous low permeability unit (aquitard) separating them. Aquifers also occur within the Cenozoic sediments of the Kalpowar Basin that overlie the Laura Basin. These include the Fairview Gravel and minor aquifers in the Lilyvale Beds and Brixton Formation. Such aquifers may be locally important sources of water. Until recently, the town water supply at Laura was sourced from Cenozoic aquifers, although it now taps from the deeper groundwater system of the Dalrymple Sandstone which is better protected from shallow contamination sources (Howley and Stephan 2005).

The only defined coal resource in the Laura Basin occurs in the north-eastern corner of the basin flanking the Bathurst Range where coal is found within the Gilbert River Formation and the Dalrymple Sandstone.

Groundwater chemistry

The distribution of groundwater chemistry data in the Laura Basin is sparse, with much of the central basin devoid of information (Figure 7). The groundwater of the Laura Basin and immediate surrounds can be divided into two main types based on pH, alkalinity and salinity (regardless of source aquifer). Type 1 is of good quality (mostly below 1000 mg/L TDS), although it tends to become alkaline with increasing salinity. Spatially, Type 1 groundwater occurs within and surrounding outcropping rises and hills, or is hosted in sediments on the colluvial slopes and alluvial plains. Depths of the bores range from <60 m to 400 m. Type 2 groundwater is brackish and likely to be more chemically evolved. Type 2 groundwater occurs in low-lying areas beneath Cenozoic sediments, such as west of the Bathurst Range.

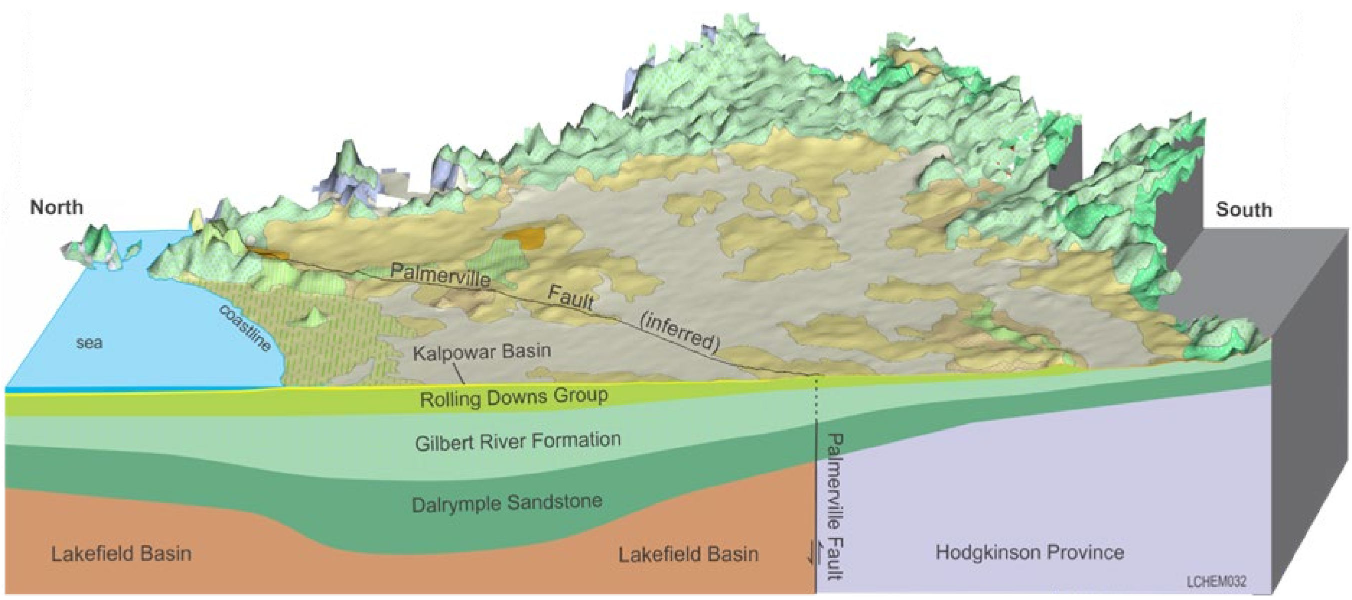

Figure 6: Schematic cross section through the Laura Basin illustrating surface and sub-surface geology.

