Australia's National
Science Agency

GISERA | Gas Industry Social and Environmental Research Alliance

Project Order

Short Project Title

Environmental baseline characterisation of the springs in Hot Springs Valley, NT

Long Project Title	Environmental baseline characterisation of the springs in Hot Springs Valley, NT
GISERA Project Number	W.33
Start Date	01/09/2023
End Date	30/06/2025
Project Leader	Cindy Ong

GISERA State/Territory

- ☐ 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
- ☐ Surat
- ☐ Other (please specify)

GISERA Research Program

- ☒ **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 Hot Springs Valley is a relatively understudied area that holds significant environmental and cultural value. Environmentally, this natural phenomenon may sustain unique ecosystems, and culturally these springs are connected to Traditional Owners with many potentially important cultural sites surrounding these springs.

The springs are unique in that they are discharging hot water, with a maximum measured temperature of 65°C. Recent surveys conducted for the Geological and Bioregional Assessments Program (GBA) and the Strategic Regional Environmental and Baseline Assessment (SREBA) for the Beetaloo region have shown that the springs support diverse terrestrial and aquatic ecosystems. Greenhouse gas surveys conducted at the springs for the SREBA detected elevated methane and ethane concentrations around one of the springs.

While studies such as the SREBA and GBA provided regional scale information across the Beetaloo Sub-basin, environmental data capture at these springs has been limited to date due to their remote location. This project will conduct a field campaign to collect detailed data on the geology, hydrogeology and ecology of the Hot Springs Valley to augment data collected in previous surveys. Engagement with local Aboriginal groups will also be included as part of this study, to help inform the research.

Collecting baseline environmental data to comprehensively characterise the springs will provide an important evidence base for protection and management of this environmentally and culturally significant area. These data are required to not only extend the existing knowledge of this unique system, but to also provide a baseline prior to any potential development of gas resources in the nearby Beetaloo Sub-basin. These data will be used to develop a model for the likely sources of water and gas in the springs, the spatio-temporal evolution of the seepage and the discharge pathways. The model will allow a better understanding of how the springs may be impacted by development. The data and model will inform future water planning and management and to inform industry and government on future groundwater and emissions monitoring programs.

2. Project description

Introduction

Springs are naturally occurring discharge points of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, they represent the point at which the water table intersects ground level. They can also occur where water under pressure in deeper formations has a pathway to flow to the surface. The pathway could be faults and fractures or permeable formations (e.g., Flook et al., 2020) and springs can be sourced from one or multiple aquifers. Springs within or adjacent to the Beetaloo region hold high environmental, cultural and recreational value. A well-known spring complex in the region is the Mataranka Thermal Pools. While the Mataranka Thermal Pools are well studied, only relatively little water baseline data have been collected for other spring complexes such as those within the Hot Spring Valley (ELA, 2022).

The recently completed Strategic Regional Environmental and Baseline Assessment (SREBA) for the Beetaloo region identified several groundwater springs that have a confirmed or potential relevance to activities in the region (Figure 1). The Roper River (including Mataranka Thermal Pools), Flora River and Top Springs are all sourced from predominantly shallow groundwater systems including the Cambrian Limestone Aquifer. In contrast, the source of the springs in Hot Springs Valley is less well understood (ELA, 2022).

The Hot Springs Valley is located on Tanumbirini Station and lies to the Northeast of the Beetaloo Sub-basin. It is within the headwaters of the Cox River catchment and includes several spring complexes. the temperature of water discharging from these springs has been recorded between 42° C (Lagoon Creek Gorge Spring system) and 65° C (Beauty Creek Hot Spring system), with the higher temperature indicating a groundwater source of around 1,000 m or deeper (Evans et al., 2020; ELA, 2022; Frery et al., 2022). SREBA studies have also observed elevated methane and ethane concentrations around these springs (Ong et al., 2022). The source of groundwater and gas discharging from these springs is not well understood.

Springs also have important cultural and environmental values. Environmentally, this natural phenomenon may sustain unique ecosystems. Culturally, these springs are connected to the traditional owners with many potentially important cultural sites surrounding these springs. Environmental baseline data are essential for the future preservation of the area as they provide important reference/benchmark of the natural/undisturbed state. Further, these environmental baseline data can be used to characterise the springs to track future potential environmental implications of the onshore gas industry.

