Australia's National Science Agency

GISERA | Gas Industry Social and Environmental Research Alliance

Project Order

Short Project Title

Baseline Groundwater and Seismicity of northern Perth Basin

Long Project Title	Establishing Baseline Groundwater and Natural Seismicity levels across the northern Perth Basin with Passive Seismic Data
GISERA Project Number	W.34
Start Date	01 March 2024
End Date	15 January 2026
Project Leader	Erdinc Saygin, Mehdi Qashqai, Peng Guo

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

In this project, we will employ non-invasive (drill-free) methods to monitor both seismicity (the occurrence and distribution of earthquakes) and groundwater depths (hydraulic head, measured in meters) at which the ground is saturated with water. These methods utilize seismic waves to detect subtle subsurface rock property changes primarily driven by fluctuations in groundwater depths within alluvial and confined aquifers, using passive seismic methods with temporal resolution as fine as days. Additionally, by integrating this rich dataset and the in-house developed subsurface monitoring techniques, we will not only detect and locate seismic activity but also assess annual variations. The primary objective is to distinguish between natural and anthropogenic factors causing variations in groundwater depths, seismic activity, and provide valuable actionable insights such as water use management for the agricultural community, resources sector and regulators.

2. Project description

Introduction

The northern Perth Basin stretches about 450 km from north to south and up to 90 km from west to east. The basin covers about 35,000 km^2, making up three-quarters of the onshore Perth Basin (Department of Water, 2017). The region hosts numerous resource exploration activities, including active natural gas production sites as well as extensive agricultural activities that rely on groundwater resources for their operations. The natural gas extraction technologies place stress on water resources and have the potential to induce seismic activity, which will raise concerns within the local community.

Prior Research

The report prepared by the Department of Water in 2017 provides an excellent, detailed account of all previous studies in the northern Perth Basin aimed at understanding geology, hydrogeology, and groundwater resources, including groundwater depth and changes over an extensive period of time. In-situ water level measurements were conducted by the department using around 600 monitoring boreholes across whole Perth Basin, with readings taken two to six times a year. Numerical modelling has also been employed to establish groundwater depth trends. For satellite studies, Parker et al. (2017) used Interferometric Synthetic Aperture Radar (InSAR) data and mapped ground subsidence of up to 15 mm per year due to groundwater extraction between 2015 and 2016 in the Perth Basin. A subsequent study carried out by Castellazzi and Schmid (2021) investigated three different Australian basins, including the South Perth Basin, using InSAR data to characterise non-groundwater deformations and other sources of noise. After accounting for all the other potential effects, they concluded that InSAR provides valuable insights for large-scale groundwater management in

Australia. In this project, using continuously recorded seismic waves, we will monitor groundwater changes with much higher fidelity compared to the temporally sparse measurements conducted by the Department of Water. Furthermore, despite having equally high resolution, InSAR-based measurements only measure changes on the surface and cannot provide direct constraints for the physical mechanisms that is happening beneath the surface.

Seismicity refers to the occurrence, distribution, and behaviour of earthquakes within a particular region or area. It is the measure of seismic activity and the study of how earthquakes, i.e., ground shaking and fault movements, occur over time. Seismicity can vary from one location to another and can be influenced by tectonic plate boundaries, geological conditions, and other factors such as resource exploration activities. It is typically measured and analysed using instruments called seismometers (seismic stations), which record the ground motion.

The seismicity of the basin remains poorly documented due to the limited historic coverage by seismic stations. With the inclusion of data from a series of recently deployed seismic arrays by the Geological Survey of Western Australia (GSWA), we anticipate a significant improvement in this regard. A recent study by Miller et al. (2023) demonstrated a significant increase in the detection of small magnitude events in the South-West of Western Australia due to the deployment of a temporary seismic array. However, instrumental coverage is still relatively sparse in the northern Perth Basin. This project will address this issue by utilising dense seismic data from GSWA to build a baseline catalogue of natural seismic activity. This catalogue can be used to create seismic hazard maps, assess earthquake risks, and gain a better understanding of the internal structure of the Earth and the forces that lead to earthquakes. Seismicity is often expressed in terms of earthquake magnitude and frequency. Regions with high levels of seismicity are more prone to experiencing earthquakes, and understanding the seismicity of a particular area is essential for earthquake preparedness and developing plans for risk mitigation. Governments can use this information to get advice on seismic hazards that could affect infrastructure projects and new development.

Need & Scope

The energy and mining sectors demand significant volumes of water annually for tasks such as pumping, cooling, cleaning, and processing. This places considerable strain on existing water resources and can lead to conflicts between these sectors and farmers. A report by McKinsey & Co (Delevingne et al., 2020) forecasts that by 2040, several regions including parts of northern Perth Basin and adjacent regions in Western Australia may experience water stress with varying degrees due to the extensive activities of the resource sector (Figure 1). Therefore, it is imperative to establish observation methods and report values in preparation for the anticipated surge in activity.

