Australia's National
Science Agency

GISERA | Gas Industry Social and Environmental Research Alliance

Project Order

Short Project Title

Sources and mobility of gas in formations below the Walloon Coal Measures

Long Project Title	Sources and mobility of gas in formations below the Walloon Coal Measures, Surat Basin, Queensland
GISERA Project Number	W.36
Start Date	01/07/2024
End Date	30/06/2026
Project Leader	Mohinudeen Faiz/Matthias Raiber

GISERA State/Territory

- [x] **Queensland**
- [ ] New South Wales
- [ ] Northern Territory
- [ ] South Australia
- [ ] Western Australia
- [ ] Victoria
- [ ] National scale project

Basin(s)

- [ ] Adavale
- [ ] Amadeus
- [ ] Beetaloo
- [ ] Canning
- [ ] Western Australia
- [ ] Carnarvon
- [ ] Clarence-Morton
- [ ] Cooper
- [ ] Eromanga
- [ ] Galilee
- [ ] Gippsland
- [ ] Gloucester
- [ ] Gunnedah
- [ ] Maryborough
- [ ] McArthur
- [ ] North Bowen
- [ ] Otway
- [ ] Perth
- [ ] South Nicholson
- [x] **Surat**
- [ ] Other (please specify)

GISERA Research Program

- [x] **Water Research**
- [ ] Health Research
- [ ] Biodiversity Research
- [ ] Social & Economic Research
- [ ] Greenhouse Gas Research
- [ ] Agriculture Research
- [ ] Land and Infrastructure Management Research
- [ ] Other (please specify)

1. Project Summary

The production of Coal Seam Gas (CSG) requires the extraction of groundwater to reduce pressure within the coal seams and allow the gas to be released. The depressurisation caused by this process extends laterally and creates a pressure difference between the target coal seams and the surrounding layers. These pressure variations can cause changes to groundwater systems that have the potential to impact other groundwater users which is a concern expressed by many members of the local community. These impacts can include reduced groundwater availability, and the migration of gas to water bores. There is a regulatory framework in place in Queensland to manage potential impacts on water bores that includes requirements to "make good" any impairment of affected water supply bores.

The Walloon Coal Measures in the Surat Basin in southeast Queensland are the target resource for Australia's largest CSG development. There is concern that increasing amounts of gas may be entering water supply bores that extract water from aquifer formations, including the Hutton and Precipice sandstones that are below the Walloon Coal Measures. Gas has been observed in these deeper formations well before CSG development commenced (e.g. Walker and Mallants, 2014) and so separating cause and effect is difficult. However, there is community interest in knowing whether CSG development is impacting these deeper groundwater systems and potentially causing mobilisation of gas.

This project will collate existing data on the prevalence of gas in water supply (e.g. stock, agricultural and town water supplies) and water monitoring bores in these aquifers underlying the Walloon Coal Measures to determine current state of the system. The project will then aim to build on the existing understanding of the groundwater systems in these aquifers and investigate the sources of gas within them and how they may be affected by non-CSG water extraction and CSG activities. The outcomes of this research will allow for the establishment of a framework for future monitoring to validate whether the presence of gas in groundwater bores is increasing or not, what the source of any such gas is and whether CSG production activities are a contributing factor.

2. Project description

Introduction

The Bowen and Surat basins in southern Queensland host the largest coal seam gas (CSG) producing fields in Australia, with production commencing in the Bowen Basin in the 1990s and from the overlying Surat Basin in 2006 (Salmachi et al 2021). Approximately 80% of the current CSG production in Queensland is derived from coals within the Walloon Coal Measures of the Surat Basin (Figure 1) and account for the majority CSG produced in Australia (https://www.data.qld.gov.au/dataset/eab09d04-05a8-41c0-92bf-02255e4d7db8/resource/974). CSG producing fields in the Surat Basin extend from Dalby in the southeast to about 80 km south of Rolleston.

Gas in coal seams is adsorbed on the internal surface area of the coal and held in place by hydrostatic pressure. Therefore, the CSG reservoir is 'capped' by the pressure of groundwater, which must be reduced (by pumping water out of the coal seam) to reach critical desorption pressure and allow gas to flow. This means that significant volumes of water are extracted, with the current rate of 54,000 ML/year (45,000 ML/year from the Surat and 9,000 ML/year from the Bowen) (OGIA, 2021).

The impact of this groundwater removal causes depressurisation that spreads in all directions from the site of extraction. As a result, pressure differences will form between the target formations and the formations above and below. This pressure difference has the potential to impact groundwater in these and other formations where aquitards or seals may be compromised by faults with significant vertical displacements or by other seal bypass features (e.g. compromised wells).

Methane in water bores is a community concern as it can lead to problems with the operation of pumps in sub-artesian bores (e.g. gas locks) and potentially can cause blockages in distribution lines from artesian bores (e.g. Walker and Mallants (2014); Mallants et al. (2014)). Moreover, given its mobility in aquifers, either dissolved or in the gas phase, increased concentrations of methane may be considered as an indicator of connectivity and a potential precursor of other water quality changes, including potential organic or inorganic contaminants associated with coal.

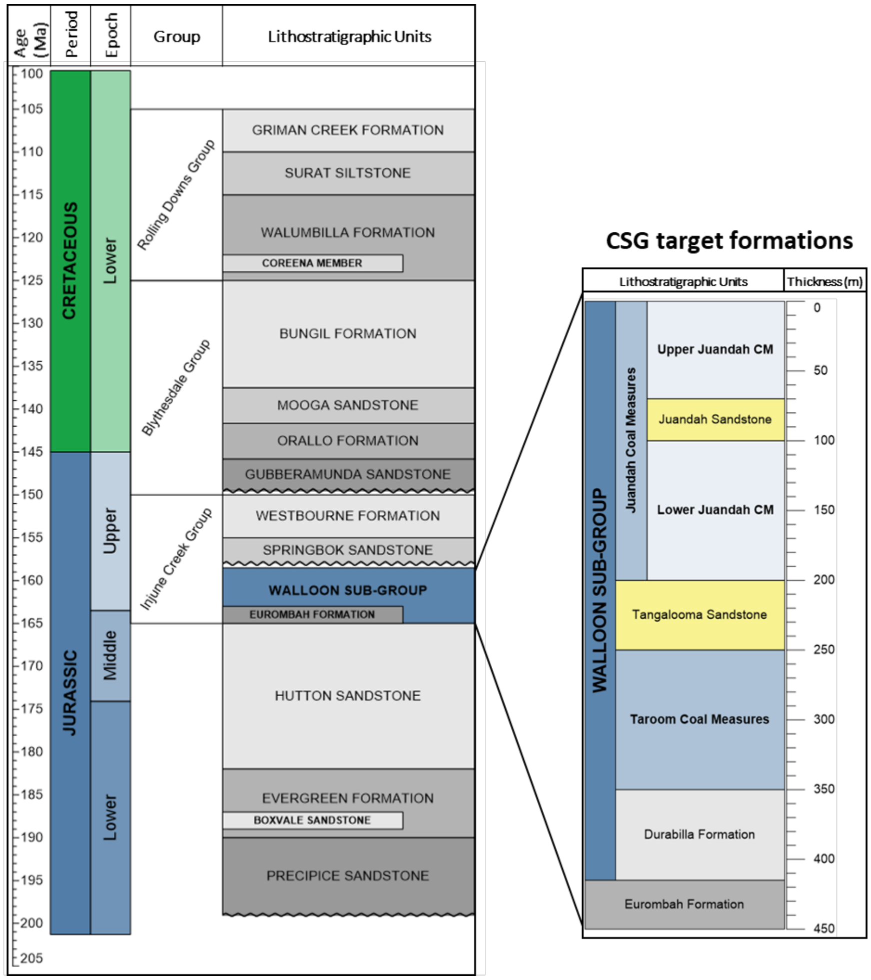

Figure 1 Generalised stratigraphy of the Surat Basin (Green et al., 1987; Hamilton et al., 2014; Scott et al., 2004)