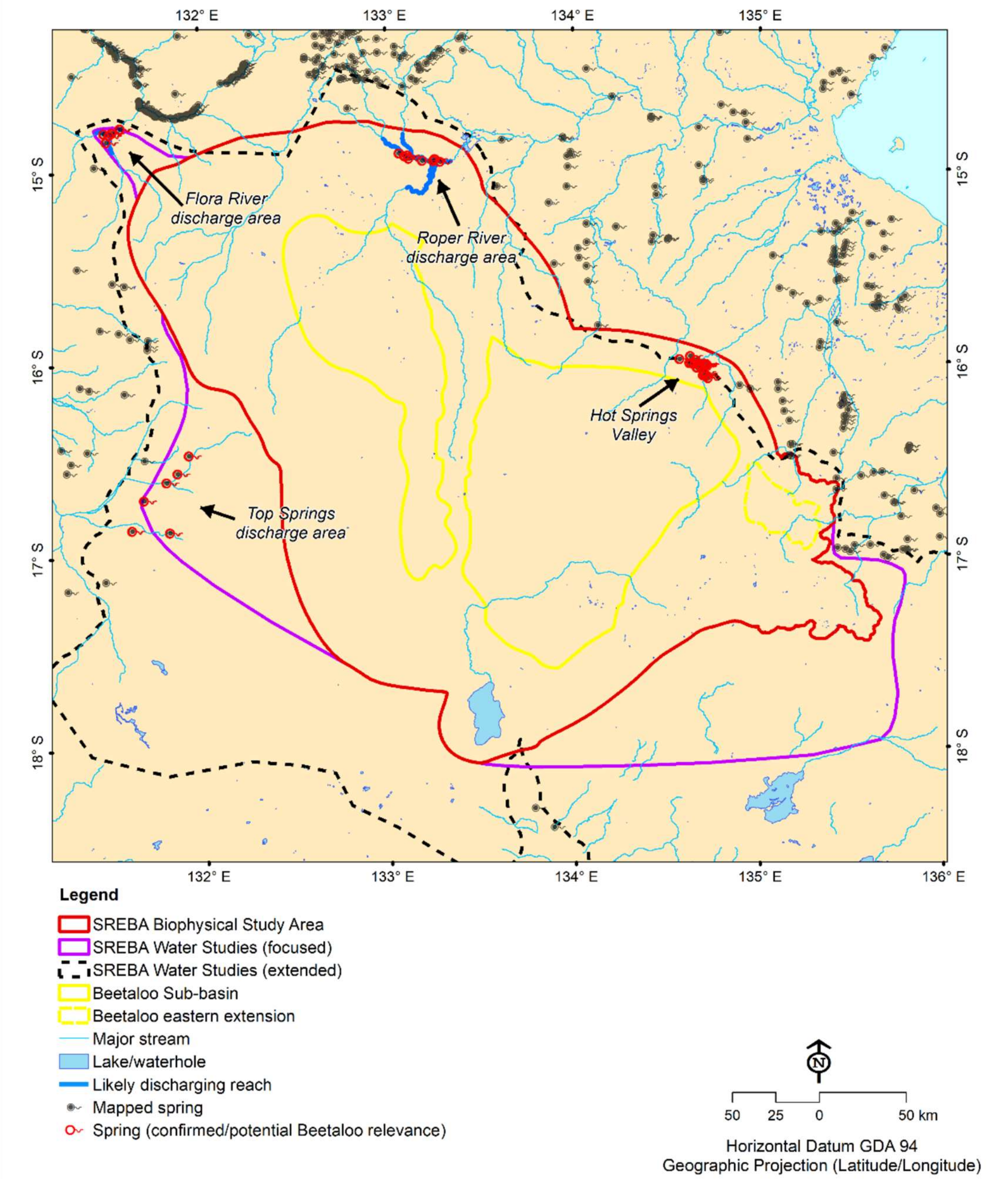

Figure 1: Location of groundwater springs that the SREBA water studies identified as having a confirmed or potential relevance to activities related to the Beetaloo Sub-basin (ELA 2022)

Prior Research

Geology and hydrogeology

The Water Quality and Quantity Baseline Summary Report (ELA, 2022) provides a recent summary of previous work conducted on the springs in Hot Springs Valley. Beauty Creek and Lagoon Creek, which host the two major spring complexes in Hot Springs Valley, have been identified in geological mapping published in 1964 (Dunn, 1964; Paine, 1964; Figure 2). Notably, this mapping shows that the springs are in an area where the Corcoran Formation, Bessie Creek Sandstone and Velkerri Formation outcrop at the surface. These formations are part of the Proterozoic sequence (the Roper Group) that contains the shale gas resources in the Beetaloo Sub-basin. This mapping also shows the presence of faults at the northern part of Hot Springs Valley, but an associated cross-section through the southern part of Hot Springs Valley did not show any significant fault displacements in this region (Figure 3). However, several recent studies have highlighted the significance of faults in this area (e.g., Evans et al., 2020; Frery et al., 2022, ELA, 2022). The Hot Springs Valley coincides with the surface expression of the OT Downs fault system that is located 10 km north of the western lobe of the geophysical Beetaloo Sub-basin (Huddlestone-Holmes et al., 2020; Orr et al., 2020; ELA, 2022; Frery et al., 2022) at the northern edge of the OT Downs Sub-basin (ELA, 2022).

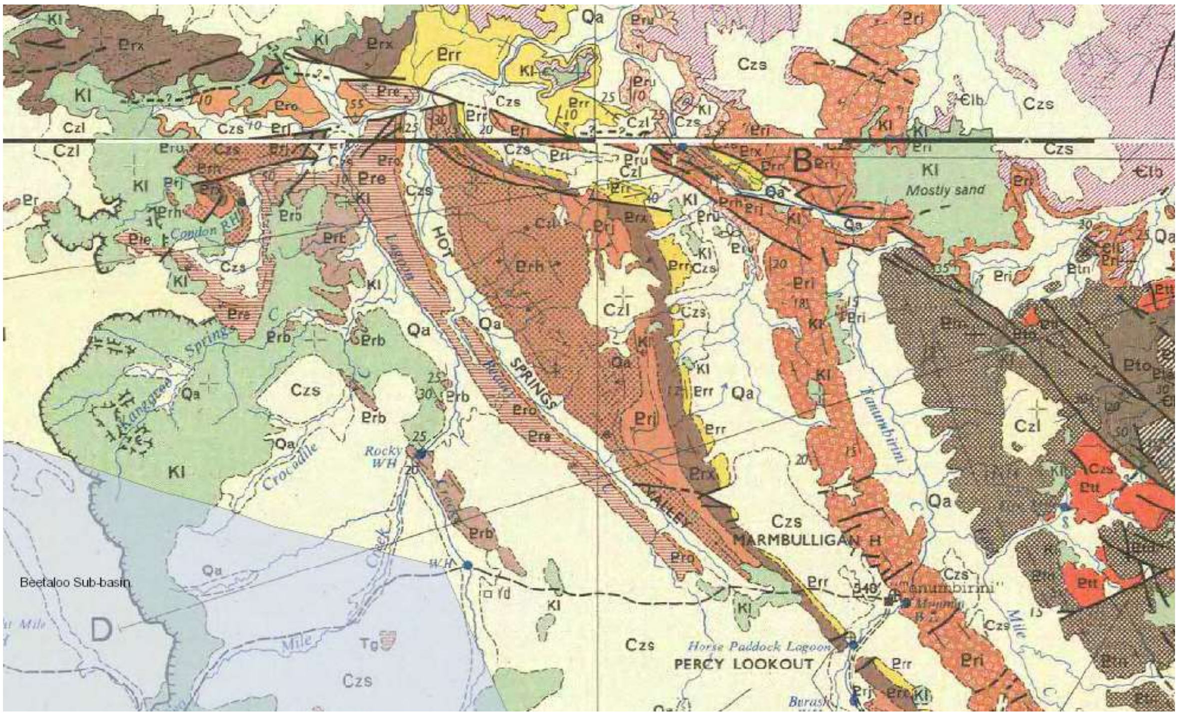

Figure 2: Extract from the 1:250,000 Tanumbirini and Hodgson Downs geological maps showing the mapped geology of the Hot Springs Valley. The north-eastern boundary of the Beetaloo-basin is in the lower left of this image (Dunn, 1964; Paine, 1964).