Figure 1*: Projected water stress level for Australia and surrounding regions by 2040 due to mining activities. Modified from McKinsey & Co (Delevingne et al., 2020).*

The traditional method for monitoring groundwater tables is through hydraulic head measurements, which directly gauge the water levels in specific aquifer layers. However, these point-scale head measurements are often too sparse in time or space to adequately capture variations in highly non-uniform aquifer systems (Mao et al., 2022). While drilling boreholes is a common approach, it is both invasive and expensive. Additionally, other geophysical and remote sensing methods can be employed, but they tend to be costly and may not provide sufficient temporal and spatial constraints due to limited sampling. Seismic waves recorded with seismograph arrays offers a cost-effective non-invasive approach to monitor time dependent variations of the water level at different depths. In essence, there is a robust correlation between fluctuations in seismic velocity that have been observed and variations in the depth of the water table. These fluctuations primarily arise from changes in pore pressure and bulk density within the near-surface materials (Qin et al., 2022).

The Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia (2018) stated that it is important to have a baseline of natural earthquake activity before unconventional gas extraction activities are started to ensure that any industrial activities are not seen to be producing excessive seismic activity. In background seismicity monitoring, it is crucial to map the complete distribution of the seismic activity (small to large magnitude earthquakes) to understand the behaviour of the earthquake activity levels. Once an earthquake catalogue is compiled based on observations, statistical analyses are performed to estimate the recurrence rates of any future seismic activity.

Meanwhile, the background earthquake activity of the basin is largely unknown. A recent study by Miller et al. (2023) improved significantly the detection of background seismicity of the Southwest Australia (Figure 2) by deploying and operating a sparse seismic network, in which the newly detected events were not registered previously by older permanent networks. However, the basin itself has very sparse instrumental coverage (Figure 2-diamonds), which fails to detect small magnitude events.

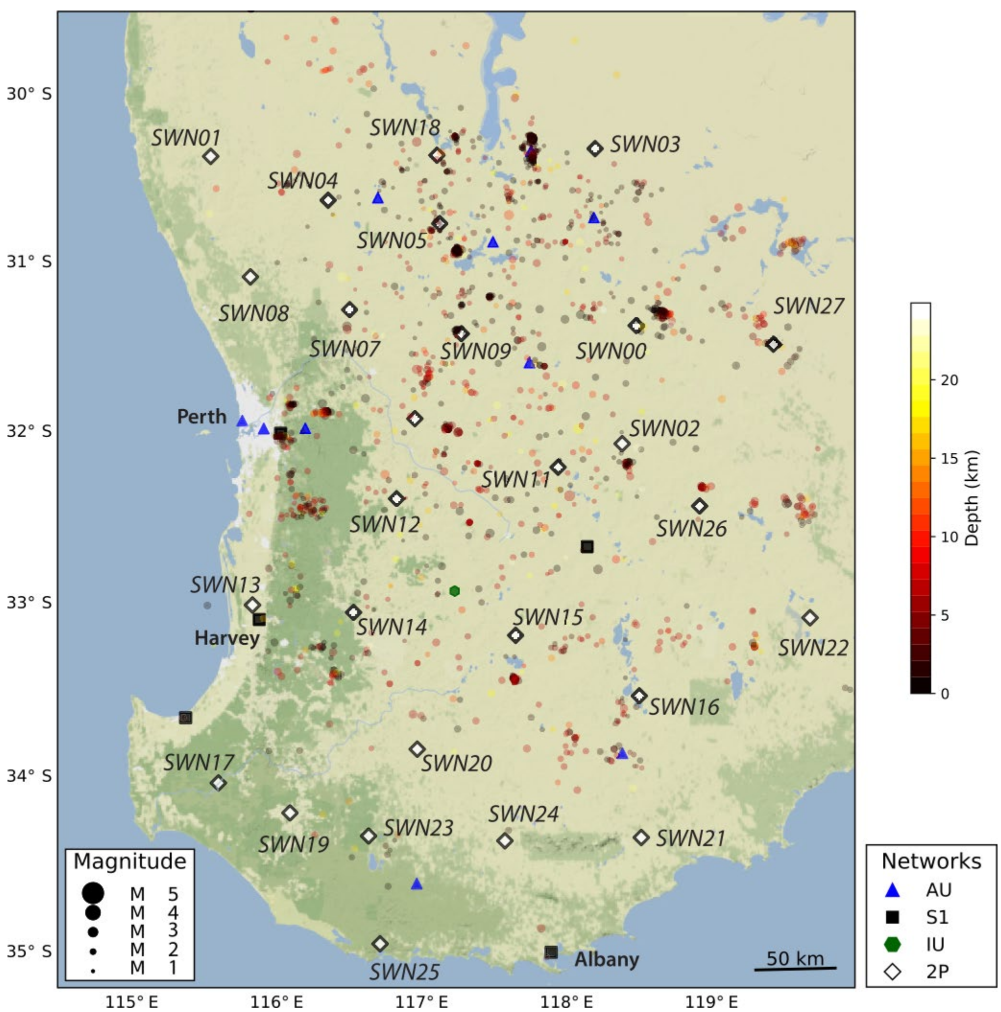

Figure 2 *A recent study by Miller et al. (2023) detected several new events (colored circles) with varying magnitudes between mid 2020 and end of 2021 by using a new temporary regional seismic array (white diamonds) – 2P. Note the large gaps in sensor coverage around northern Perth Basin and the lack of detected seismicity.*

Any information gap in the input data has the potential to distort the results. Figure 3 illustrates the impact of missing information of earthquake magnitudes in the curve fitting process, where the missing data significantly alters the predictive power of the analysis for estimating future earthquake activity.