Dissolved gas including methane and minor amounts of higher hydrocarbons are pervasive in porous sandstones interbedded with coal seams in the Surat Basin (Harris et al., 2014; Mallants et al., 2014; Pearce et al. 2023a, 2023b) and are also commonly observed in aquifers elsewhere within the Great Artesian Basin (e.g. Raiber et al., 2022a; Raiber et al., 2022b). Pearce et al (2023b) estimated that concentration of dissolved methane and ethane in the Hutton Sandstone is up to 96 mg/L and 1 mg/L, respectively. Gas dissolved in these sandstones are of potential concern to communities as these aquifers are tapped through numerous water bores drilled across the Surat Basin. Gas geochemistry analyses conducted by the UQ Centre for Natural Gas and the operating companies have demonstrated that hydrocarbon and carbon dioxide dissolved in these aquifers have similar stable carbon and hydrogen isotopic signature to that in the coal seams (Pearce et al. 2023a, 2023b). These data also imply that gas in the Hutton Sandstone may have been largely derived from the Surat Basin whereas that in the Precipice Sandstone from both Surat and Bowen basins. Substantial volumes of water are extracted from these sandstones through numerous boreholes drilled across the Surat Basin where the release of dissolved gas potentially contributes to greenhouse gas emissions. Gassiness of the water produced from various water bores is variable and this is likely to be the result of the lateral variations in gas concentration in the aquifers. Occurrence of gas in drinking water has been a concern to the local communities who utilize water for domestic consumption as well as for farming and irrigation. Therefore, understanding the source of gas in the aquifers and, in particular, the ability to predict the variation in gassiness of the produced bore-water are considered invaluable for the community and other stakeholders across the Surat Basin.

The key factors influencing the gas concentration in sandstone aquifers include the volume of gas generated and expelled from organic matter in the sandstones and interbedded coals, inter-connectivity between the aquifers and the CSG reservoirs, the presence of sealing rock layers and potential seal by-pass features (e.g. faults) between the aquifers and coal, hydraulic gradient, and flow paths within the aquifers. The gas in the Surat and Bowen basin reservoirs can be either generated through microbial or thermogenic processes (as a result of deep burial and high temperatures; Faiz and Hendry 2006). However, to our knowledge, the factors controlling the distribution of this gas have not been investigated on a whole-of basin basis in the Surat and Bowen basins in a collective manner. Such a study would require a detailed basin model integrating a gas generation model (i.e., petroleum systems model) with aquifer flow dynamics and subsequently simulating pressure depletion associated with CSG production (including dewatering) activities. The integrated basin model will seek to provide key information on:

- the source of gas in the Hutton and Precipice sandstones including the timing of gas migration into these aquifers
- the composition of gas (i.e. methane, ethane, carbon dioxide)
- the amount of gas that was present in the aquifers prior to CSG development in the Surat Basin
- lateral distribution of gas in the aquifers as a function of geological complexities
- the exsolution of dissolved gas during basin uplift and anthropogonic depressurization of the aquifers.

A mass balance of gas from the above sources may be attempted if sufficient gas concentrations data from the producing water bores can be compiled, which will also be important to calibrate the model.

Stage gate / Decision point

There is a decision point towards the end of the discovery and conceptual modelling phase where the GISERA Queensland Research Advisory Committee will be presented with the refined conceptual models and what the petroleum systems model will address before proceeding to the final stage. Figure 1 in section 6 Project Plan provides a schematic outlining the project stages and decision point.

Prior Research

Characterization of groundwater aquifers within the Surat Basin and impact of CSG development on groundwater resources have been the subject of numerous studies conducted by industry as well as CSIRO, the Centre for Natural Gas at the University of Queensland and The Office of Groundwater Assessment (OGIA). The Underground Water Impact Report (UWIR) produced by OGIA is a key document that provides detailed assessment and information on management of cumulative ground water impacts resulting from the extraction of groundwater through resource development in the Surat and southern Bowen basins including CSG, coal mining and conventional petroleum (OGIA, 2021). OGIA has conducted various technical studies to understand the subsurface groundwater system within the area likely to be impacted by multiple petroleum operations known as the cumulative management area (CMA) established in 2011 (OGIA 2012). OGIA has also developed a groundwater model primarily to predict changes in regional groundwater levels in aquifers within the Surat CMA in response to production of ground water from CSG reservoirs as well as that associated with coal mining and conventional petroleum. The model specifically attempts to predict short- and long-term impacts in aquifers, volumes of water extracted as well as groundwater movement between geological formations (OGIA, 2021). OGIA's model, however, does not characterise dissolved gas in the aquifers, its source/origin and flow within the aquifers or changes of gas concentrations across various geological formations triggered by CSG production activities.

Multiple studies have investigated methane concentrations within the Surat and Bowen basins. For example:

- Harris et al. (2012) investigated the presence of gas across the Surat and southern Bowen basins; they suggested that natural methane is present across the study area in all Great Artesian Basin (GAB) aquifers from which samples were collected.

- Walker and Mallants (2014) provided an overview of historic gas occurrences (prior to CSG developments) in groundwater bores in the Surat and Bowen basins. They report that there has been a long history of anecdotal reports on gas occurrences within groundwater bores in the Surat and Bowen basins, dating back to the beginning of the twentieth century near Roma.

- Mallants et al. (2014) developed a desktop procedure to assess the likelihood for CSG operations to be the cause of increased methane gas in water bores. This consisted of devising a decision support system (DSS) that uses site-specific information such as bore construction and bore history, hydrogeological relationship between the 'increased gas' aquifer and CSG target formations, distance from a water bore to a gas field, and presence of other sources of methane in the subsurface. Mallants et al. (2014) also provided summary statistics of methane concentrations in various hydrostratigraphic formations under and overlying the Walloon Coal

Measures. This highlighted that methane is present in many groundwater bores in all formations where data existed.

- Raiber and Suckow (2017) assessed the hydrochemistry (major and minor elements and, where available, methane concentrations of the Hutton and Precipice sandstones in the northern Surat Basin as part of the GISERA project 'Constraining groundwater flow rates in the Surat Basin through environmental tracer and hydrochemical data'. This highlighted that both within the Hutton and Precipice sandstones, methane concentrations above detection limit and up to approximately 35 mg/L have been measured in many groundwater samples in the northern Surat Basin. The comparison of hydrochemical composition and methane concentrations also indicated that in the Hutton Sandstone there was a clear relationship between water (hydrochemistry) type and methane concentrations, with some groundwater chemistry groups being associated with elevated concentrations of methane, whereas other groundwater chemistry groups were not associated with high methane concentrations. In contrast, within the Precipice Sandstone, all different groundwater chemistry groups were associated with methane concentrations above detection limit.

