Australia's National
Science Agency

GISERA | Gas Industry Social and Environmental Research Alliance

Progress report

Geochemical modelling and geophysical surveys to refine understanding of connectivity between coal seams and aquifers

Progress against project milestones

Progress against milestones/tasks are approved by the GISERA Director, acting with authority in accordance with the GISERA Alliance Agreement.

Progress against project milestones/tasks is indicated by two methods: Traffic light reports and descriptive Project schedule reports.

1. Traffic light reports in the Project Schedule Table below show progress using a simple colour code:

- **Green**:
  - Milestone fully met according to schedule.
  - Project is expected to continue to deliver according to plan.
  - Milestone payment is approved.
- **Amber**:
  - Milestone largely met according to schedule.
  - Project has experienced delays or difficulties that will be overcome by next milestone, enabling project to return to delivery according to plan by next milestone.
  - Milestone payment is withheld.
  - Milestone payment withheld for second of two successive amber lights; project review initiated and undertaken by GISERA Director.
- **Red**:
  - Milestone not met according to schedule.
  - Problems in meeting milestone are likely to impact subsequent project delivery, such that revisions to project timing, scope or budget must be considered.
  - Milestone payment is withheld.
  - Project review initiated by GISERA Director.

2. Progress Schedule Reports outline task objectives and outputs and describe, in the ‘progress report’ section, the means and extent to which progress towards tasks has been made.

Project schedule table

TASK NUMBER	TASK DESCRIPTION	SCHEDULED START	SCHEDULED FINISH	COMMENT
1	Hydrochemical baseline sampling (water)	Jul 2022	Dec 2022	Completed
2	Geochemical baseline characterisation (rocks)	Jul 2022	Mar 2023	Completed
3	Airborne electromagnetic (AEM) survey	Jul 2022	Jan 2024	Completed
4	Analysis of groundwater samples for environmental tracers	Sept 2022	Nov 2023	Completed
5	Geochemical modelling to test conceptual models	Jul 2023	Jul 2024	This milestone will be completed end January 2025
6	Data integration and refinement of conceptual models	Oct 2023	Oct 2024	This milestone will be delivered in January 2025.
7	Project reporting	Jul 2022	Dec 2024	This milestone will be delivered in January 2025.
8	Communicate findings to stakeholders	Jul 2022	Dec 2024	This milestone will be delivered in February 2025.

Project schedule report

TASK 1: Hydrochemical baseline sampling (water)

BACKGROUND

A previous GISERA project (‘Assessment of faults as potential hydraulic seal bypasses in the Pilliga Forest area, NSW’; Raiber et al., 2022) identified multiple potential hydrogeological connectivity pathways between the Gunnedah Basin (containing the targeted CSG formations) and the Surat Basin (including the Pilliga Sandstone, the major Great Artesian Basin aquifer in this region) (Figure 1).

The study showed that there is a distinct change in hydrochemistry from east to west and north-west within the Pilliga Sandstone in the NGP area. The interpretation of the observed patterns was that there is no or only limited connectivity between the Gunnedah Basin (including coal seams) and Surat Basin in the south and east of the NGP area. However, in some of the areas where there may be some connectivity, there remains significant ambiguity in the interpretations due to the lack of hydrochemistry and environmental tracer data from Gunnedah Basin strata and the

Purlawaugh Formation, the deepest formation of the Surat Basin which directly underlies the Pilliga Sandstone.

To close these knowledge gaps, additional water samples from the Purlawaugh Formation and from shallow Gunnedah Basin hydrostratigraphic units (e.g. Digby Formation and Napperby Formation and Hoskissons coal seam) are required, thus providing critical pre-CSG development data and reduce the uncertainty of geochemical mixing models.

NSW DPIE have installed multi-level monitoring wells (screening different formations at the same site) throughout the region over the last few years (mostly drilled between 2019 to 2020) as part of its NSW Coal Basins water monitoring strategy (NSW DPIE, 2019), with many of the bores screened within the formations inferred to interact with the Pilliga Sandstone where there is a current lack of baseline data (Figure 2). However, so far, only basic water chemistry parameters have been analysed on groundwater samples collected from these bores. This new monitoring bore network provides an excellent opportunity to collect more baseline chemistry and tracer data prior to CSG development and close the knowledge gaps identified by Raiber et al. (2022).