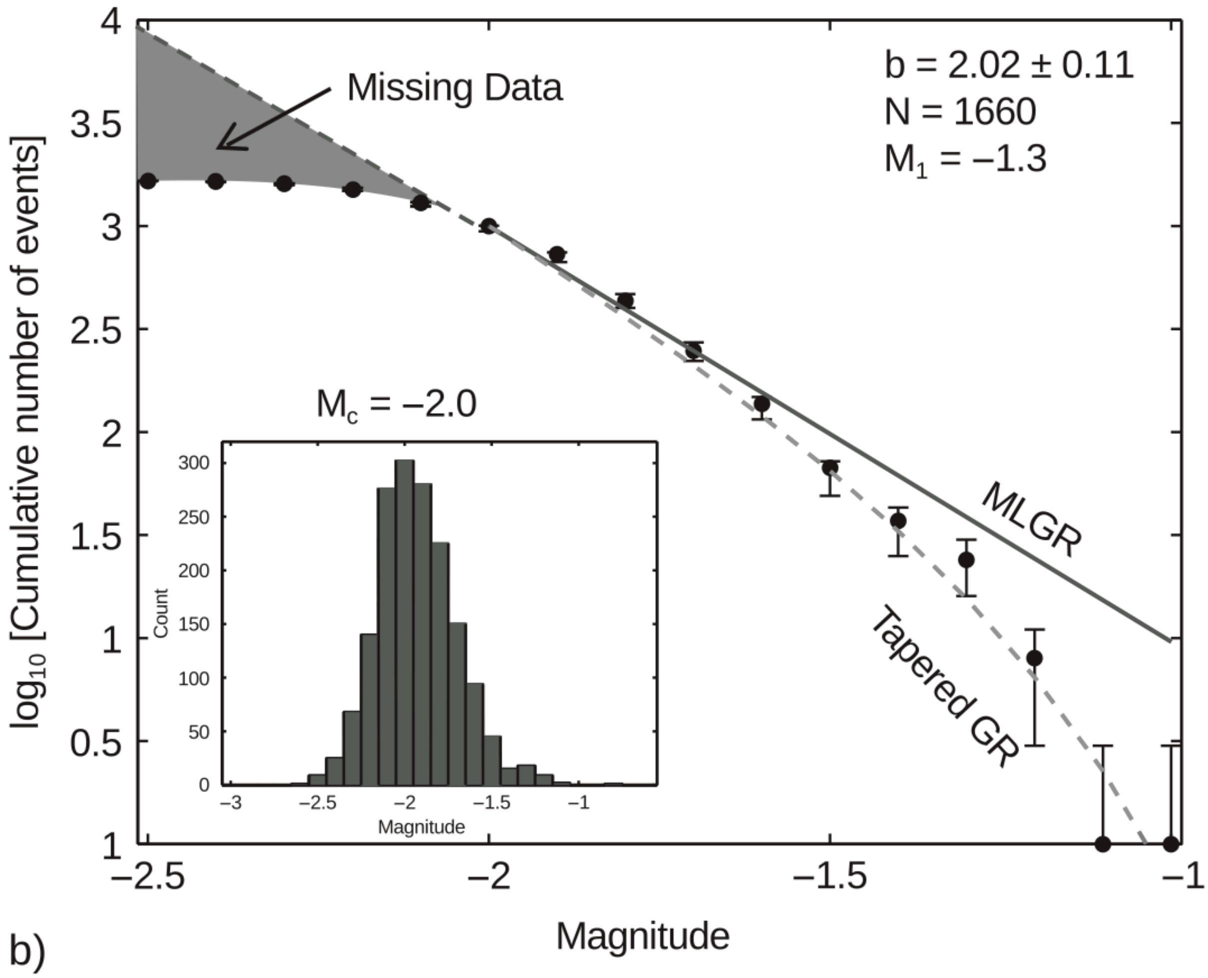

Figure 3 *The distribution of cumulative number of earthquake events as a function of their magnitude. In the top left, the missing low magnitude earthquakes changes the slope of the fitted curve and affects the predictive power of this analyses (Eaton, 2018).*

With the addition of the new passive seismic dataset from GSWA seismic networks, this project will provide important and transparent information to the community and regulators about the current earthquake activity. This information can be used to compare future seismic events and determine whether they are consistent with the current background activity in the northern Perth Basin.