Since these earlier studies, a large volume of additional gas concentration data have been collected from groundwater bores in the Surat and Bowen basins as part of scientific research projects and as part of the regulatory process, where CSG companies are required by the Water Act to collect and analyse baseline samples and for the results to be reported to the Queensland Government (Walker and Mallants, 2014).

For example, the Centre for Natural Gas at the University of Queensland studied the concentration of gases (methane, ethane and carbon dioxide) in the Surat Basin aquifers and their stable C and H isotope composition from water samples collected from various water bores. The objective of these studies was to specifically understand source and concentration dissolved gases in the Hutton and Precipice sandstones as water extracted from these are important resources for town water supply, agriculture, feedlots and private landholders (Pearce et al. 2023a and 2023b). The water samples they analysed indicated that gas dissolved in the Hutton Sandstone aquifer is consistent with microbial gas whereas that in the Precipice Sandstone aquifer is mixture of thermogenic and biogenic gas. As is the case with the other studies, their study did not investigate pathways from the coal seams to the aquifers, its timing (i.e., geological or as a result of CSG dewatering) or variations in gas concentration along the aquifer with respect to its reservoir and seal properties.

Other studies focussed on the challenges of obtaining reliable gas concentration data; multiple studies in the Surat Basin and other coal basins in eastern Australia suggested that the concentration of dissolved gas in the subsurface aquifers cannot be determined accurately through collection of groundwater samples obtained from water bores due to changes in pressure during pumping of the well, variation in solubility of various gases (e.g. methane, ethane, propane, carbon dioxide) and effervescence during sample collection (e.g. Walker and Mallants, 2014; Banks et al., 2017; Suckow et al., 2019; Pearce et al., 2021; Raiber et al., 2022a). For example, studies comparing different gas sampling techniques by Banks et al. (2017) in the Gloucester Basin in NSW and by Pearce et al. (2021) in shallow aquifers in the Surat Basin in Queensland suggested that the mostly-applied "open" gas sampling techniques where groundwater is exposed to the atmosphere during sample collection likely result in a loss of dissolved gases and underestimate methane concentrations especially in gassy bores. This highlighted that the measurements on the in-situ gas pressure in the aquifer is, therefore, important to back calculate the dissolved gas content in the subsurface; such information, however, is not widespread across the Surat Basin.

Need & Scope

There are several thousand water supply bores that extract water from sandstone aquifers, including the Hutton and Precipice sandstones, that are below the Walloon Coal Measures. Gas has been historically observed in these deeper formations well before CSG development commenced (e.g. Walker and Mallants, 2014). However, there is community interest in knowing whether CSG development is impacting these deeper groundwater systems and potentially mobilising dissolved gas and emitting to the surface during water extraction from boreholes. As noted in the previous section, the source of gas in these aquifers including its lateral distribution and the causes for the variations in gassiness of water extracted from various water bores across the Surat Basin have not been studied in detail. Scope of this project will be to develop an understanding of the dynamics of the groundwater systems in these deep aquifers, the sources of gas within them and how they may be affected by non-CSG water extraction and CSG activities.

Existing models for groundwater impacts developed by OGIA focus on the impacts on groundwater, in accordance with OGIA's jurisdiction. There is a knowledge gap around how groundwater impacts in these deeper formations may influence the distribution and concentration of gas in the deeper aquifers.

Objective

The overall objective of the study is to provide the evidence base to allow for the prediction of the likelihood of water bores across Surat Basin being gassy and how the gassiness may change over time including during CSG development. The study will not directly address the natural gas seep around the region. The study requires a holistic approach through integrating outputs from existing groundwater models for the Surat Basin (i.e. OGIA model) with a petroleum system analyses to understand gas generation from the coal seams and any organic matter dispersed within the aquifers as well as flow characteristics.

The specific objectives include:

- Collate existing gas concentration and isotope data from bores screened within the formations below the Walloon Coal Measures.
- Assess spatial patterns of gas in bores within groundwater bores screened in the different formations.
- If/where time series data of methane (or other hydrocarbons) of groundwater in bores are available, determine if there are any statistically significant temporal changes.
- Collate major and minor ion hydrochemical data and assess spatial patterns of hydrochemistry within the aquifers of interest to determine if there are any relationships between hydrochemistry and gas concentrations following the methodology described by Raiber and Suckow (2017). While there are likely to be only limited pre-development baseline gas concentration data available, there are decadal hydrochemistry time-series data available for many groundwater bores in the Hutton and Precipice sandstones. The aim of this assessment is to determine if there are any hydrochemical patterns that could indicate changes in connectivity or be used as a proxy to identify increases in gas concentrations.
- Establish new and/or refine existing conceptual models for the groundwater systems in these deeper formations including potential gas migration pathways, and the sources of gas within groundwater systems,
- Evaluate how these groundwater systems may be affected by non-CSG water extraction and CSG activities, and
- Identify options for future monitoring to validate whether the presence of gas in groundwater bores is increasing or not, what the source of any such gas is and whether CSG activities are a contributing factor.

The project will comprise two stages where at the completion of stage 1 the refined conceptual models will be presented and reviewed to determine the key aspects that the petroleum systems and numerical models will address, and a suitable workflow will be established. A key requirement for development of the petroleum system model is obtaining outputs from the geological model including structure maps previously developed by OGIA. Depending on the direction determined during the stage gate/decision point, OGIA in principle has indicated their support for a strong dependency on collaboration between OGIA, UQ’s Centre for Natural Gas and CSIRO for delivery of stage two of this project.

Methodology

STAGE 1 – Discovery and conceptual modelling

Discovery phase

In order to implement the study, GISERA will liaise with OGIA, UQ and CSG companies operating in the area selected for the study. To ensure access to the required data (e.g., seismic, interpreted depth maps and faults, gas concentrations, gas chemistry, gas isotope and hydrochemistry data) it is critical that the project team directly communicates with these external parties so that GISERA can deliver the project in a timely manner and avoid duplication of existing effort. OGIA has compiled a considerable volume of data and understanding of the geology, hydrogeology and groundwater systems in the region and the project team will work closely with OGIA in the discovery phase. Regional data available for the CMA will be assessed and the area of interest (AOI) for modelling will be determined according to the availability of suitable data.

During the discovery phase, we will leverage existing data and models. This will include, for example, existing data on the presence of gas in Hutton and Precipice sandstones (e.g. gas concentrations, gas isotopes and hydrochemistry), geological and petrophysical data (e.g. depth-structure maps, fault surfaces and hydraulic properties) and existing models (e.g. 3D geological, conceptual hydrogeological and numerical groundwater models) from key stakeholders such as OGIA, industry and research organisations.

A deliverable of this stage will be a data package that will be made available through CSIRO's data portal for future users.