TASK OBJECTIVES

Groundwater samples will be collected from at least 15 groundwater monitoring bores for a comprehensive set of hydrochemical and isotopic tracers (e.g. stable noble gases such as He, Ne, Ar, Kr, Xe, ^{222}Rn, dissolved methane (concentrations and isotopes), major and minor ion hydrochemistry, stable isotopes of water and strontium, tritium, carbon-14 and ^{36}Cl). Sampling sites will include primarily the new NSW DPIE groundwater monitoring bores in the Narrabri region (Figure 2), although samples from selected alluvial groundwater monitoring bores within the vicinity of the NGP area may also be collected.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

Collection of groundwater samples for a wide range of parameters from NSW DPIE groundwater monitoring bores and selected alluvial bores, and shipment of samples to laboratories (samples will be analysed at a wide range of laboratories in Australia and overseas (e.g. United States of America and New Zealand)).

PROGRESS REPORT

This milestone is complete.

As of March 23/3/2023, as part of three sampling campaigns to the Narrabri region, we have completed collection of samples of 15 groundwater bores which are part of the NSW coal basins monitoring bore network (https://www.industry.nsw.gov.au/water/science/groundwater-archive/managing-impacts-from-coal-mining-and-coal-seam-gas/water-monitoring-strategy-nsw-coal-basins) and from Santos monitoring bores within the proposed Narrabri Gas Project area.

We have collected samples for a very wide range of hydrochemical and environmental tracer parameters from these bores. With the collection of these 15 samples, this milestone is complete (although we may collect some additional samples to further enhance the baseline dataset should the opportunity arise at a later stage).

TASK 2: Geochemical baseline characterisation (rocks)

BACKGROUND

A previous GISERA project ('Assessment of faults as potential hydraulic seal bypasses in the Pilliga Forest area, NSW'; Raiber et al., 2022) demonstrated that there is likely some groundwater mixing between the major GAB aquifer (Pilliga Sandstone) in the Narrabri region and underlying formations (and possibly also with the overlying Orallo Formation) in the north and north-western part of the NGP area. However, the assessment also showed that other hydrochemical processes (e.g., mineral dissolution and ion exchange) may also proceed in parallel and confirmed that with the currently available data, it is not possible to remove the ambiguity.

To further understand and quantify the relative significance of inter-aquifer mixing between coal seams (and more broadly, Gunnedah Basin formations) and aquifers (e.g. Pilliga Sandstone and alluvial aquifers) and hydrogeochemical evolution from rock-water interactions, analyses of existing core samples (readily available from the NSW core library) from selected bores screened within key formations (e.g. Pilliga Sandstone, Purlawaugh Formation, Digby Formation and Early and Late Permian coal seams) for $^{87}Sr/^{86}Sr$ and mineral assemblage (i.e. the presence and relative quantities of rock-forming minerals) are critical. The assessment of the $^{87}Sr/^{86}Sr$ ratio of both rocks and groundwater has proven to be very useful to determine connection of aquifers in the Surat Basin in Qld (Raiber et al., 2019)

Furthermore, the study by Raiber et al. (2022) (and other previous studies) highlighted the significance of igneous intrusion in this area. This suggested that in addition to faults, igneous intrusions such as dykes (dykes are igneous intrusive bodies that are often near-vertical and cross-cut (intrude into) horizontal sedimentary formations along pre-existing faults or fractures) and sills can also form potential hydrogeological connectivity pathways in the wider Narrabri Gas Project area.

It is very important to understand the timing when these igneous intrusions have occurred, as this will allow to refine the understanding on the structural history of the wider NGP area and help to determine whether the intrusions are present only within deeper formations or whether they are likely to intersect Gunnedah and Surat basins strata (thus, forming a potential connectivity pathway from the Gunnedah Basin to the Surat Basin).

TASK OBJECTIVES

The objective of this task is to provide baseline geochemistry data on the Pilliga Sandstone and under- and overlying formations (e.g., Purlawaugh Formation, Orallo Formation and Gunnedah Basin strata). When assessing connectivity between aquifers using geochemical modelling, it is important to characterise the different end members (e.g., the geochemistry of the rock and the hydrochemistry of different aquifers). To date, no such assessment has been conducted within the Narrabri region (or data are not publicly available). This assessment will include:

- analysis of 15 to 20 samples from different formations for their rock mineralogical assemblage using X-ray diffraction (XRD) and X-ray fluorescence (XRF).
- analysis of the $^{87}Sr/^{86}Sr$ ratio of selected rock samples (15 to 20 samples) from different stratigraphic formations.
- analysis of the age of selected samples (approximately five samples) from intrusive rocks to determine the timing of emplacement of the intrusions.