Objective

We aim to measure the seasonal and spatial fluctuations of the hydraulic head of water in aquifers and background seismic activity in the northern Perth Basin using the statewide dense passive seismic data currently being acquired from the seismic array deployed by the Geological Survey of Western Australia (GSWA) (refer to Figure 4). This will run for over one year.

This project will provide data on the current level of variation in groundwater depth, which will provide context against which future variation (both natural and man-made) will be able to be compared against. At a time when demand for groundwater resources for mining, petroleum, agriculture, communities and environment is increasing, this dataset will become important information for successful management of this resource.

Monitoring background seismic activity involves employing a variety of techniques and technological resources to identify and pinpoint or locate seismic events. However, distinguishing between naturally occurring seismic events and those caused by human activities is often quite challenging when there is no extensive record of natural seismic activity as a reference point. Therefore, the primary objective in this project is to create a comprehensive, extended-term catalogue for monitoring seismic activity.

This research will provide stakeholders in the northern Perth Basin with objective and actionable information. Throughout this project, we will closely work with scientists from GSWA and will not collect new field data. This project will also interact with the team of another GISERA project 'Assessment of potential conflicts of subsurface resources development in the North Perth Basin', where our outputs of water level change and seismicity maps will be integrated into their GIS layer.

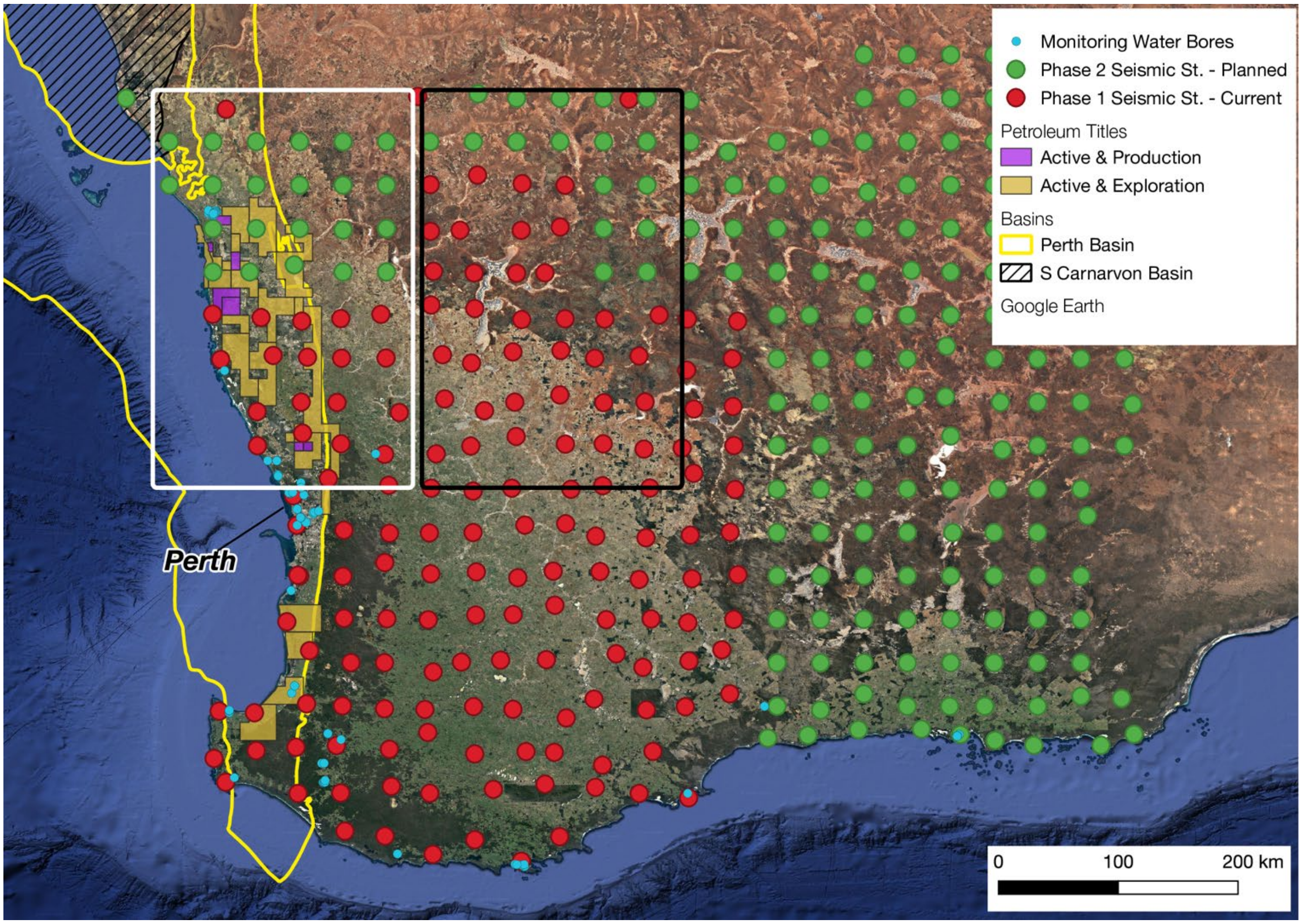

Figure 4 *Current and planned passive seismic station distributions of the Geological Survey of Western Australia in Western Australia. Two rectangles show the regions of interests. White rectangle shows stations that are partially located in North Perth Basin and coinciding with petroleum titles. Black rectangle shows the location of seismic stations that is outside the petroleum titles and will be used as control group. Monitoring water bores are shown with blue circles (Source: Water Corporation).*