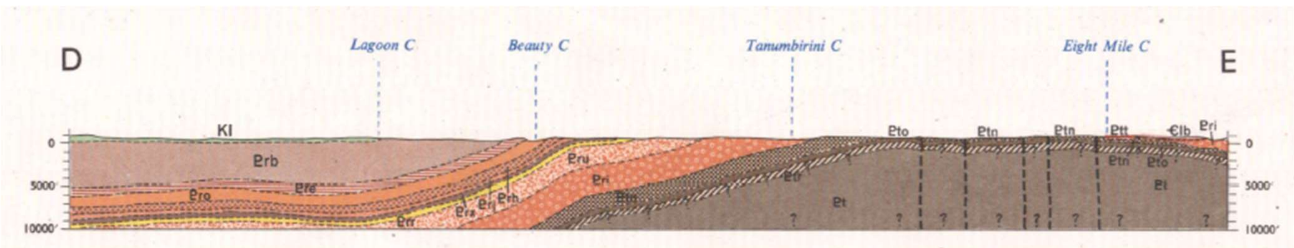

Figure 3: Cross-section through the Hot Springs Valley region from the 1:250,000 Tanumbirini Geological Map (Paine 1964).

As part of the study by Frery et al. (2022), which was conducted as part of the Geological Bioregional Assessment, the authors identified zones of discontinuous, low-magnitude and localised seismic signals beneath Hot Springs Valley. The authors suggested that one possible explanation of these observed signals is the presence of fluid or gas escape pathways, although migration artefacts could not be ruled out as a source of the signals. Furthermore, this study included a spatial assessment of the surface drainage patterns and fault lineages within the Beetaloo Sub-region, aiming to identify indications of structural controls on surface water drainage development. This suggested that a 90-degree stream diversion of Lagoon Creek (approximately two km down-gradient of Lagoon Creek Gorge Spring) indicates the presence of faults and their influence on the development of the stream network.

ELA (2022) provided a comprehensive overview on existing groundwater and geological data availability, knowledge and knowledge gaps in the Hot Springs Valley. They summarized the results of previous water quality sampling at Beauty Creek Hot Spring and Lagoon Creek Gorge Spring. This demonstrated that water of both spring complexes is fresh (with a TDS of <500 mg/L). ELA (2022) also highlighted that the relative ion concentrations and temperatures of the spring water at these two spring complexes are different (e.g., 42° C and Lagoon Creek Gorge Spring and 65° C at Beauty Creek Hot Spring), suggesting they may have different source aquifers.

Evans et al. (2020) summarised groundwater temperature data within the Beetaloo sub-region using bottom hole temperatures and drill stem test data from exploration wells. Based on this data compilation, the water temperature of 65° C measured at Beauty Creek Hot Spring corresponds to bottom hole temperatures observed at more than 1000 m depth.

The salinity of water observed at springs in Hot Springs Valley is significantly lower than salinities measured for example at the Mataranka Springs (e.g., Department of Environment and Natural Resources (NT) (2013), Evans et al., 2020; Lamontagne et al., 2021). The freshness of the water in Hot Springs Valley indicates that the springs are likely fed by aquifers (e.g., a formation composed of permeable sandstone), as low permeability units such as shale gas target units (generally more likely composed of low permeability rocks such as mudstone and claystone) in sedimentary basins in Australia typically contain more saline water (e.g., Raiber et al., 2022 a, b). Evans et al. (2020) identified the Roper Group as a potential source aquifer of the springs in Hot Springs Valley. ELA (2022) hypothesized that the Crawford Formation, the Mainoru Formation or the Limmen Sandstone (which are all part of the Roper Group and underlie the potential shale gas target units) could be source aquifers of the Beauty Creek springs and Bessie Creek Sandstone the source aquifer of Lagoon Creek Gorge Spring. They also suggested that the springs are in an area of significant uplift (vertical displacement) at the northern edge of the OT Downs fault system. However, both studies acknowledged that the source aquifer of these springs remains poorly constrained and that more baseline data collection is required for an improved conceptualisation.

No existing study documents the sources and the composition of the gas bubbling at the springs in Hot Springs Valley. This gas phase may result from the exsolution of gas dissolved in the aquifer or can have a mixed origin involving other sources.

Greenhouse Gas

In addition to the collection of limited baseline hydrochemistry samples, previous work also considered greenhouse gas in Hot Springs Valley. These baseline measurements for greenhouse gas conducted for SREBA showed elevated and correlated methane and ethane concentrations above the springs in the Hot Springs Valley near Clint's Gorge (Ong et al., 2022). The results indicate that the source of these gasses may be thermogenic (derived from a geological hydrocarbon source), but the authors explained that the presence and correlated nature of methane and ethane could also be related to biological methane and ethane generated closer to the surface. Only limited data were collected at one spring for this work, and the study did not extend to identifying the source of the methane and ethane. Tracking the source is an important component of characterizing the geology and hydrogeology of the springs.

Ecology

The GBA BESA carried out multiple visits to Clint's Gorge (Davis et al, 2021). The aquatic ecology team visited in both July 2020 and April 2021. A total of two species of freshwater turtle, 17 species of fish, and 27 species of aquatic invertebrates were observed and identified during these visits using a range of approaches including active sampling and eDNA sampling of water. The invertebrates noted included freshwater shrimp, beetles, mayflies, dragonflies and caddisflies.

The GBA BESA terrestrial ecology team carried out waterhole counts in the vicinity of Clint's Gorge searching for Gouldian finch. None were recorded (Davis et al, 2021).

The SREBA aquatic ecology survey included Clint's Gorge as one of its study sites (Department of Environment, Parks and Water Security, 2022a). It concluded that Clint's Gorge was one of the 10 sites sampled during the SREBA for total aquatic species richness. A total of 61 species was recorded from the site (compared to the top site of Little Roper River with 80 species). The study concluded that the springs in the vicinity of Clint's Gorge were one of two main clusters of groundwater springs in the region and that it sustained a distinctive aquatic ecosystem. The study also concluded that Clint's Gorge should be a priority site for on-going aquatic monitoring.

The SREBA terrestrial ecology team did not visit the Hot Springs Valley area.

Cultural heritage

The Hot Spring Valley is understood to have important cultural values for local Aboriginal people and there are several recorded sacred sites in the area. However, there is limited information documented about the perspectives of Aboriginal people in the area.

Impacts

The assessment conducted for GBA found that impacts on springs from unconventional resource development were of low concern (see GBA Explorer). However, this assessment primarily focused on spring systems supplied by shallower water sources such as the Mataranka Springs. Characterising the sources of water and gas for the spring in Hot Springs Valley will allow any potential for impacts to be better understood.

Need & Scope

While there is some data available for the springs in Hot Springs Valley there are gaps that have been identified (e.g., Evans et al., 2020; ELA, 2022). The acquisition of additional data including atmospheric gas measurements and quantification of emission rates from the gas seepages, water chemistry, geochemistry and geological mapping is important for providing a baseline prior to significant development of gas resources.

These data will also contribute towards the characterisation of the discharge pathways to understand the sources of water of the hot springs and connectivity to deeper formations. Understanding the discharge pathways is important for groundwater resources planning and management. A more comprehensive understanding of these pathways will further help inform the industry on future emission and groundwater monitoring programs should significant gas production commence.