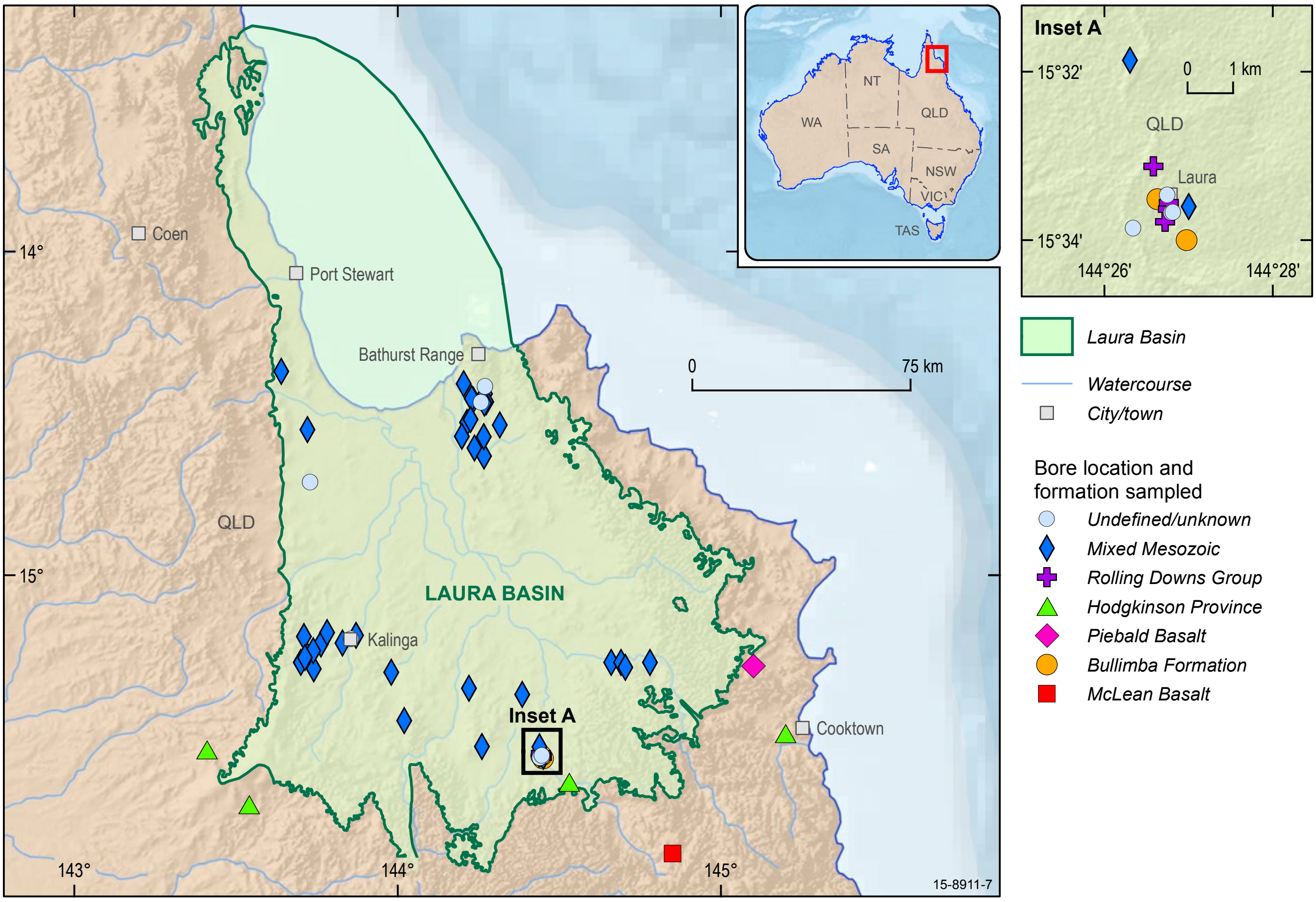

Figure 7: Groundwater bore hydrochemistry data distribution in the Laura Basin.

Depths of the bores containing Type 2 groundwater range from 100 to 350 m below surface but are mostly 250 m. Most of groundwater from the Gilbert River Formation and Dalrymple Sandstone aquifers is of sodium-bicarbonate-chloride (i.e. bicarbonate>chloride) water type. However, some bores near Princess Charlotte Bay (e.g., Bathurst Head) contain sodium-chloride-bicarbonate (i.e. chloride>bicarbonate) type water.