Conceptual modelling phase

Based on observations collated in the discovery phase, establish:

- Conceptual models of the Surat Basin's groundwater system
  - Hydrodynamics largely from OGIA, from previous GISERA and from UQ's work
  - Dynamics of the gas/water system
- Conceptual models for interaction and connectivity between formations
  - Due to ground water extraction
  - Due to CSG activities
  - Geological factors including structures and lithofacies

STAGE 2 – Modelling, analysis and reporting

Modelling phase

Petroleum systems model – determining the amount and distribution of gas in the sandstone aquifers prior to CSG development.

Petroleum system modelling will be conducted using Petromod or Trinity petroleum systems analysis software, which are world leading tools for simulating petroleum systems in various geological settings. This software allows modelling of the timing and quantities of hydrocarbons generated and expelled from the coals and assessment of the volumes entrapped in various permeable sandstones, including those dissolved in groundwater. In the proposed study we will model thermogenic gas expulsion from the Permian coals underlying the Precipice and Hutton aquifers as well as biogenic gas expulsion from the Jurassic (Walloon) coals overlying these aquifers. Furthermore, we will consider a scenario with hydrocarbon generation from dispersed organic matter within the Hutton Sandstone and its contribution to the total gas contained in the aquifer.

Thermogenic gas generation from coal will be modelled using well established reaction kinetics for terrigenous organic matter. However, there are no such kinetics for biogenic gas generation from coal (e.g., Pepper and Corvie, 1915). Therefore, biogenic gas generation may be modelled using Petromod's reactions for Biomethane reaction formula, which is a function of organic matter content, burial depth, sedimentation rate and temperate.

According to conventional wisdom gas expelled from the coals largely moves upwards, however, data from various petroleum systems worldwide indicate that a proportion of the gas may also expel to underlying permeable layers down concentration gradients through geological time (e.g. diffusive flow). Stable carbon isotope composition of the gas in the Hutton and Precipice sandstones will allow the calibration of the model with respect to source of gas and to verify if the gas currently encountered in these aquifers was introduced during the Cretaceous when the coals generated and expelled gas. Re-migration of gas from the coals and within the aquifers would also have occurred during Late-Cretaceous and Tertiary when the Surat-Bowen basin system tectonically uplifted by about 1 to 1.5 km. During the project multiple gas expulsion and migration scenarios will be tested and calibrated against the gas isotope and concentration data available from various wells.

Where required, outputs from the petroleum systems model can be exported and directly incorporated (or coupled) with hydrogeological models (e.g. OGIA's model). A deliverable of this stage will be a data package of the model that will be made available through CSIRO's data portal for future users.

Numerical modelling of scenarios developed in the conceptual modelling phase

Scenarios developed during the conceptual modelling phase will be quantified using numerical modelling. The numerical models will examine the interaction between water bores abstracting from the sandstone aquifers and CSG extraction from the overlying Walloon Coal Measures, taking into consideration existing gas distributions within these formations. The model parameters will be derived from the other components of this project, including:

- Geological scenarios derived from the discovery phase and conceptual modelling phase,
- Historical water extraction rates derived from the discovery phase,
- Initial gas content and distribution estimates derived from the petroleum systems model, and
- Impacts on groundwater in the sandstone aquifers and overlying formations derived from OGIA's groundwater models.

Models will be run for representative scenarios identified in the conceptual models rather than the full system, since developing a coupled model of the full area of CSG development in the Surat Basin would be complex and likely to require compromises between accurate representation of geological features/scenarios and the overall scale of the development.

Outputs from the models will include changes in gas content and distribution within the sandstone aquifers, flow paths for movement of gas and water and associated changes in groundwater head.

The modelling will be conducted using PorousFlow module of the MOOSE software. PorousFlow can handle multi-phase, multi-component flows, and is high quality, being certified under the US nuclear quality assurance standards. It has been used by CSIRO in large projects similar to this proposal, such as the bioregional assessments and modelling of the CO2-CRC's Otway CO2-storage site.

Analysis phase

- Which conceptual models remain valid?
- How could future monitoring further improve understanding?
- How could future monitoring validate whether CSG (or other activities) are having an impact on the deeper aquifers?

Reporting and communication of results as outlined in the Communications plan

- Preparation of a Final report for peer review via CSIRO's ePublish process and publication to the GISERA website.
- Communication of project aims and results to broader stakeholder groups via fact sheets, newsletters and news articles, scientific paper publication, and various presentations including a Knowledge Transfer session with support from the GISERA Communication and Engagement Team.

3. Project Inputs

Resources and collaborations

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Mohinudeen Faiz	101 days	Coal seam gas systems and modelling	+25 years	CSIRO
Matthias Raiber	83 days	Groundwater modelling	+20 years	CSIRO
Cameron Huddlestone-Holmes	20 days	Geologist and impact assessment	+25 years	CSIRO
Kyle Gavrily	50 days	Gas geochemistry and analyses	+5 years	CSIRO
Andy Wilkins	40 days	Multiphase numerical modelling	15 years	CSIRO

Subcontractors (clause 9.5(a)(i))	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Nil				

The project team has engaged with OGIA during development of this proposal and have in principle agreement from OGIA for data and knowledge sharing through discovery and conceptual modelling stages of the project. The project team acknowledges that CSIRO-GISERA will be responsible for obtaining permission for the use of any in-confidence data from the entity that supplied the data.

Technical Reference Group

The project will establish a Technical Reference Group (TRG) aimed at seeking peer-to-peer technical advice on contextual matters and to discuss research needs as well as outputs as the project progresses. The TRG will include the project leaders, key task leads and a group of different stakeholders as appropriate, which may include a range of subject matter experts from government and industry. The group will have significant experiences on local contextual contacts in the study region, groundwater system of the Surat Basin and coal seam gas geochemistry. The organisations associated with the TRG would include:

- Office of Groundwater Impact Assessment
- Natural Gas Centre of University of Queensland
- Queensland Department of Resources, Petroleum and Gas Inspectorate representative
- Hydrogeologists/geochemists from CSG operating companies

Budget Summary

Source of Cash Contributions	2023/24	2024/25	2025/26	2026/27	% of Contribution	Total
GISERA	$0	$312,519	$288,623	$0	70.1%	$601,143
- Federal Government	$0	$267,937	$247,450	$0	60.1%	$515,388
- APLNG	$0	$21,176	$19,557	$0	4.75%	$40,734
- Origin	$0	$21,176	$19,557	$0	4.75	$40,734
- QGC	$0	$2,229	$2,059	$0	0.5%	$4,288
Total Cash Contributions	**$0**	**$312,519**	**$288,623**	**$0**	**70.1%**	**$601,143**

Source of In-Kind Contribution	2023/24	2024/25	2025/26	2026/27	% of Contribution	Total
CSIRO	$0	$133,300	$123,108	$0	29.9%	$256,407
Total In-Kind Contribution	**$0**	**$133,300**	**$123,108**	**$0**	**29.9%**	**$256,407**

TOTAL PROJECT BUDGET	2023/24	2024/25	2025/26	2026/27	-	TOTAL
All contributions	**$0**	**$445,819**	**$411,731**	**$0**	**-**	**$857,550**
TOTAL PROJECT BUDGET	**$0**	**$445,819**	**$411,731**	**$0**	**-**	**$857,550**