An initial screening confirmed that suitable samples are held by the NSW core library, and communication with the core library confirmed that these samples are readily available for collection and analysis.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

This task will provide a comprehensive understanding of the geochemical composition and isotopic signature of the Pilliga Sandstone as well as under- and overlying formations within the wider NGP area. The outputs will form a critical component of Task 5, representing the rock end member within the geochemical modelling.

PROGRESS REPORT

This milestone is complete. We have collected and analysed several samples (sixteen).

We have had 3 visits to the NSW core library and have collected samples from 31 depth intervals of Surat and Gunnedah Basin strata and from 17 igneous intrusions, providing a detailed overview on the spatial variability of the geochemical composition and the age and timing of intrusive activity in this region.

We have received analytical results for $^{87}Sr/^{86}Sr$ of whole-rock analysis and for partly digested samples, and results of analyses for geochemical characterisation of the rocks (XRD, XRF and trace elements). We have received results for analysis of the rock age.

TASK 3: Airborne electromagnetic (AEM) survey

BACKGROUND

The previous GISERA study by Raiber et al. (2022) assessed the subsurface architecture in the NGP area using newly collected data (ground-based transient electromagnetic (TEM) and AgTEM) together with the compilation of a vast amount of historic geological and geophysical data, followed by re-processing of a limited number of representative seismic sections. This has helped to hypothesise multiple potential hydrogeological pathways in the wider NGP area. Although this has significantly contributed to the understanding of connectivity between Gunnedah Basin and Surat Basin, the study has also highlighted on-going knowledge gaps and identified areas where additional data would be beneficial to further reduce the uncertainty.

The TEM surveys highlighted that there is a lack of a conductive cover, thus ‘opening a window’ into the subsurface. This suggests that conducting an AEM survey using a regular grid would provide extremely valuable insights into the subsurface to considerable depths (likely extending to depths beyond 400 m). This would underpin the assessment of the aquifer framework presented in this study and importantly also allow to identify concealed structures that may be present in areas not covered by previous geophysical surveys (e.g., areas such as the south and east of the NGP area where there is a lower density of seismic lines).

TASK OBJECTIVES

Acquisition of AEM survey data will provide new insights into the hydrogeological framework of the wider NGP region. The benefits of these surveys include that they provide a more comprehensive and continuous 3D model of the upper approximately 400 m of the subsurface than seismic surveys, as the surveys are conducted along regular grid lines (a hypothetical example of such a grid is shown in Figure 3). This will therefore help to

- further increase the confidence in the findings by Raiber et al. (2022) and other previous studies on the subsurface geometry
- confirm that no major concealed geological structures have been missed by seismic surveys (e.g., in areas where the spacing between the seismic survey lines is wider)

- determine the spatial extent of igneous intrusions
- provide the physical framework for future 3D geological and numerical groundwater models.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

Preparation and organisation of AEM survey, conducting AEM survey (via a contractor), inversion and electrical conductivity volume creation and preparation for layer-based 3D volume interpretation.

PROGRESS REPORT

The AEM survey has been completed over a 3-week interval in November and December 2023 and the final data delivery was completed in January 2024. During the survey, 86 AEM lines and two repeat lines were flown by SkyTEM along a regular grid (1200 m spacing).

The inverted data are provided as cross-sections and geotiffs for 30 different depth slices (e.g. 23.5 to 29 m depth, 29 to 35 m etc.).

The AEM survey was accompanied by a comprehensive communication strategy to inform the community about the AEM survey and its goals (e.g. fact sheet, media release, Q&A and twice weekly advertisement Courier Advert Narrabri AEM Survey).

TASK 4: Analysis of groundwater samples for environmental tracers

BACKGROUND

This task is associated with Task 1, and it will involve the analysis of samples collected as part of Task 1

TASK OBJECTIVES

Laboratory analysis of samples collected as part of Task 1 for parameters such as noble gas (He, Ne, Ar, Kr, Xe including $^{3}He/^{4}He$), ^{222}Rn, dissolved methane (concentrations and isotopes), other selected hydrochemical and isotopic tracers, including stable isotopes of water and strontium, tritium and carbon-14. Samples will be analysed at a wide range of laboratories in Australia and overseas.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

Analytical results of noble gases and other selected environmental tracers will be obtained, providing new evidence on the potential hydrogeological connectivity between the Gunnedah Basin (including coal seams) and shallow aquifers (e.g., Pilliga Sandstone and alluvium).