There is no existing data relating to gas or isotope compositions.

Environmental values of groundwater

Assessment of the environmental values of groundwater in the Surat Region and Laura Basin, primarily using salinity and major ions, based on the Australian drinking water guidelines (NHMRC/NRMMC 2011) and the livestock watering, irrigation and ecosystem protection guidelines (ANZECC/ARMCANZ 2000) indicated that:

- All the Great Artesian Basin (GAB) aquifers in the Surat Region are generally suitable for stock water supplies, recreational use and ecosystem protection, but limited value for potable water supply or irrigation use (without treatment). Fluoride is commonly detected at elevated concentrations in most of the GAB aquifers which can cause human health issues.
- The groundwater in the Walloon Coal Measures generally has limited use without further treatment, other than for some stock watering and possible industrial purposes.
- Groundwater quality within the Condamine River Alluvium is generally good and is suitable for potable, irrigation, stock watering, recreational use and ecosystem protection.
- Most groundwater in the Dalrymple Sandstone and Gilbert River Formation in the Laura Basin is suitable for stock watering and human consumption with treatment for fluoride and iron.

Monitoring groundwater in CSG areas

Groundwater monitoring requirements depend on the purpose, scale, and hydrogeological system to be monitored and assessed. Where a groundwater resource has many environmental values (existing or potential), detailed monitoring is typically required to ensure its protection. Conversely, where groundwater has limited potential use (for example, where it is highly saline or contains elevated levels of toxic substances), coarser monitoring networks may be suitable or could be focused on the potential movement of any identified problem groundwater into usable parts of nearby aquifers.

Monitoring the effects of CSG development activities on groundwater systems will ideally use nested bores drilled in production areas that monitor the range of potentially impacted aquifers and the coal seams (Figure 8).

Regional groundwater monitoring is as important as local monitoring as it:

1. Allows tracking of water levels over time to determine long term trends.
2. Provides the context for any identified or predicted water impacts (e.g. If potable aquifers remain good quality down gradient of production areas) that may have a natural decrease in quality down gradient.
3. Identifies anomalies that may otherwise be missed on the basis of only local scale monitoring (e.g. local areas of inter-aquifer mixing may only be identified with support of regional chemistry data).

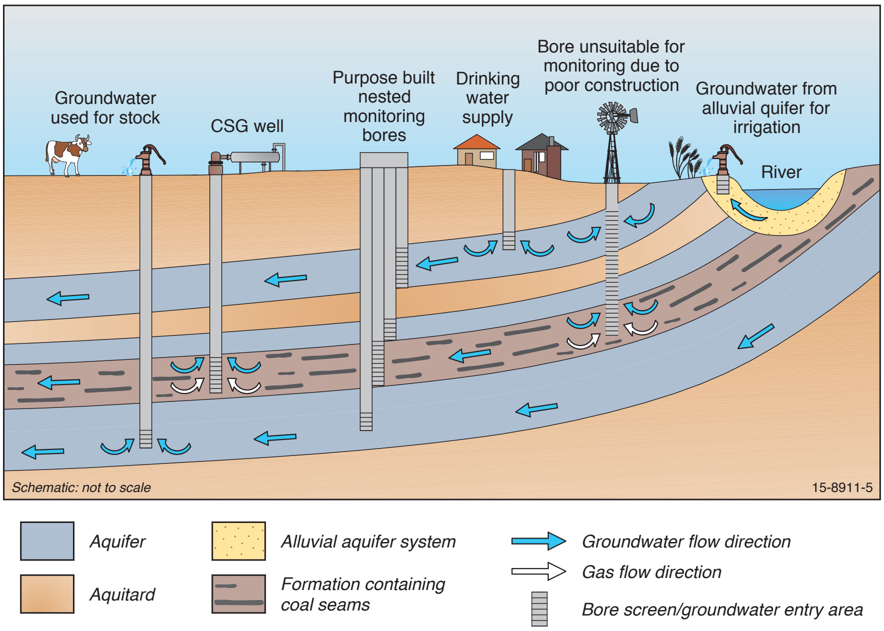

Figure 8: Conceptual diagram illustrating potential groundwater monitoring sites.