4. Communications Plan

Stakeholder	Objective	Channel (e.g. meetings/media/factsheets)	Timeframe (Before, during at completion)
Regional community stakeholders including landholders, traditional owners and wider public	To communicate project objectives, and key messages and findings from the research	A fact sheet at commencement of the project that explains in plain English the objectives of the project.	At project commencement
		Project progress reported on GISERA website to ensure transparency for all stakeholders including regional communities.	Ongoing
		Public release of final reports. Plain English fact sheet summarising the outcomes of the research.	At project completion
		Preparation of article for the GISERA newsletter and other media outlets as advised by GISERA's communication team.	At project completion
		Presentation/s about the project and on research findings where appropriate.	At completion or within 6 months of completion of project.
Gas Industry & Government	Industry and government regulators get an improved understanding of source of gas in aquifers interbedded with coal seam gas reservoirs. Awareness of the extent of CSG operations affecting gassiness of groundwater bores in the Surat Basin	Project progress reporting (on GISERA website).	Ongoing
		Final project report and fact sheet(s).	At project completion
		Presentation of findings at joint gas industry/government Knowledge Transfer Session.	At project completion
		Dataset and outputs of basin model available through CSIRO's data repository.	After completion of project
Scientific Community	Provide scientific insight into origin of gas in the sandstone aquifers interbedded with coal seam gas reservoirs. Improved methods of modelling dissolved gas in aquifers associated with coal seam gas systems.	Peer-reviewed scientific publication.	After completion of project
		Dataset and outputs of basin model available through CSIRO's data repository.	After completion of project

In addition to project-specific communication activities, CSIRO's GISERA has a broader communication and engagement strategy. This strategy incorporates activities such as webinars, workshops, newsletters and development of other communication products.

5. Project Impact Pathway

Activities	Outputs	Short term Outcomes	Long term outcomes	Impact
Data sourcing from various stakeholders and databases	• Compilation of existing data on hydrochemistry and gas in the Hutton and Precipice aquifers. • Compilation of input data required for the geological model largely sourced from OGIA and UQ. • Compilation of basin model calibration parameters including temperature, pressure, porosity and vitrinite reflectance	• Database for model building and calibration and definition of area of interest for the model and sub-models	• Evidence base to allow for the prediction of the likelihood of water bores across Surat Basin being gassy and how the gassiness may change over time including during CSG development. • A model that can be updated and further improved as more data from ground water bores and CSG wells become available.	Increased understanding and awareness of different sources of methane in the Hutton and Precipice sandstones as well as any possible impacts from CSG production and abstraction of groundwater from the aquifers.
Conceptual modelling	• Conceptual models of the Surat Basin's groundwater system. • Interaction and connectivity between CSG reservoirs and aquifers.	• Conceptual model for building basin model architecture for petroleum and ground water system analyses		
Petroleum system modelling	• Petroleum systems model for the area of interest defined according to availability of data. • The base model for numerical modelling of gas in groundwater aquifers	• Likely sources of gas identified in the aquifers associated with CSG reservoirs and model for variations in gassiness of groundwater in the aquifers. • Improved understanding of impact of water abstraction from water bores intersecting the Hutton and Precipice aquifers as well as evaluation of any impacts from gas production from		
Groundwater modelling	• Numerical models for specific areas with scenarios developed during the conceptual modelling phase. • Interaction between water bores abstracting from the sandstone aquifers and CSG extraction from the overlying Walloon Coal Measures.			
Analyses and reporting	• Petroleum systems model with a focus on generation and expulsion of gas from Permian and Jurassic coals and accumulation/dissolution in the Precipice and Hutton aquifers.			

Activities	Outputs	Short term Outcomes	Long term outcomes	Impact
	• Gas distribution within the sandstone aquifers, flow paths for movement of gas and water and associated changes in groundwater head.	the overlying CSG reservoirs		
Information sharing and communication	• Knowledge transfer session with industry and engagement • Final report • Factsheets and articles on GISERA website and in GISERA newsletter • Interactions with the project Technical Reference Group	• Knowledge on the various sources of gas in aquifers as a result of natural processes of coal maturation, geological evolution of the Surat Basin and possible impacts from CSG production activities		