PROGRESS REPORT

This task has been completed at end of November 2023.

The results for hydrochemistry and environmental tracers have been received (e.g. hydrochemical and isotopic tracers, including stable isotopes of water and strontium, boron and lithium, tritium and carbon-14). The analysis of samples for stable noble gas analysis had been delayed due to technical issues at the Adelaide noble gas laboratory. However, it has now been completed (as of November 2023).

TASK 5: Geochemical modelling to test conceptual models

BACKGROUND

Raiber et al. (2022) identified different potential hydrogeological connectivity pathways, and their likelihood of forming actual hydrogeological connectivity pathways was assessed using multiple lines of evidence (i.e., geology, hydrogeology, geophysics, hydrogeochemistry and environmental tracers). This assessment suggested that some pathways are more likely to occur than others. The assessment showed that there is a distinct change in hydrochemistry within the major GAB aquifer in this region (Pilliga Sandstone) from east to west and north-west within the NGP area, with an increase of salinity towards the north and north-west indicating the potential of connectivity between the Pilliga Sandstone and underlying formations.

Simple two and three parameter mixing models were then used to test the conceptual models and further refine the understanding of hydrogeological connectivity pathways. Although such simple models are very useful to give an indication of mixing, there are also some uncertainties and limitations. This includes the uncertainty in representativeness of the available samples selected as end-members and the limited number of tracers considered (only two) for the calculations. Furthermore, as discussed in Task 1, although a good spatial distribution of hydrochemical records for the Pilliga Sandstone exists within the wider NGP area, there is only a small number of records available for the Purlawaugh Formation, Digby and Napperby formations and the Late Permian Gunnedah Basin coal seams (although there is a larger number of hydrochemical records available for the deeper Early Permian coal seams within the Maules Creek Formation, which are the primary CSG target unit).

Expanding the end-member mixing modelling conducted during this project to a comprehensive geochemical mixing model including both rock geochemistry and groundwater hydrochemical records as end-members and including the selection of multivariate parameters and the assessment of uncertainty of end-members and potential hydrochemical reactions is considered the most reliable approach to further reduce the uncertainty of interpretations from the current study.

TASK OBJECTIVES

The objective of this task is to develop a comprehensive geochemical mixing model for the aquifers within the NGP area, building on all the data collected and compiled during the previous studies (Creswell, 2014; Iverach et al., 2017 and 2020; Suckow et al. (2019) and Raiber et al., 2022) and combining with the newly acquired data from Tasks 1, 2 and 4.

This will be conducted in PHREEQC (a public-domain geochemical and hydrochemical modelling software available from the United States Geological Survey, USGS). Hydrochemical modelling with PHREEQC provides the means to test concepts and a suite of proposed reactions to determine the degree of connection or separation between the Pilliga Sandstone and underlying or overlying formations. This will allow to refine the understanding of the different hydrogeological pathways presented in Figure 1 by means of identifying the reactions responsible for the hydrochemical evolution within the Pilliga Sandstone aquifer from south/east to north and north-west.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

A PHREEQC mixing model will be developed. This will allow testing and refinement of conceptual hydrogeological models and differentiate between different processes contributing to the change of hydrochemistry observed within the Pilliga Sandstone in the Narrabri region from south and east to north and north-west, and assess the significance of the following hydrochemical processes:

- mixing with other formations;
- silicate weathering reactions;
- dissolution of salts;
- precipitation of calcite, amorphous silica, and clay minerals;
- ion exchange reaction.

This will also allow to quantify the relative contribution of mixing between the Pilliga Sandstone and adjacent aquifers.

PROGRESS REPORT

This milestone is partially complete.

We have held a one-week project team workshop to develop the methodology for this task with CSIRO officers and external sub-contractors. During the workshop, we have developed the methodology and have applied it to test multiple geochemical and reactive transport model realisations along an initial transect. For this purpose, we have created a simplified cross-section that represents the subsurface geometry as framework for the numerical model. We have then used the data from tasks 2 and 4 as input data for initial hydrochemical mixing and reactive transport models. We have also used ^{36}Cl to constrain groundwater flow rates.