The SREBA Regional Report made the following recommendation for the Hot Springs Valley (Department of Environment, Parks and Water Security, 2022b):

"Assessment of groundwater sources and potential impacts to Hot Springs Valley
The petroleum industry (either as a collective or through the GISERA program) should prioritise investigations of the Hot Springs Valley area, especially those companies undertaking work within 50 km of the springs. This will likely necessitate significant initial work to more accurately define the groundwater source(s) for this feature. These investigations will be crucial to understanding the risk of potential impacts and appropriate management and ongoing monitoring (if required). The area is also likely to be important for monitoring natural surface emissions of greenhouse gases from Beetaloo Sub-basin formations."

This work builds on knowledge developed from SREBA and GBA to provide scientific evidence to assist in addressing this recommendation.

Objective

This project aims to:

- Extend the SREBA and GBA work to provide a comprehensive baseline of terrestrial ecology, water and gas discharge at the environmental and culturally significant Hot Springs Valley as a pre-development benchmark before significant development of gas resources;

- Extend the work conducted as part of SREBA and GBA to provide a comprehensive characterisation of the likely discharge pathways and determine the likely sources of water and gas and its evolution with time and space at the hot springs that may be used to inform ongoing management, monitoring and preservation of the springs; and

- Engage with local Aboriginal communities, and representatives from other community groups where relevant, to share knowledge about the project, and ensure the research is conducted in a culturally sensitive way.

Methods

We propose the project methods outlined below:

Part 1: Stakeholder engagement, access and permissions.

The Hot Spring Valley is understood to have important cultural values for Aboriginal people. The project team will work with these stakeholders to consider their perspectives and to ensure that we have the appropriate permissions and authorities to access the site. The Hot Spring Valley lies primarily on a pastoral lease, extending on to the Aboriginal Land (Aboriginal Land Rights Act). We will also engage with these stakeholders to arrange access.

The project will also engage with traditional owners to share knowledge about the project and the planned field activities. This will inform the environmental data collection and interpretation process, as well as allowing cultural values to be considered. The project team will initially engage with the Northern Land Council (NLC) to identify stakeholders and define an appropriate process for this engagement.

Communicating the intent of this research project and its findings to community stakeholders has been identified as highly important for the success of this project. The project team will leverage the resources of the GISERA communication team throughout the lifecycle of the project to ensure that appropriate communication materials are developed, and stakeholder engagement takes place.

Part 2: Desktop studies and field trip planning:

This first phase of the research will be to gather existing data on the Hot Valley Springs and refine the plan for field studies.

- Conduct a desktop study to develop more comprehensive fault architecture/fluid flow path models integrating industry seismic reflection data, other geophysical data, satellite remote sensing & other associated relevant mineral data as to define the field work zones of interest.
- Compile existing geochemistry, hydrochemistry and gas emissions data.
- Review existing ecological data.

These datasets will be used to refine conceptual models for the springs in the Hot Spring Valley and to optimise the planned field work. Planning of logistics for the field trip will also be done at this stage so that stakeholders can be informed and to limit the disturbance of the field work on land holder's activities.

Part 3: Field studies:

A single field campaign is planned. This field trip will involve:

- Intensive field geological mapping of the fault segments and outcrops in the Hot Spring Valley guided by the mapping provided above and comprehensive atmospheric gas sampling, investigation of paleo leakages recorded in rock concretions and fractures, joins and fault zones (including laboratory characterisation via microscopy, XRD, XRF, trace element characterisation, radiogenic dating (Uranium-Thorium or Uranium-Lead) and stable isotope methods). This approach will document the natural evolution of the fault-controlled circulation and provide a baseline of the natural fluctuations with time and space before any human activities, providing information recorded on time scales of ten thousands of years or more.
- Hydrogeochemical and biological baseline characterisation of the source of actual gas seepages. Both gas phase and water phases will be sampled. The samples will be analysed for a wide range of hydrochemical, gaseous (headspace and dissolved) and isotopic parameters to determine the gas source (e.g., biological versus geologic) and the origin of spring water. Each parameter provides a valuable piece of information. For example, hydrochemistry combined with Sr and Li isotopes can be used as a tracer to understand interaction of water with different lithological materials. Other parameters can indicate long water residence times and the presence of deep connectivity pathways (e.g., ^{14}C, ^{36}Cl and stable and radioactive noble gases) or interaction with coal and other organic material (e.g., headspace and dissolved gas analysis, microbiology and hydrocarbon concentrations). The added benefit of incorporating gas sampling at this early stage is that the dataset will extend the baseline greenhouse gas data. This is important even if the source of the methane and ethane was found to be biological, as providing a strong benchmark of the baseline levels is necessary to track any industry impact irrespective of the source.
- Biological baselining, which will include 16S rDNA profiling of microbial communities. To do this, the project will collect spring water samples into collection bottles containing a preservative, followed by DNA extraction, PCR amplification of the 16S rRNA region of the genomes of microbes contained therein, after which massive DNA sequencing will be completed on the amplicons. The analysis of the sequenced amplicons essentially result in a list of prokaryotic (bacterial and archaeal) taxa, and their abundance, that are detected at sites were springs emerge at the surface. Such data can be used to determine connectivity belowground and provide insights into biological and geochemical processes which predominant subsurface and complement the hydrochemistry and isotopes data collection. For example, microbial communities can provide information about the dominant forms of metabolism belowground (e.g., sulfur or nitrate reduction or methanogenesis). In addition, microbes can also be thought of as biosensors which respond rapidly to relatively modest

changes in their environment. As such, it is important to baseline these communities prior to development of any potential gas industry in the region.

- Comprehensive atmospheric and groundwater sampling and characterisation of the flux from gas bubbles across the Hot Springs region. Floating flux chambers will be used to quantify the methane and ethane emission rates from the springs. Atmospheric methane and ethane concentration measurements will also be collected in the Hot Springs Valley region.
- Terrestrial ecology survey to determine the water-dependent terrestrial species that occur in the region (i.e., those species that live in terrestrial environments but depend on regular access to the water from the springs to persist in the area). This work will involve on-site bird, mammal, reptile and frog surveys that will be carried out using active search methods such as spotlighting and bird surveys and waterhole counts. It will also involve a limited amount of targeted harp trapping to capture echolocating bats.

Part 4: Collation of baseline data from.

The data collected from this project will be incorporated with existing baseline data collected for the Hot Springs Valley region. These data will be made publicly available. The project may also incorporate cultural knowledge as part of the baseline description of the springs in accordance with the wishes of traditional owners.