6. Project Plan

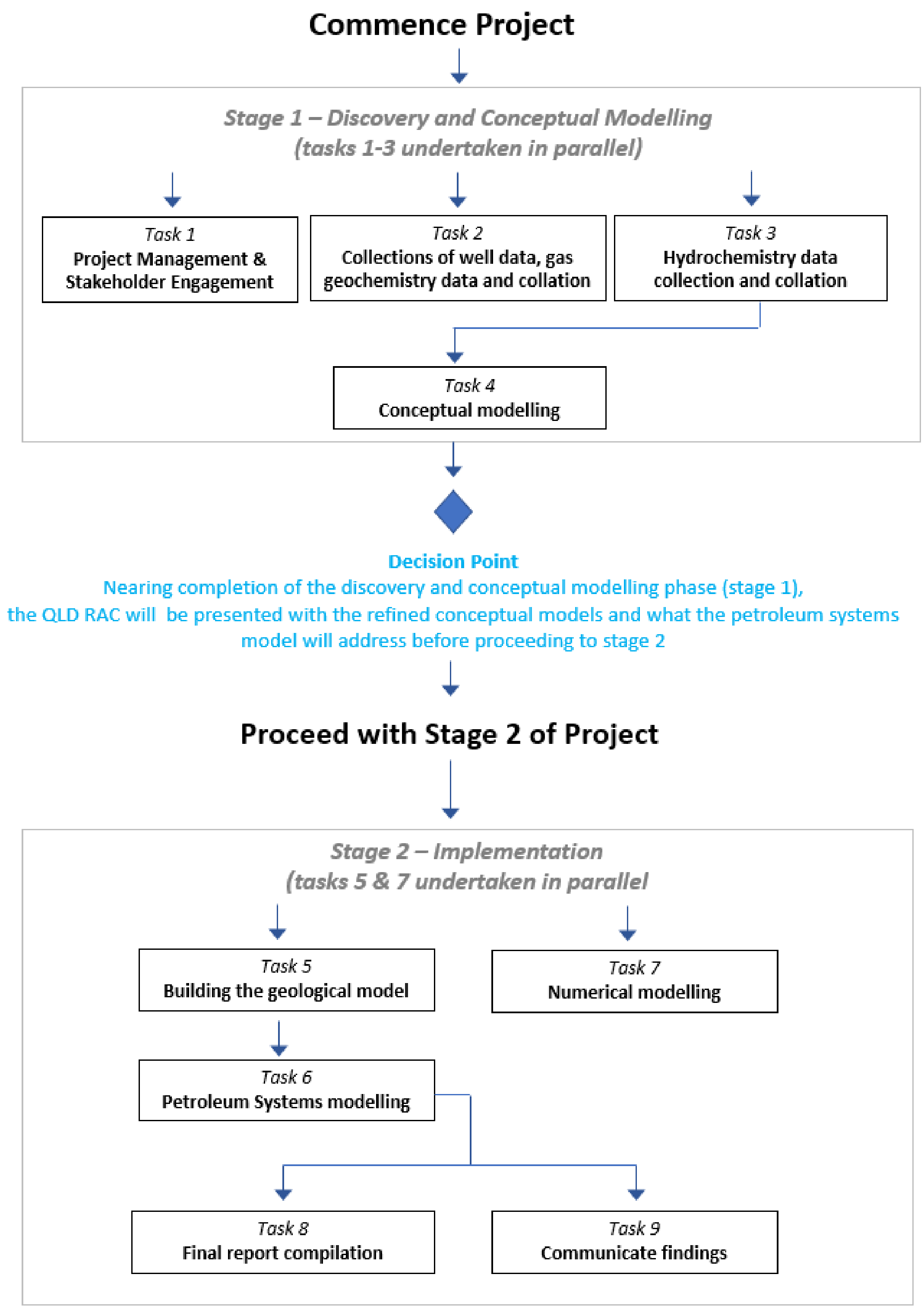

Figure 1. Pathway schematic outlining the project stages and decision point

Project Schedule

ID	Activities / Task Title (should match activities in impact pathway section)	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Project management, stakeholder engagement including with OGIA, UQ and CSG operating companies as well as communication management	Mohinudeen Faiz	Duration of the project		
Task 2	Collection of well data, gas geochemistry data and collation	Kyle Gavrily	1 July 2024	30 November 2024	
Task 3	Hydrochemistry data collection and collation	Matthias Raiber	1 July 2024	30 November 2024	
Task 4	Conceptual modelling	Matthias Raiber	1 September 2024	30 April 2025	Tasks 2, 3
Stage gate / QLD RAC decision point					
Taks 5	Building the geological model	Mohinudeen Faiz	1 January 2025	31 July 2025	
Task 6	Petroleum Systems modelling	Mohinudeen Faiz	1 July 2025	31 January 2026	Tasks 2,3,4,5
Task 7	Numerical modelling	Andy Wilkins	1 December 2024	31 January 2026	Tasks 2,3,4,5
Task 8	Final report compilation	Mohinudeen Faiz and Matthias Raiber	1 February 2026	30 June 2026	Tasks 2,3,4,5,6,7
Task 9	Communicate findings to stakeholders	Cameron Huddlestone-Holmes	1 July 2024	30 June 2026	Tasks 1,2,3,4,5,6,7

Task description

Task 1: Project management, stakeholder engagement including with OGIA, UQ and CSG operating companies as well as communication management

OVERALL TIMEFRAME: Full duration of project (1 July 2024 – 01 June 2026)

BACKGROUND: This project will require engagement with industry, OGIA and the Centre for Natural Gas Research at UQ. These institutions have previously conducted hydrogeological and geochemical studies in the Surat Basin region that will provide important background information required to conduct the proposed modelling study. This task also includes time for the project leaders to manage the project and undertake administrative actions associated with project progress.

TASK OBJECTIVES**:** Engage with OGIA, UQ, industry, government agencies and Technical Reference Group representatives to obtain information for the project, manage project staff, deliverables and project reporting.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Communicate project objectives, progress and results to GISERA stakeholders according to standard GISERA project procedures which may include, but not limited to:

1. Communicate and engage with OGIA, UQ, industry and various government regulators are required to implement and communicate the project
2. Complete milestone reports, undertake project team meetings
3. Establish and engage with Technical Reference Group
4. Engage with industry and government and record these interactions via the GISERA communications register
5. Oversee overall project delivery and preparation of final reporting

Task 2: Collection of well data, gas geochemistry data and collation

OVERALL TIMEFRAME: 5 months (1 July 2024 – 30 November 2024)

BACKGROUND: Well data required to develop the model include stratigraphy, depth and ages for top of key formations, lithologies, coal layers, porosity, bottom hole temperature, pressure and vitrinite reflectance. Gas data from water bores including concentrations as well as stable C and H isotopic compositions of methane are required to determine the volumes and origin of gas.

TASK OBJECTIVES: Collate the data from well completion reports, OGIA database and other company reports where accessible. Communicate with the operating companies to access data that are not publicly accessible. Structural, stratigraphic and geochemical database construction.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: The area of interest (AOI) for the basin model will be determined according to availability of suitable data. A database of available data compiled in Excel and included in the Petromod or Trinity basin modelling package.

Task 3: Hydrochemistry data collection and collation

OVERALL TIMEFRAME: 5 months (1 July 2024 – 30 November 2024)

BACKGROUND: Previous studies (e.g. Mallants et al., 2014 and Raiber and Suckow, 2017) suggested that there are distinct relationships between concentrations of major and minor ions and methane in many groundwater samples in the Hutton and Precipice sandstones. While pre-CSG development methane concentration baseline data are limited throughout the Surat and Bowen basins, there are abundant pre-CSG development hydrochemistry data available.

TASK OBJECTIVES: Collate and QA/QC hydrochemistry data from published literature, industry, the Queensland groundwater and the OGIA data bases in the Surat and Bowen basins. Integrate with data from Task 2 and identify spatial patterns in hydrochemistry (major and minor ions) and methane data for Hutton and Precipice sandstones. Use multivariate statistics to determine if there are correlations of hydrochemistry and methane and if major and/or minor ion hydrochemistry can under certain conditions represent proxies for presence/absence of methane where no measured methane concentrations exist; in bores where high post CSG-development methane concentrations have been observed and where long-term (decadal) hydrochemistry data are available, determine if any changes in hydrochemistry have occurred that could be explained by an increased degree of connectivity.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: An inventory of available hydrochemistry data for the Hutton and Precipice sandstone throughout the assessment area (combined with gas data collated as part of Task 2) will be created in Excel or Access. Hydrochemistry data are a fundamental component of conceptual hydrogeological models, and the results of Task 3 will be integrated with other lines of evidence to inform conceptual hydrogeological models developed in Task 4.

Task 4: Data integration and conceptual modelling

OVERALL TIMEFRAME: 8 months (1 September 2024 – 30 April 2025)

BACKGROUND: Conceptual hydrogeological models form the basis of groundwater management and numerical models developed for impact predictions in resource development projects. The development of reliable conceptual hydrogeological models of potential hydrogeological connectivity and gas migration pathways relies on the integration of multiple lines of evidence. This includes for example integration of geological and geophysical data and models that characterise the geometry of the subsurface with gas concentrations and isotopes and hydrochemical data.

TASK OBJECTIVES: The data and knowledge from previous studies in the Surat and Bowen basins and from Tasks 2, 3 and 5 of this project will be integrated to develop multiple conceptual models of hydrogeological connectivity pathways.

The integration of data from multiple lines of evidence (geophysics, geology including surface mapping and rock characterisation), gas concentrations and isotopes and hydrochemistry will provide valuable insights into connectivity and potential gas migration pathways.

Building up on previous work conducted by various stakeholders in the Surat and Bowen basins and in close consultation with key stakeholders, we will develop new or adopt existing conceptual hydrogeological models that describe potential gas migration pathways and development scenarios that could result in an increase of gas concentrations in the Hutton and Precipice sandstones in different parts of the Surat and Bowen basins.