We have liaised with the GISERA Groundwater modelling and predictive analysis project lead and team to get their input into the geochemical modelling and reactive transport modelling strategy.

Tasks to be completed: after testing the methodology, we will now develop further representative cross-sections (informed for example by Task 3). Along these cross-sections, we will develop geochemical mixing and reactive transport models to test different conceptual hydrogeological models.

Update November 4th 2024: we have created new cross-sections based on the integration of AEM, seismic data and geological data. We are currently setting up the geochemical and reactive transport models along these cross-sections to tests multiple conceptual hydrogeological models.

Expected completion date is January 2025.

TASK 6: Data integration and refinement of conceptual models

BACKGROUND

Conceptual hydrogeological models form the basis of numerical models developed for impact predictions. The development of reliable conceptual hydrogeological models of potential hydrogeological connectivity pathways relies on the integration of multiple lines of evidence.

This includes geological and geophysical methods that characterise the geometry of the subsurface including identification of geological structures, and hydrochemistry, environmental tracers and geochemical modelling, which provide an independent line of evidence of how groundwater moves through the subsurface.

TASK OBJECTIVES

The data from previous studies and Tasks 1 to 5 will be integrated to test the conceptual models of hydrogeological connectivity pathways from CSG units to near surface environmental assets presented in Figure 1 (Raiber et al., 2022). The integration of data from multiple lines of evidence (geophysics, geology, geochemistry and hydrochemistry, environmental tracers and geochemical mixing models) will help to further reduce the uncertainty on the understanding of connectivity between aquifers and aquitards. The existing conceptual models will be updated, or new alternative conceptualisation of the hydrogeological system may be proposed if the newly acquired evidence shows that the present conceptual models are not accurate representations of the regional hydrogeological system.

TASK OUTPUTS AND SPECIFIC DELIVERABLES

An improved conceptual hydrogeological model based on the integrated datasets from this study and previous studies. The project output will increase the confidence in the understanding of hydrogeological dynamics of the region and in particular the interaction between deep and shallow formations.

Two dimensional cross-sections and 3D geological representations will be used to represent the understanding of local geology, hydrostratigraphic layers and presence of geological structures derived from the geophysical surveys and the spatial distribution of environmental tracers, which may correspond to anomalies in proximity to and under the influence of geological structures. This will also involve the quantification of exchange fluxes between different formations and uncertainties associated with this assessment.

PROGRESS REPORT

We have commenced the integration of data from tasks 1-4 and previous projects. We are updating conceptual hydrogeological models of aquifer geometry and describe the distribution and timing of intrusive history (when dykes intruded into the Gunnedah and Surat Basin host rocks). As this partly relies on Task 5, we will only be able to complete this after completion of Task 5.

Expected completion is January 2025.

Variations to Project Order

Changes to research Project Orders are approved by the GISERA Director, acting with authority, in accordance with the GISERA Alliance Agreement. Any variations above the GISERA Director's delegation require the approval of the relevant GISERA Research Advisory Committee.

The table below details variations to research Project Order.

Register of changes to Research Project Order

DATE	ISSUE	ACTION	AUTHORISATION
15/03/23	Following consultation with the various stakeholders the project team have requested to extend and add lines to the AEM survey.	An additional $80,000 ($61,696 GISERA funding and $18,304 CSIRO funding) is allocated to complete this project taking the overall budget from $1,044,719 to $1,124,719.	

DATE	ISSUE	ACTION	AUTHORISATION
25/10/23	This activity has been delayed due to staff availability, an extensive stakeholder consultation process on scope and design of the survey and availability of AEM providers	Milestone 3 extended from September 2023 to January 2024.	
25/10/23	This activity has been delayed due to technical issues at the Adelaide noble gas laboratory.	Milestone 4 extended from September 2023 to November 2023.	
09/02/24	Delayed deliveries of analytical results from lab associated with previous milestones have caused a on flow affect.	Milestone 5 extended from January 2024 to July 2024, milestone 6 extended from March 2024 to July 2024, milestone 7 and 8 extended from June 2024 to September 2024.	
11/09/24	Staffing changes meant that CSIRO had to outsource specialist skills via subcontract agreement. These delays have had a follow-on effect on remaining milestones.	Milestone 6 extended from July 2024 to October 2024, milestones 7 and 8 extended from September 2024 to December 2024.	

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