Part 5 Integration and data interpretation

The data collected in this project will be integrated to develop conceptual models of potential gas and water connectivity pathways across the Hot Springs region. Previous hydrogeological investigations within the Beetaloo Sub-basin and other sedimentary basins in Australia where resource exploration or development occurs demonstrated the value of applying approaches that integrate multiple lines of evidence (e.g., geophysics, geological mapping, hydrochemistry and isotopes). These integrated approaches allow to test and refine conceptual hydrogeological models of potential hydrogeological connectivity pathways between gas reservoirs, aquifers and springs (e.g., Flook et al., 2020; Frery et al., 2022; Raiber et al., 2022). In this stage, we integrate pre-existing historical data and knowledge with data collected during the field campaign to improve the hydrogeological conceptualisation of springs in the Hot Springs Valley. This will involve:

- Development of chemical and gaseous geothermometers based on hydrochemical (water and gas phases) and isotopic data collected during previous stages. These are commonly used in geothermal systems to estimate reservoir temperature and depth.
- Integration of data from multiple lines of evidence (atmospheric survey data, geophysics, geology, geochemistry and hydrochemistry and environmental tracers).
- Development of conceptual models (e.g., as annotated 2D cross-sections, maps and 3D block diagrams) that describe potential hydrogeological connectivity pathways, source of methane and ethane and origin of geothermal spring water.

- Identification of on-going data and knowledge gaps to inform future groundwater management.

The project will use this new hydrogeological conceptualisation of the springs to consider the potential for impacts due to gas development. The causal network developed for the Beetaloo Sub-basin developed in the GBA program will be used as a basis to explore the potential for onshore gas development activities to interact with the springs in the Hot Springs Valley area. This analysis will not be a risk assessment as that would require details of development activities and mitigation approaches and these are hypothetical at this point in time.

3. Project Inputs

Resources and collaborations

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Cindy Ong	55 days	GHG emission, remote sensing	29 years	CSIRO
Ema Frery	74 days	Structural geology, carbonate characterisation (including geochemistry and absolute dating)	18 years	CSIRO
Cameron Huddlestone-Holmes	20 days	Geoscience, resource development	25 years	CSIRO
Matthias Raiber	30 days	Geology, hydrogeology and hydrochemistry (including environmental tracers)	18 years	CSIRO
Margaux Dupuy	35 days	Water chemistry and isotope sampling and interpretation	6 years	CSIRO
Axel Suckow	20 days	Noble gas sampling, analysis & interpretation	30 years	CSIRO
Charles Heath	20 days	GHG emissions	+10 years	CSIRO
Jelena Markov	15 days	Geophysics modelling & data integration	+10 years	CSIRO
Punjehl Crane	10 days	Noble gas analysis	5 years	CSIRO
Chris Pavey	15 days	Ecology	30 years	CSIRO
Carla Mariani	5 days	Molecular biology	5 years	CSIRO
David Midgley	2.5 days	Microbial ecology and bioinformatics	+20 years	CSIRO
Nai Tran-Dinh	2.5 days	Molecular microbiology	+20 years	CSIRO
Field technician	16 days	Fugitive emission field technician	+10 years	CSIRO

Subcontractors (clause 9.5(a)(i))	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Routine water chemistry analyses	N/A	Routine analytical services.	Many, commercial laboratory	To be determined.
Specialist analytical services for rock samples	N/A	Specialist analyses of rock samples.	Many, specialist laboratory	To be determined.
Specialist analytical services for water samples	N/A	Specialist analysis of water samples for environmental tracers.	Many, specialist laboratory	To be determined.

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 leader and a group of different stakeholders as appropriate which may include:

- Representative(s) from the Flora and Fauna Division, NT Department of Environment, Parks and Water Security
- Representative from the Water Resources Division, NT Department of Environment, Parks and Water Security
- Representative from the NT Geological Survey
- Representative from the Petroleum Operations Group, NT Department of Industry, Trade and Tourism
- Indigenous groups
- Company representatives
- Technical expertise in hydrogeology, geology, ecology and anthropology.

Budget Summary

Source of Cash Contributions	2022/23	2023/24	2024/25	2025/26	% of Contribution	Total
GISERA	$0	$179,258	$369,113	$0	80%	$548,370
- Federal Government	$0	$119,206	$245,460	$0	53.2%	$364,666
- NT Government	$0	$48,848	$100,583	$0	21.8%	$149,431
- Santos	$0	$11,204	$23,070	$0	5%	$34,273
Total Cash Contributions	**$0**	**$179,258**	**$369,113**	**$0**	**80%**	**$548,370**

Source of In-Kind Contribution	2022/23	2023/24	2024/25	2025/26	% of Contribution	Total
CSIRO	$0	$44,814	$92,278	$0	20%	$137,093
Total In-Kind Contribution	**$0**	**$44,814**	**$92,278**	**$0**	**20%**	**$137,093**

TOTAL PROJECT BUDGET	2022/23	2023/24	2024/25	2025/26	-	TOTAL
All contributions	$0	$224,072	$461,391	$0	-	$685,463
TOTAL PROJECT BUDGET	**$0**	**$224,072**	**$461,391**	**$0**	**-**	**$685,463**

4. Communications Plan

Stakeholder	Objective	Channel (e.g. meetings/media/factsheets)	Timeframe (Before, during at completion)
Regional community stakeholders including, landholders, and traditional owners and the wider public	To communicate project objectives, key messages and findings from the research	A fact sheet at commencement of the project, which explains in plain English the objective of the project.	At project commencement
		Engagement with local Aboriginal people and other regional community stakeholders about the planned research activities – this is integral to Task 1 of the project.	At project commencement
		Project progress reported on the GISERA website to ensure transparency for all stakeholders including regional communities.	Ongoing
		Sharing of research findings with regional community stakeholders. This may also be done in conjunction with other GISERA community engagement activities.	At completion of the project.
		Public release of final reports. Plain-English fact sheet summarising the outcomes of the research.	At project completion
		Preparation of an article for the GISERA newsletter and other media outlets as advised by GISERA's communication team	
Government	To gain background knowledge	Engagement with NT government expertise to capture existing knowledge about the Hot Springs Valley area. Discuss how datasets may be incorporated into existing datasets (SREBA).	At project commencement
Gas Industry & Government	To communicate the final results of the project.	Fact sheet that explains the objective of the project.	At project commencement
		Project progress reporting (on GISERA website)	Ongoing
		Final project report and fact sheet.	At project completion
		Presentation of findings at joint gas industry/government Knowledge Transfer Session	At project completion
Scientific Community	Provide scientific insight into and baseline data on the Hot Springs Valley.	Peer-reviewed scientific publication. Dataset(s) available through CSIRO's data repository.	After completion of project