Summary of key findings

Key findings from this investigation are:

- Not all of the available groundwater chemistry data is suitable for discriminating between coal seams targeted for CSG extraction and adjacent aquifers. A number of limitations have been identified in both the spatial and temporal distribution of groundwater chemistry data as well as the level of analysis carried out for individual samples. Parameters such as field pH, a full suite of major ions and isotope data are essential for characterising groundwater chemistry and inter-aquifer connectivity between coal seams and adjacent aquifers.
- At a regional scale, groundwater chemistry varies within the aquifers of the Surat Region. This can be attributed to differing aquifer hydraulic and lithological properties which control processes such as groundwater recharge, aquifer redox conditions, interaction between aquifers and groundwater-surface water interactions.
- In general, the Walloon Coal Measures in the north-east of the Surat Region has elevated salinity, pH, alkalinity, sodium, chloride, sodium adsorption ratio and low sulfate concentrations.
- Within the vicinity of the current CSG production area of the Surat Region, groundwater chemistry compositions appear to discriminate between the Walloon Coal Measures production wells and other parts of the Walloon Coal Measures and associated aquifers. This seems due to abundant groundwater chemistry data and, in many cases, more comprehensive suite of analyses available. Further analysis is required to confirm this observation.
- Based on limited carbon-13 isotope data in methane, methane in the Walloon Coal Measures is from a mixture of thermogenic and biogenic sources, whereas in the overlying aquifers it has biogenic signatures. The preliminary results indicate that measuring the isotopic compositions of methane in groundwater can be a useful technique for distinguishing between different methane production processes and sources.
- Hydrochemical characterisation of groundwater is a useful technique to identify the 'signature' or 'fingerprint' associated with different aquifers and aquitards. Combining interpretations based on hydrochemistry with additional geological and hydrogeological data such as groundwater flow and geological structures will lead to more robust and accurate predictions on the behavior of groundwater systems that may be influenced by CSG extraction.

- Groundwater within the GAB aquifers of the Surat Region is generally suitable for stock water supplies, recreational use and ecosystem protection but has limited value for potable supplies or irrigation use (without treatment) due to elevated salinity. The groundwater in the Walloon Coal Measures generally has limited use without further treatment, other than some stock and possible industrial purposes. Groundwater within the Condamine River alluvium is generally good and is suitable for potable use, irrigation, stock watering, and ecosystem protection.
- Limited groundwater chemistry data exist for four main aquifers in the Laura Basin. The groundwater of the Laura Basin and immediate surrounds is divided into two main types: Type 1 is of good quality and tends to become alkaline with increasing salinity; Type 2 is brackish and likely to be more chemically evolved.

Future work and research

This preliminary assessment has identified significant knowledge gaps that limit our ability to better understand groundwater chemistry and potential inter-aquifer connectivity between coal seams and adjacent aquifers in the Surat Region and Laura Basin.

Recommendations for targeted research in future should focus on:

- Collecting groundwater levels and comprehensive groundwater chemistry data including dissolved gas and isotope data (stable and radiogenic ^{18}O, δ^2H, $\delta^{13}C$, ^{36}Cl, $^{87}Sr/^{86}Sr$) from targeted nested bores in multiple aquifers to better understand the chemical characterisation of groundwater, origin of pore waters, regional flow paths, and potential inter-aquifer connectivity.
- Integrating hydrochemical and isotopic information with topographic, geological, hydrogeological and spatial information to assess major factors controlling groundwater processes. This would improve the understanding of potential inter-aquifer connectivity.
- Acquiring additional isotopic data on the composition of methane in the Walloon Coal Measures and adjacent aquifers to distinguish between different methane production processes and sources.
- Collecting major rock geochemistry, mineralogy and mineral isotopic composition of the aquifer materials to enhance understanding the evolution of groundwater ion chemistry.
- Designing future groundwater chemistry monitoring and sampling strategies to ensure more uniform distribution of data across basins of interest. This should look at improving the spatial and temporal distribution of both local and regional groundwater chemistry characterisations.
- Developing national groundwater quality monitoring guidelines either specifically for or including CSG related monitoring requirements. Development of such guidelines would include detailed literature review and jurisdictional consultation.

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