Methodology

Seismic waves traversing the Earth on a regular basis carry valuable information from the Earth. These waves result from natural and human-made seismic activity, i.e., earthquakes, and also Earth's own vibrations, which are created through complex interactions between the Earth's atmosphere, ocean and the crust. These waves, during their passage, carry a wealth of information from the physical structure of the Earth.

A descending groundwater table depth will increase the propagation velocity of seismic waves in the subsurface rocks, and vice versa. This can be continuously monitored by analysing the associated changes in the time-lapse seismic waveform. For example, in recent years, it has been well documented that these continuously excited seismic ambient noise waves are capable of detecting groundwater level depth as demonstrated by Clements and Denolle (2018) for the San Gabriel Valley, California, He et al. (2020) for Harvey, South Perth Basin in WA, and more recently by Mao et al. 2022 for California. Figure 5D, using the CSIRO developed geophysical 4D monitoring technique. The common premise underlying these studies is that the passively recorded seismic waves provide changes in the groundwater level depths in a near real time basis. Mao et al. (2022) demonstrated borehole water depth Figure 5B at different depths compared with InSAR Figure 5C.

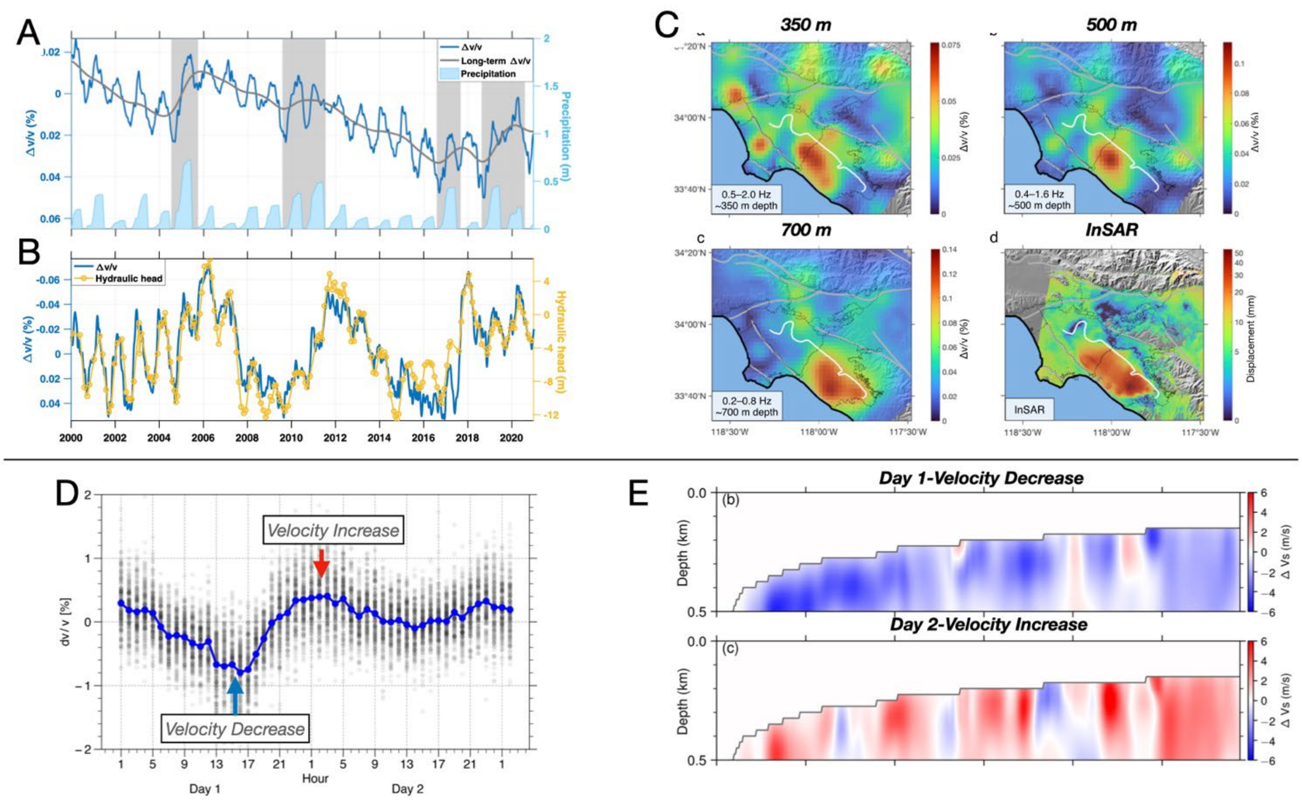

Figure 5 *Examples of subsurface monitoring with passive seismic measurements. Mao et al.(2022) showed that the changes in the seismic velocity ($\Delta v/v$) correlates well with the hydraulic lead (B) and does not necessarily follow precipitation events (A). In C, horizontal slices show the changes of the seismic velocities as function of different depth slices, where the last panel shows the independent estimate from InSAR. Guo et al. (2023) showed that it is possible to image these changes even with a higher temporal (D) and depth resolution (E)-daily changes with depths from surface to 500 m by only using the passive seismic signals.*