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

5. Project Impact Pathway

Activities	Outputs	Short term Outcomes	Long term outcomes	Impact
Engagement and access arrangements	• Identification and consultation with key stakeholders • Necessary access arrangements and permits in place • Agreement on ongoing engagement	• Necessary access agreements to conduct field work and research informed by stakeholder views.	• Ongoing protection of the springs in Hot Springs Valley. • Enduring knowledge of the springs and their likely source. • Future monitoring activities will have a baseline for comparison and evaluation of measures put in place to protect the springs in Hot Springs Valley.	The impact of this research will be improved protection and baseline data for monitoring of the environmental of the springs in Hot Springs Valley
Hydrogeological architecture/conceptual modelling	• Compilation of existing data on the springs • Development of a conceptual model and refinement of field work objectives	• Additional baseline data for the Hot Springs Valley to provide a baseline for future monitoring activities. • Conceptual model of likely sources for water and gas discharge at the springs that will allow for strategies to protect them to be refined. • Identification of any remaining uncertainty/knowledge gaps.		
Field campaign: • Geology • Water • GHG • Ecology	• Additional data on the geology, hydrogeology, hydrochemistry, atmospheric emissions and terrestrial ecology to augment existing data sets			
Analyses and reporting	• Improved characterisation of the springs in Hot Springs Valley and their environment • Implications for potential impacts on the springs due to gas development			
Information sharing and communication	• Knowledge transfer session with industry and engagement • Engagement activities with regional communities	• Knowledge and data available about the springs to stakeholders.		

6. Project Plan

Project Schedule

ID	Activities / Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Stakeholder consultation, access and permission (land owners & TO)	Cameron Huddlestone-Holmes	01/09/2023	31/01/2025	-
Task 2	Hydrogeological architecture/fluid flow path models	Ema Frery	01/09/2023	30/04/2024	-
Task 3	Field geology mapping & sampling	Ema Frery	01/07/2024	31/05/2025	Task 1-2
Task 4	GHG survey, analysis & interpretation	Cindy Ong	01/05/2024	31/03/2025	Task 1-2
Task 5	Water Sampling, laboratory analysis and interpretation	Axel Suckow and Margaux Dupuy	01/05/2024	31/03/2025	Task 1-2
Task 6	Terrestrial ecology survey, analysis & interpretation	Chris Pavey	01/05/2024	31/03/2025	Task 1
Task 7	Data integration and conceptual model development	Ema Frery and Matthias Raiber	01/09/2024	31/03/2025	Task 1-5
Task 8	Project reporting	Cindy Ong	01/09/2023	31/05/2025	-
Task 9	Communicate findings to stakeholders	Cindy Ong	01/09/2023	30/06/2025	-

Task description

Task 1: Stakeholder consultation, access and permission (land owners & Indigenous engagement)

OVERALL TIMEFRAME: September 2023 – January 2025

BACKGROUND**:** The areas around the Hot Springs Valley has been under a pastoral lease ownership for the past four decades. Further, the area holds significant historical and cultural significance. Therefore, consultation with the relevant stakeholders is an important first step before the research work can commence. Engagement with the current pastoral lease owners to enable access to the areas to be studied is essential. The project team will also obtain any necessary permits or approvals from traditional owners and representative bodies (such as AAPA and the NLC). Communicating the goals and objectives of the research with community stakeholders is of high importance. Engagement with local Aboriginal communities will be undertaken where welcomed. This will enable some knowledge sharing and allow the project team to undertake their research in a culturally sensitive way. This will also assist CSIRO's understanding of the cultural and historical significance of the area, which will help to inform the environmental data collection and interpretation process.

TASK OBJECTIVES:

The objectives of this task are

- Obtain relevant ethics approvals, if required,
- To gain necessary approvals, permits and certificates to access the Hot Springs Valley area and conduct the planned field activities from land holders and traditional owners; and,
- Engage with traditional owners to understand the cultural and historical significance of the Hot Springs Valley and to share information about the objectives of this project.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- All necessary approvals, permits and certificates to access the study site and to complete the planned field work.
- An understanding of the traditional owners the Hot Springs Valley.

Task 2: Hydrogeological architecture/conceptual fluid flow paths model

OVERALL TIMEFRAME: September 2023 – April 2024

BACKGROUND: The Hot Spring Valley is located along the northern part of the major fault systems of the OT Downs fault zone that is bounding the northern part of the eastern Beetaloo Sub-basin. These regional fault systems are likely to have accommodated episodes of fluid flow as old as 1645-1640 My and are targeted for mineral exploration as potential fluid pathways for ascending metalliferous brines. They are likely to have been reactivated through the more recent tectonic history of the region with current hot springs such as Lagoon Creek springs and Beauty Creek springs (Frery et al., 2022). There are existing geological, geophysical and hydrogeological data that can be compiled and interpreted in a desktop study to develop conceptual models that allow for targeted field data collection. There is existing knowledge with Northern Territory Government about the Hot Springs Valley.

TASK OBJECTIVES: Conduct a desktop study to develop more comprehensive hydrogeological architecture/fluid flow path models integrating existing geological, geophysical, satellite remote sensing & other associated relevant data as to define the field work zones of interest. This task will also involve compilation of all existing Hot Springs Valley data (e.g., hydrogeology and hydrochemistry) and engagement with Northern Territory Government staff to capture as much existing information as possible.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- Compiled dataset and hydrogeological architecture/fluid flow path conceptual model for the springs of the Hot Spring Valley.
- Field work plan for additional data collection.

Task 3: Field geology mapping, sampling and rock analysis

OVERALL TIMEFRAME: July 2024 – May 2025

BACKGROUND: Mapping the geology around the springs will allow the geological setting to be constrained through understanding the stratigraphy and structural history (faulting and fracturing) associated with the springs. Carbonate rock concessions associated with fossil seeps are records of paleoclimatic and paleotectonic events (Altunel and Hancock, 1993; Frery et al., 2017). These rocks, called travertines are calcium carbonate agglomerates known to be built under near ambient conditions in continental areas (Capezzuoli et al.,2014). They can be studied to unravel the source of the paleo-leaky gas and fluids (stable isotopes) and well as the timing of circulation (absolute dating).

TASK OBJECTIVES: Document the geology of the Hot Springs Valley area, the current geological setting of the springs and the natural evolution of structural controls on circulation to provide a baseline understanding of the natural fluctuations with time and space.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- Interpreted geological map of the Hot Springs Valley area.
- Laboratory characterisation of rocks sampled in the mapped zones, the characterisation method will be defined based on the characteristics of the rock sample recovered in the field.