It is generally acknowledged that due to geological and hydrogeological uncertainties and data limitations, multiple plausible conceptual hydrogeological models may be possible in different settings. In such circumstances, we will develop multiple models that can underpin and be tested in subsequent tasks through petroleum systems and hydrodynamic modelling.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A set of representative conceptual hydrogeological models (e.g., via annotated cross-sections, maps and simple 3D block diagrams) of connectivity and gas migration pathways in the Surat and Bowen basins based on the integrated datasets from this study and previous studies.

STAGE GATE / DECISION POINT:

Present to the Queensland RAC the refined conceptual models and what the petroleum systems model will address and seek approval to proceed with the final stage of project.

Task 5: Building the geological model

OVERALL TIMEFRAME: 7 months (1 January 2025 – 31 July 2025)

BACKGROUND: A geological model needs to be built to develop the petroleum systems and the hydrodynamic models. The extent (AOI) and resolution of the model will be determined according to the maps and data sourced from various sources, largely from OGIA's Petrel model which includes UQ's seismic interpretations.

TASK OBJECTIVES: Review and quality control of the data and maps for their suitability to be included in the model. Construction of the basin model using depth-structure maps for the key stratigraphic layers, faults, lithofacies.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: This task will produce a static 3D geological model for the AOI (AOI determined according to data availability) that will be used for Petroleum systems and hydrodynamic modelling. 1D models calibrated with respect to temperature, porosity and pressure at well locations where appropriate data are available.

Task 6: Petroleum systems modelling

OVERALL TIMEFRAME: 7 months (01 July 2025 – 31 January 2026)

BACKGROUND: This task involves analysing the petroleum system and developing a model to investigate the source of gas in the sandstone aquifers interbedded with the coal seams.

TASK OBJECTIVES: Development of a detailed petroleum systems model for the AOI, where the AOI will be identified based on availability of suitable data. The model will be calibrated with respect to formation pressure, temperature, porosity and thermal maturity of the coals and dispersed organic matter in the sandstones. Thermogenic gas generation will be modelled and tested using published kinetics representing humic coal (Pepper and Covie, 1995). Currently there are no published kinetics for biogenic gas generation that can be included in petroleum systems models. Therefore, biogenic gas generation will be simulated by defining arbitrary generation rates and calibrating against observed gas data in the reservoirs. Migration modelling scenarios will be tested using Darcy, 'Invasion percolation' and 'Combined flow', to match the current hydrocarbon distribution in the sandstone aquifers accumulation by minimising the difference between the observed accumulations and the simulated hydrocarbon saturations at present day – selection of a base case scenario.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A Petroleum system model for the selected AOI calibrated against pressure, porosity, temperature and thermal maturity of the coals. Output will include digital maps.

Task 7: Numerical modelling

OVERALL TIMEFRAME: 14 months (01 December 2024 – 31 January 2026)

BACKGROUND: Conceptual models in Task 4 will have identified scenarios in which there are potential gas migration pathways. Quantification via numerical models will provide understanding of the conditions under which the gas does or does not migrate and will enable risk assessment and understanding of uncertainties.

TASK OBJECTIVES:

1. Creation of numerical models for each scenario, parameterised using water abstraction rates from the discovery phase, gas contents and distributions from the petroleum systems modelling, and information from OGIA's groundwater modelling.
2. By running the numerical models with a variety of input parameters: exploration of: (a) the conditions under which gas migrates; (b) risk, and; (c) understanding of key drivers of uncertainty.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: MOOSE numerical models for each scenario studied. Quantification of gas-migration conditions. Quantification of drivers of uncertainty.

Task 8: Final report compilation

OVERALL TIMEFRAME: 5 months **(**01 February 2026 – 30 June 2026)

BACKGROUND: Information from this project including outputs of the model is to be made publicly available after completion of standard CSIRO publication and review processes.

TASK OBJECTIVES: Information from this project is to be made publicly available after completion of standard CSIRO publication and review processes. Outputs of the model will be presented in the report. Access to the model will be available for those who possess licence for Petromod or Trinity software package.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

1. Preparation of a final report outlining the scope, methodology, scenarios, assumptions, findings and any suggestions/options for future research;
2. Following CSIRO ePublish review, the report will be submitted to the GISERA Director for final approval; and
3. Provide 6 monthly progress updates to GISERA office.

Task 9: Communicate project objectives, progress and findings to stakeholders

OVERALL TIMEFRAME: Full duration of project (01 July 2024 – 30 June 2026)

BACKGROUND: Communication of GISERA's research is an important component of all research projects. The dissemination of project objectives, key findings and deliverables to relevant and diverse audiences allows discourse and decision making within and across multiple stakeholder groups.

TASK OBJECTIVES: Communicate project objectives, progress and findings to stakeholders through meetings, Knowledge Transfer Session, fact sheets, project reports and journal article/s, in collaboration with the GISERA Communication Team.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Communicate project objectives, progress and results to GISERA stakeholders according to standard GISERA project procedures, which may include but are not limited to:

1. Knowledge Transfer Session with relevant government/gas industry representatives.
2. Presentation/s about the project and research findings to community stakeholders where appropriate.
3. Preparation of an article for the GISERA newsletter and other media outlets as advised by GISERA's communication team.
4. Two project fact sheets: one developed at the commencement of the project, and another that will include peer-reviewed results and implications at completion of the project. Both will be hosted on the GISERA website.
5. Peer-reviewed scientific manuscript ready for submission to relevant journal.

Project Gantt Chart

Task	Task description	2024-25												2025-26											
		Jul 24	Aug 24	Sep 24	Oct 24	Nov 24	Dec 24	Jan 25	Feb 25	Mar 25	Apr 25	May 25	Jun 25	Jul 25	Aug 25	Sep 25	Oct 25	Nov 25	Dec 25	Jan 26	Feb 26	Mar 26	Apr 26	May 26	Jun 26
1.	Project management, stakeholder engagement	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2.	Collection of well data, gas geochemistry data and collation	■	■	■	■	■																			
3.	Hydrochemistry data collection and collation	■	■	■	■	■																			
4.	Conceptual modelling			■	■	■	■	■	■	■	■														
Stage Gate / Decision point						■	■																		
5.	Building the geological model							■	■	■	■	■	■	■											
6.	Petroleum Systems modelling													■	■	■	■	■	■	■					
7.	Numerical modelling						■	■	■	■	■	■	■	■	■	■	■	■	■	■					
8	Final report compilation																				■	■	■	■	■
9	Communicate findings to stakeholders	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

7. Budget Summary

Expenditure	2023/24	2024/25	2025/26	2026/27	Total
Labour	$0	$272,319	$268,231	$0	$540,550
Operating	$0	$173,500	$143,500	$0	$317,000
Subcontractors	$0	$0	$0	$0	$0
Total Expenditure	**$0**	**$445,819**	**$411,731**	**$0**	**$857,550**