Another limiting factor for reliable water head measurements in the northern Perth Basin is the limited number of active monitoring water boreholes, as indicated by the cyan circles in Figure 4. With the data coming from the GSWA WA Array (Figure 4), this project will concentrate on two adjacent regions, as denoted by the coloured rectangles. One of these regions encompasses exploration activity (white rectangle), while the other (black rectangle) serves as a control group where no such activity is present. We will apply the same techniques and methodology to both regions, both of which have different levels of agricultural and resource-related activity. The inferred water levels and detected earthquake activity from both regions will help distinguish the effects of human-made activities.

The project will measure seismic velocity changes caused by fluctuations in groundwater depths and then quantify the relationship between seismic velocity change and groundwater depth variation using the borehole hydraulic head measurement. Eventually, the groundwater depth variations for the whole region will be mapped from the directly measured seismic velocity changes.

With the same dataset, the project will detect seismic activity and any temporal changes. As in the water level depth monitoring case, the project will use both adjacent regions as one of them will work as a control group. Here, state-of-the-art algorithms will be used to detect and locate natural and/or induced seismicity over a relatively long term to establish a regional earthquake catalogue for (induced or natural) seismic monitoring purposes. Induced seismicity typically refers to earthquakes caused by human activities such as hydraulic fracking, geothermal energy production, mining, gas injection and extraction, and CO_2 injection. These activities have been shown to alter the stresses and strains within the Earth's crust, leading to seismic events or earthquakes (Atkinson et al., 2020).

Monitoring induced seismicity involves the application of various techniques and technologies to detect, locate, and analyse seismic events. However, distinguishing between natural seismic activities and induced seismicity is often challenging without the establishment of comprehensive and long-term baseline seismic monitoring catalogues. Therefore, the primary objective here is to create a long-term seismic monitoring catalogue in the absence of earlier baseline data acquisition.

Overall, the project aims to deliver actionable information that effectively conveys the temporal and spatial changes in the region, presented in a clear and comprehensible manner for the stakeholders to take prompt and informed action.

Stage 1 Water Level Monitoring with Passive Seismic Data: The incoming passive seismic data from GSWA will be analysed to map the physical changes in the subsurface mainly caused by the fluctuations of the groundwater table. The following workflows will be applied:

- Preprocess the seismic data that GSWA provide;
- Auto and cross-correlation of the seismic data to map the daily/hourly changes in the seismic velocities beneath each seismic station and also between seismic station pairs;
- Apply wave-equation based seismic imaging to map the seismic velocity changes in 3D as a function of time;
- Conduct modelling to investigate the cause of velocity changes i.e. Water level depth, precipitation, thermal changes and any other physical mechanisms. Also compare the measurements with nearby monitoring water boreholes and detected earthquakes (Stage 2); and
- Produce a comprehensive catalogue of time dependent velocity changes and the modelling for both of the regions (black and white rectangles).

Stage 2 Detection & Initial Identification of Seismic Sources: The same passive seismic data from GSWA will be analysed to detect and identify the seismic sources of the region via use of automatic seismic detectors. This stage will run simultaneously with Stage 1. The following workflow will be applied:

- Preprocess the seismic data that GSWA provided;
- Apply machine learning based seismic detector to scan the continuous data to create a detailed list of events; and
- Create an initial list of events for both regions (black and white rectangles).

Stage 3 Integration of Geological Model: In seismic event location and seismic imaging problems, accurate initial subsurface seismic models are crucial for achieving modelling convergence. In this project, additional studies to create a subsurface model will not be conducted. Instead, the project will utilise the outputs of another project to be funded by GSWA that will commence simultaneously with this project (subject to final approval). The model will be used by the 4D wave equation-based imaging, as well as the seismic event location of this project.

Stage 4 Final Estimation of the Locations of detected earthquakes: After the integration of geological model, the previously detected and refined earthquake, quarry blasts and any other coherent signals can be located in 3D (latitude, longitude and depth). In this step, the following workflows will be followed:

- Application of hypodd algorithm;
- Application of double difference algorithm; and
- Creation of a final list of a catalogue of earthquakes including an uncertainty estimate for each entry.

It is important to note there are activities that will be conducted by GSWA that represent in-kind investment and dependency for CSIRO delivery to the project:

<u>GSWA Activity 1</u>: Installation and operation of the real-time seismic monitoring network in the North Perth Basin and surrounding location: GSWA will deploy, operate in total over 110 stations (covering black and white rectangles) in the study region.