Task 4: GHG survey, analysis & interpretation

OVERALL TIMEFRAME: May 2024 – March 2025

BACKGROUND: The results of a recently completed SREBA project indicated elevated and correlated methane and ethane concentration above the bubbles at the Hot Spring near Clints Gorge. While the presence and correlated nature of methane and ethane does not necessarily indicate that the source is thermogenic, as biogenic methane and ethane may also be possible, irrespective of its origin, the quantification of the natural emissions pre-development is essential benchmark. The work conducted for SREBA was limited due to the limited access and time hence there remains a gap in baseline emissions for the Hot Springs Valley. Specifically, only one hot spring was visited and sampling limited to the small area where bubbles were found. In addition, no emission rate measurement were collected.

TASK OBJECTIVES:

The objectives of this task are

- Comprehensive characterisation of the atmospheric methane and ethane (where relevant & within detection limit) concentration surrounding up to 5 hot springs;
- Comprehensive characterisation of emission rates at bubble locations for up to 5 hot springs;

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- Baseline atmospheric methane and ethane (where relevant & within detection limit) vector maps for each hot springs visited;
- Baseline emission rates vector maps for each hot springs visited.

Task 5: Water Sampling, laboratory analysis and interpretation

OVERALL TIMEFRAME: May 2024 – March 2025

BACKGROUND: Previous water and dissolved gas sampling programmes in the Beetaloo Sub-basin region focussed on the characterisation of groundwater within the Cambrian Limestone Aquifer (CLA) and the characterisation of the source of the Mataranka springs (e.g., Deslandes et al. 2019; Lamontagne et al. 2021). However, only a limited understanding of the source aquifer of geothermal springs in the Hot Spring Valley and their connections to, or isolation from, gas reservoirs exist at present (e.g., ELA, 2022; Frery et al., 2022). The groundwater sampling in this project focusses on closing these important knowledge gaps through the collection and analysis of spring samples for a wide range of hydrochemical, gaseous and isotopic parameters from Hot Springs valley. This will provide an important baseline data set to benchmark the present state to help track any changes should they occur. This will also help to better understand the origin of gas and hydrogeological connectivity pathways. We will compare the existing and newly collected analytical results from Hot Springs Valley with those of Mataranka Springs and other spring systems in the Beetaloo Sub-basin as a useful reference point for the baseline of the different spring complexes in this region.

Upon completion of the field sampling campaign, spring water and gas samples will be analysed at well-established national and international laboratories. For example, stable noble gases will be analysed at the CSIRO Environmental Tracer laboratory in Adelaide, whereas samples for other hydrochemical and isotopic parameters will be analysed at commercial laboratories in Australia and overseas (e.g., Canada, United States of America and New Zealand).

TASK OBJECTIVES:

The first objective of this task is the collection of samples from up to 5 groundwater springs in Hot Spring Valley. Samples will be collected for a wide set of parameters, including:

- Major, minor and rare earth element chemistry
- Isotopes (stable isotopes (H, O and C), $^{87}Sr/^{86}Sr$, Li-6/Li-7, boron isotopes)
- Hydrocarbon concentrations
- Headspace and dissolved gas analysis: this includes N_2, CO_2, O_2, Ar, H_2, He, CH_4, C_2H_6, C_3H_8, i-C_4H_{10}, n-C_4H_{10}, i-C_5H_{12}, n-C_5H_{12} and C^{6+} (all in headspace), and quantification of CH_4 (methane), C_2H_6 (Ethane) and C_3H_8 (propane) dissolved in water, as well as ^2H and $^{13}C/^{12}C$ analysis of methane, ethane and propane isotopes (if present), ^{13}C and ^{18}O of CO_2 and dissolved hydrogen sulphide (H_2S).
- Stable noble gases concentrations and isotope ratios (He, Ne, Ar, Kr, Xe)
- Age tracers (e.g., tritium, carbon-14 and ^{36}Cl)
- Radioactive noble gases (^{39}Ar, ^{81}Kr, ^{85}Kr)
- 16S rDNA microbial community profiling

The second objective of this task is to complete the analysis of spring water samples in Hot Springs Valley. Once the results have been supplied by laboratories, the new data will be integrated with results from previous investigations using multiple complementary graphical and statistical techniques to characterise the source of gas and the origin of water in the assessed spring complexes. The analysis of the different parameters will allow to refine the understanding of hydrogeological connectivity pathways.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- Samples are collected from up to 5 springs for a wide range of baseline hydrochemical, gas and isotope parameters from springs in Hot Springs Valley;
- Baseline hydrochemistry and environmental tracer data sets for the parameters listed above; and,
- Interpretation of hydrochemical and tracer data to characterise source aquifer of springs, differentiate between gas source and determine hydrogeological connectivity pathways.
- Interpretation of microbial community data to examine linkages between spring samples, microbial community descriptive statistics and descriptions of the dominant microbial processes that occur in the springs.

Task 6: Terrestrial ecology survey, analysis & interpretation

OVERALL TIMEFRAME: May 2024 – March 2025

BACKGROUND: The GBA BESA and SREBA studies conducted aquatic ecology surveys at Clint's Gorge in the Hot Springs Valley area. Terrestrial ecology has not been studied in as much detail. Documenting the terrestrial species that rely on the springs is an important component of the baseline assessment.

TASK OBJECTIVES:

The objectives of this task are:

- Summary of existing ecological baseline data; and
- Conduct a terrestrial ecology survey to determine the water-dependent terrestrial species that occur in the region.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

- Baseline of ecological data for the Hot Springs Valley area focussing on species that rely on the springs.

Task 7: Data integration and conceptual model development

OVERALL TIMEFRAME: September 2024 – March 2025

BACKGROUND: Conceptual 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 pathways relies on the integration of multiple lines of evidence. This includes for example integration of geological and geophysical methods that characterise the geometry of the subsurface with chemical, hydrochemical, microbiological and environmental tracer data that provide an understanding of the composition of atmospheric and dissolved gases and groundwater. Although previous water and gas sampling has been conducted on springs in the Beetaloo Sub-basin region, most of this work has focussed on the Mataranka Springs and only limited data are available for springs in Hot Springs Valley.