Expenditure per task	2023/24	2024/25	2025/26	2026/27	Total
Task 1	$0	$14,849	$17,092	$0	$31,941
Task 2	$0	$47,689	$0	$0	$47,689
Task 3	$0	$17,136	$0	$0	$17,136
Task 4	$0	$55,137	$0	$0	$55,137
Task 5	$0	$120,251	$0	$0	$120,251
Task 6	$0	$135,702	$187,344	$0	$323,046
Task 7	$0	$49,173	$50,681	$0	$99,854
Task 8	$0	$0	$144,450	$0	$144,450
Task 9	$0	$5,882	$12,164	$0	$18,046
Total Expenditure	**$0**	**$445,819**	**$411,731**	**$0**	**$857,550**

Source of Cash Contributions	2023/24	2024/25	2025/26	2026/27	Total
Federal Govt (60.1%)	$0	$267,937	$247,450	$0	$515,388
APLNG (4.75%)	$0	$21,176	$19,557	$0	$40,734
Origin (4.75%)	$0	$21,176	$19,557	$0	$40,734
QGC (0.5%)	$0	$2,229	$2,059	$0	$4,288
Total Cash Contributions	**$0**	**$312,519**	**$288,623**	**$0**	**$601,143**

In-Kind Contributions	2023/24	2024/25	2025/26	2026/27	Total
CSIRO (29.9%)	$0	$133,300	$123,108	$0	$256,407
Total In-Kind Contributions	**$0**	**$133,300**	**$123,108**	**$0**	**$256,407**

	Total funding over all years	Percentage of Total Budget
Federal Government investment	$515,388	60.1%
APLNG investment	$40,734	4.75%
Origin investment	$40,734	4.75%
QGC investment	$4,288	0.5%
CSIRO investment	$256,407	29.9%
Total Expenditure	**$857,550**	**100%**

Task	Milestone Number	Milestone Description	Funded by	Start Date (mm-yy)	Delivery Date (mm-yy)	Fiscal Year Completed	Payment $ (excluding CSIRO contribution)
Task 1	1.1	Project management, stakeholder engagement including with OGIA, UQ and CSG operating companies as well as communication management	GISERA	Jul-24	Jun-26	2025/26	$22,391
Task 2	2.1	Collection of well data, gas geochemistry data and collation	GISERA	Jul-24	Nov-24	2024/25	$33,430
Task 3	3.1	Hydrochemistry data collection and collation	GISERA	Jul-24	Nov-24	2024/25	$12,012
Task 4	4.1	Conceptual modelling	GISERA	Sep-24	Apr-25	2024/25	$38,651
Stage gate / Queensland RAC decision point							
Task 5	5.1	Building the geological model	GISERA	Jan-25	Jul-25	2025/26	$84,296
Task 6	6.1	Petroleum Systems modelling	GISERA	Jul-25	Jan-26	2025/26	$226,455
Task 7	7.1	Numerical modelling	GISERA	Dec-24	Jan-26	2025/26	$69,998
Task 8	8.1	Final report compilation	GISERA	Feb-26	Jun-26	2025/26	$101,259
Task 9	9.1	Communicate findings to stakeholders	GISERA	Jul-24	Jun-26	2025/26	$12,650

8. Intellectual Property and Confidentiality

Background IP (clause 11.1, 11.2)	**Party**	**Description of Background IP**	**Restrictions on use (if any)**	**Value**
				$
				$
Ownership of Non-Derivative IP (clause 12.3)	CSIRO			
Confidentiality of Project Results (clause 15.6)	Project Results are not confidential.			
Additional Commercialisation requirements (clause 13.1)	Not Applicable			
Distribution of Commercialisation Income (clause 13.4)	Not applicable			
Commercialisation Interest (clause 13.1)	**Party**		**Commercialisation Interest**	
	CSIRO		N/A	
	APLNG		N/A	
	Origin		N/A	
	QGC		N/A	

9. References

Banks, E., Smith, S., Hatch, M., Burk, L., Suckow, A. (2017). Sampling Dissolved Gases in Groundwater at in Situ Pressure: A Simple Method for Reducing Uncertainty in Hydrogeological Studies of Coal Seam Gas Exploration. Environmental Science & Technology Letters, Volume 4, 535-539

Green, P. M., Carmichael, D. C., Brain, T. J., Murray, C. G., McKellar, J. L., Beeston, J. W., and 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.

Hamilton, S. K., Esterle, J. S., and 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

Harris K, Morris R and Pointon V (2012). The presence of methane in Great Artesian Basin aquifers of the Surat Basin. APPEA Conference & Exhibition, 14 ‐ 16 May, 2012

Mallants, D., Raiber, M., and Davies, P. (2016). Decision Support System for investigating gas in water bores and links to coal seam gas development. Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Queensland Department of Natural Resources and Mines.

Pearce, J. K., Golding, S. D., Hayes, P., Baublys, K. A., Hofmann, H., Herbert, S. J. and Gargiulo, G. (2021). Gas sources and concentrations in Surat Basin shallow aquifers: a field sampling method comparison, and isotopic study. The APPEA Journal, 61 (2), 707-713. https://doi: 10.1071/aj20061

Pearce, J.K., Hofmann, H., Baublys, K., Golding, S.D., Rodger, I. and Hayes, P. (2023a). Sources and concentrations of methane, ethane, and CO_2 in deep aquifers of the Surat Basin, Great Artesian Basin. International Journal of Coal Geology, 265 (2023), 104162.

Pearce, J.K., Golding, S.D., Baublys, K., Hofmann, H., Gargiulo, G., Herbert, S.J. and Hayes, P. (2023b). Methane in aquifers and alluvium overlying a coal seam gas region: Gas concentrations and isotopic differentiation. Science of the Total Environment 861 (2023), 160639.

Pepper AS and Corvie PJ (1995) Simple kinetic models of petroleum formation – Part I, Oil and gas generation from Kerogen. Marine and Petroleum Geology 12, 291-319.

Raiber, M. and Suckow, A. (2017) Hydrochemical assessment of the Hutton and Precipice sandstones in the northern Surat Basin. CSIRO, Australia

Raiber, M., Martinez, J., Suckow, A., Deslandes, A., Gerber, C. (2022a). Assessment of the influence of geological structures on aquifer connectivity in the Pilliga Forest area, NSW – an integrated hydrogeological, geophysical, hydrochemical and environmental tracer approach. Canberra: CSIRO; 2022. csiro:EP2022-1375. https://doi.org/10.25919/exee-za89

Raiber, M., Martinez, J., Suckow, A., Deslandes, A., Gerber, C. (2022b). Assessment of the influence of geological structures on aquifer connectivity in the Pilliga Forest area, NSW – an integrated hydrogeological, geophysical, hydrochemical and environmental tracer approach . Canberra: CSIRO; 2022. csiro:EP2022-1375. https://doi.org/10.25919/exee-za89

Scott, S., Anderson, B., Crosdale, P., Dingwall, J., and 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.

Suckow, A., Raiber, M., Deslandes, A. and Gerber, C. (2019). Constraining groundwater recharge in the Pilliga Sandstone (Surat Basin, NSW) through environmental tracer data. Australia: CSIRO, 81 pp.

Walker, Glen R., and Mallants, Dirk (2014) Methodologies for Investigating Gas in Water Bores and Links to Coal Seam Gas Development. CSIRO, Australia.