GSWA In-kind investment: Totals $638,400 for 2 years (includes procurement of stations, operational costs of staff to deploy and maintain monitors, IT support and infrastructure).

<u>GSWA Activity 2</u>: GSWA will provide a copy of the raw passive seismic data on a timely basis to the CSIRO team.

GSWA Activity 3: Collaborate with CSIRO team on the integration of subsurface models. GSWA will also share results of their analyses with different methods than CSIRO.

The diagram below outlines the various activities to be undertaken by CSIRO and Geological Survey of Western Australia.

CSIRO activities (GISERA / CSIRO to fund)	**GSWA activities** (provided as in-kind by GSWA)
~ Prior to GISERA project commencement ~	
	Installation and operation of seismic monitoring network as part of GSWA WA Array
	↓
~ GISERA project commencement ~	
Ground water depth monitoring with seismic waves	
↓	↓
Initial Identification of seismic sources	Provide a copy of continuous seismic data to the CSIRO team
↓	
Integration of geological models north Perth Basin (another project output)	
↓	↓
Final Estimation of the locations of seismic sources	Work with CSIRO team on the geological model integration, interpretation of seismicity and groundwater depth levels
↓	
Project report	
↓	
Communication activities	

3. Project Inputs

Resources and collaborations

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Erdinc Saygin	56 days	Geophysics/Seismology	21	CSIRO
Peng Guo	157 days	Theoretical and computational seismology	10	CSIRO
Mehdi Qashqai	107 days	Geophysics/Seismology	10	CSIRO

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

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:

- Regulators (Department of Water and Environmental Regulation of Western Australia)
- Geoscience Australia
- Technical expertise from GSWA and other industry representatives (Agriculture Sector)

Budget Summary

Source of Cash Contributions	2022/23	2023/24	2024/25	2025/26	% of Contribution	Total
GISERA	$0	$42,690	$143,775	$100,939	24.83%	$287,404
- Federal Government	$0	$42,690	$143,775	$100,939	24.83%	$287,404
Total Cash Contributions	**$0**	**$42,690**	**$143,775**	**$100,939**	**24.83%**	**$287,404**

Source of In-Kind Contribution	2022/23	2023/24	2024/25	2025/26	% of Contribution	Total
CSIRO	$0	$34,379	$115,784	$81,287	20%	$231,450
Geological Survey of WA	$0	$239,400	$399,000	$0	55.17%	$638,400
Total In-Kind Contribution	**$0**	**$273,779**	**$514,784**	**$81,287**	**75.17%**	**$869,850**

TOTAL PROJECT BUDGET	2022/23	2023/24	2024/25	2025/26	-	TOTAL
All contributions	**$0**	**$316,469**	**$658,559**	**$182,226**	**-**	**$1,157,254**
TOTAL PROJECT BUDGET	**$0**	**$316,469**	**$658,559**	**$182,226**	**-**	**$1,157,254**

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 the 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 an article for the GISERA newsletter and other media outlets as advised by GISERA's communication team.	At project completion
		Presentation of research findings to regional community stakeholders such as business and/or community groups in a workshop (virtual or face-to-face).	At completion or within 6 months of completion of the project.
Gas Industry & Government	To communicate the outcome of the project.	Fact sheet that explains the objectives 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 seismicity and ground water variation patterns	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 communication products.

5. Project Impact Pathway

Activities	Outputs	Short term Outcomes	Long term outcomes	Impact
Water Level Monitoring: - Preprocessing - Data analysis - 4D Mapping and water level changes	Spatial maps and images of ground water level changes presented daily, monthly and yearly.	Variation of the groundwater levels with an unprecedented resolution compared to current monitoring methods.	• Gaining new insights about ground water level variations and seismicity of the region will inform policy makers and industry about the activity of the resources and agricultural sectors. It also has the potential to develop a more comprehensive monitoring policy of water resources. • Groundwater management is a particularly important topic for the community. These outputs of the project will document the effects of different industries on groundwater. The creation of a seismic catalogue will raise awareness and also serve as foundational information in case an 'unexpected' earthquake occurs in the region. • The project will clarify the impact of these activities on the ground water levels and also any induced seismicity.	Environmental impact: • New insights about ground water level depth variation with an unprecedent resolution. • New insights about the seismicity levels of the region, which is currently unknown. Social Impact: • Awareness about groundwater usage and potential effects of increased seismicity. Economic Impact: • Guiding the investment decisions of the agricultural and resources sector especially about the use ground water resources.
Seismicity: - Preprocessing - Event Detection - Initial Event Location	Preliminary lists of earthquake activity showing locations and magnitudes of the earthquakes not detected by Geoscience Australia	Detection of seismicity that was not detected by Geoscience Australia		
Local Velocity Model Integration	Improved ground water level imaging and seismicity location	Overall improvement of the key activities of this project.		
Final estimation of the locations of seismic events and catalogue building	A representative catalogue of seismic activity in north Perth Basin which is currently non-existent due to the lack of seismic stations.	A comprehensive list of seismic activity with temporal variations that can be later used in seismic hazard calculations.		
Analysis and reporting - Interim reports - Final report	Communicating the results of groundwater level variations, detected seismicity distribution, as well as investigating the causal links of these with regional activity.	Creating awareness across different sectors about alternative and supplementary monitoring activities, as well as the insights that this project offers.		
Information sharing and communication	Informing community and the other stakeholders about the findings	Creating awareness of the seismicity and ground water variation patterns		