TASK OBJECTIVES: The data and knowledge from previous studies and Tasks 1 to 5 of this project will be integrated to develop and test conceptual models of hydrogeological connectivity pathways between deeper formations and the springs in the Beetaloo Sub-basin. The integration of data from multiple lines of evidence (atmospheric survey data, geophysics, geology (including surface mapping and rock characterisation), hydrochemistry and environmental tracers) will provide valuable insights into connectivity pathways and source aquifer (or aquifers) of groundwater and gas (methane and ethane) in Hot Springs Valley. Options for monitoring of the springs and their water sources will also be considered. Monitoring could include periodic observation, flow gauges or monitoring bores.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Conceptual hydrogeological models (e.g., via annotated cross-sections, maps and simple 3D block diagrams) of springs and connectivity pathways in Hot Springs Valley 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. As currently only limited deep borehole infrastructure is available to hydrochemically characterise different aquifers and gas reservoirs, this assessment may not be able to resolve all knowledge gaps; however, it will provide critical baseline data and through identification of on-going data and knowledge gaps will help to support groundwater management and monitoring, future groundwater infrastructure decisions, and greenhouse gas monitoring programs.

Task 8: Project Reporting

OVERALL TIMEFRAME: September 2023 – June 2025

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

TASK OBJECTIVES: To ensure that the information generated by this project is documented and published after thorough CSIRO internal review.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

1. Preparation of a final report outlining the scope, methodology and findings;
2. Preparation of datasets for publication through CSIRO's data portal;
3. Following CSIRO ePublish review, the report will be submitted to the GISERA Director for final approval; and
4. Provide 6 monthly progress updates to GISERA office.

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

OVERALL TIMEFRAME: Full duration of project

BACKGROUND: Communication of GISERA research is an important component of all 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.

Specific communication and engagement activities will be undertaken with local community stakeholders to address their communication needs and interests. These are likely to include visits to local communities and development of targeted communication materials.

TASK OBJECTIVES: Communicate project objectives, progress and findings to stakeholders through meetings, knowledge transfer session, fact sheets and journal articles, in collaboration with GISERA Communication officers.

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. Engagement with an established technical reference group.
2. 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.
3. Project reporting
4. Knowledge Transfer session with Government/Gas Industry
5. Presentation of findings to community stakeholders such as business and/or community groups in a community forum (virtual or face-to-face) to learn of research results.
6. Preparation of article for the GISERA newsletter and other media outlets as advised by GISERA's communication team
7. Peer reviewed scientific manuscript ready for submission to relevant journal

Project Gantt Chart

		2023/24										2024/25											
Task	**Task Description**	**Sep 23**	**Oct 23**	**Nov 23**	**Dec 23**	**Jan 24**	**Feb 24**	**Mar 24**	**Apr 24**	**May 24**	**Jun 24**	**Jul 24**	**Aug 24**	**Sep 24**	**Oct 24**	**Nov 24**	**Dec 24**	**Jan 25**	**Feb 25**	**Mar 25**	**Apr 25**	**May 25**	**Jun 25**
1	Stakeholder consultation, access and permission	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
2	Hydrogeological architecture/fluid flow path models	■	■	■	■	■	■	■	■														
3	Field geology mapping & sampling											■	■	■	■	■	■	■	■	■	■	■	
4	GHG survey, analysis & interpretation									■	■	■	■	■	■	■	■	■	■	■			
5	Water Sampling, laboratory analysis and interpretation									■	■	■	■	■	■	■	■	■	■	■			
6	Terrestrial ecology survey, analysis & interpretation									■	■	■	■	■	■	■	■	■	■	■			
7	Data integration and conceptual model development													■	■	■	■	■	■	■			
8	Project reporting	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
9	Communicate findings to stakeholders	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

7. Budget Summary

Expenditure	2022/23	2023/24	2024/25	2025/26	Total
Labour	$0	$165,072	$350,791	$0	$515,863
Operating	$0	$59,000	$45,600	$0	$104,600
Subcontractors	$0	$0	$65,000	$0	$65,000
Total Expenditure	**$0**	**$224,072**	**$461,391**	**$0**	**$685,463**

Expenditure per task	2022/23	2023/24	2024/25	2025/26	Total
Task 1	$0	$73,946	$14,972	$0	$88,918
Task 2	$0	$65,023	$0	$0	$65,023
Task 3	$0	$0	$58,585	$0	$58,585
Task 4	$0	$21,542	$57,289	$0	$78,831
Task 5	$0	$29,257	$98,331	$0	$127,588
Task 6	$0	$10,006	$33,919	$0	$43,925
Task 7	$0	$0	$79,529	$0	$79,529
Task 8	$0	$24,298	$108,794	$0	$133,092
Task 9	$0	$0	$9,972	$0	$9,972
Total Expenditure	**$0**	**$224,072**	**$461,391**	**$0**	**$685,463**

Source of Cash Contributions	2022/23	2023/24	2024/25	2025/26	Total
Federal Govt (53.2%)	$0	$119,206	$245,460	$0	$364,666
NT State Govt (21.8%)	$0	$48,848	$100,583	$0	$149,431
Santos (5%)	$0	$11,204	$23,070	$0	$34,273
Total Cash Contributions	**$0**	**$179,258**	**$369,113**	**$0**	**$548,370**

In-Kind Contributions	2022/23	2023/24	2024/25	2025/26	Total
CSIRO (20%)	$0	$44,814	$92,278	$0	$137,093
Total In-Kind Contributions	**$0**	**$44,814**	**$92,278**	**$0**	**$137,093**

	Total funding over all years	Percentage of Total Budget
Federal Government investment	$364,666	53.2%
NT Government investment	$149,431	21.8%
Santos investment	$34,273	5%
CSIRO investment	$137,093	20%
Total Expenditure	**$685,463**	**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	Stakeholder consultation, access and permission (land owners & TO)	GISERA	Sep-23	Jan-25	2024/25	$71,134
Task 2	2.1	Hydrogeological architecture/fluid flow path models	GISERA	Sep-23	Apr-24	2023/24	$52,018
Task 3	3.1	Field geology mapping & sampling	GISERA	Jul-24	May-25	2024/25	$46,868
Task 4	4.1	GHG survey, analysis & interpretation	GISERA	May-24	Mar-25	2024/25	$63,065
Task 5	5.1	Water Sampling, laboratory analysis and interpretation	GISERA	May-24	Mar-25	2024/25	$102,070
Task 6	6.1	Terrestrial ecology survey, analysis & interpretation	GISERA	May-24	Mar-25	2024/25	$35,140
Task 7	7.1	Data integration and conceptual model development	GISERA	Sep-24	Mar-25	2025/26	$63,623
Task 8	8.1	Project reporting	GISERA	Sep-23	May-25	2025/26	$106,474
Task 9	9.1	Communicate findings to stakeholders	GISERA	Sep-23	Jun-25	2024/25	$7,978

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	
	Santos		N/A	

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