6. Project Plan

Project Schedule

ID	Activities / Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Water Level Monitoring – Preprocessing	Peng Guo	01/03/2024	30/04/2024	
Task 2	Water Level Monitoring – Data Analysis	Peng Guo	01/05/2024	31/12/2024	Task 1
Task 3	Water Level Monitoring – 4D Mapping of WL Changes	Peng Guo	01/01/2025	31/12/2025	Tasks 2, 8
Task 4	Interim Report 1	Erdinc Saygin	14/07/2024	31/07/2024	Tasks 1, 2, 3, 5, 6
Task 5	Seismicity-Preprocessing	Mehdi T. Qashqai	01/04/2024	30/04/2024	
Task 6	Seismicity – Event Detection	Mehdi T. Qashqai	01/05/2024	30/09/2024	Task 5
Task 7	Seismicity-Initial Event Location	Mehdi T. Qashqai	01/10/2024	31/03/2025	Task 6
Task 8	Local Velocity Model Integration	Mehdi T. Qashqai & Peng Guo	01/04/2025	15/01/2026	
Task 9	Final Estimation of the Locations of Seismic Events and Catalogue Building	Mehdi T. Qashqai	01/07/2025	15/01/2026	Tasks 5, 6, 7, 8
Task 10	Interim Report 2	Erdinc Saygin	15/02/2025	01/03/2025	Tasks 6, 7
Task 11	Final Report	Erdinc Saygin	14/12/2025	15/01/2026	Tasks 1-3, 5-9
Task 12	Communicate project objectives, progress and findings to stakeholders	Erdinc Saygin	01/03/24	15/01/2026	

Task description

Task 1: Water Level Monitoring – Preprocessing

OVERALL TIMEFRAME: March 2024 – April 2024

BACKGROUND**:** A number of steps need to be followed to make the data ready for the next stage of the data analysis.

TASK OBJECTIVES**:** Removing instrument gain, homogenising the records, removing problematic recordings, and quality control the data.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A homogenised seismic data collection, ready to be used in the next steps of the 4D seismic imaging.

Task 2: Water Level Monitoring – Data Analysis

OVERALL TIMEFRAME: May 2024 – December 2024

BACKGROUND: For the proposed groundwater depth monitoring with seismic waves, a correlational data processing step is needed to be applied to the homogenised dataset. This step includes auto and cross-correlation of seismic data for short term time windows e.g., hourly for the whole recording duration.

TASK OBJECTIVES: Estimation of hourly seismic velocity changes via auto and cross-correlation of the passive seismic data

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Temporal velocity change curves for several station pairs and stations. These outputs will be later used for modelling and estimation of water levels.

Task 3: Water Level Monitoring – 4D Mapping of WL Changes

OVERALL TIMEFRAME: January 2025- December 2025

BACKGROUND: Changes in the seismic velocities measured via auto and cross-correlation of passive seismic data ultimately corresponds to the subsurface physical changes. So far, several studies showed that the largest contribution comes from ground water level fluctuations.

TASK OBJECTIVES: In this step, the team invert the previously computed velocity change curves to map the changes in the subsurface and also perform the physics-based modelling to constrain the depth of the changes from these results. Comparison of results between two regions (black and white rectangles).

TASK OUTPUTS AND SPECIFIC DELIVERABLES**:**

- 4D seismic velocity images across both networks.
- Water level depths estimated for several months.

Task 4: Interim Report 1

OVERALL TIMEFRAME: 14 July - 31 July 2024

BACKGROUND: This part uses the continuous seismic data from GSWA's WA Array and analyses the ground water level depths and seismic activity in northern Perth Basin.

TASK OBJECTIVES: Provide a general outline of the velocity changes and detected seismic events from the GSWA WA Array.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A detailed report showing the results of the velocity analyses and detected seismic events using the GSWA WA Array seismic data.

Task 5: Seismicity - Preprocessing

OVERALL TIMEFRAME: 1 April - 30 April 2024

BACKGROUND: Seismic raw datasets often contain the signature of the measurement setup and also potential data glitches. Before proceeding to actual data processing, these effects need to be removed from the data and a QC analysis needs to be performed.

TASK OBJECTIVES: Application of instrument removal, filtering, and format conversion of the raw records.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A homogenised seismic data library to be used in the coming steps.

Task 6: Seismicity – Event Detection

OVERALL TIMEFRAME: May 2024 – September 2024

BACKGROUND: It is a well-known fact that, with the deployment of dense seismic arrays, the seismic activity of a region can be mapped with an unprecedented resolution. Several locations that were considered seismically quiet can be found to be active after the operation of dense arrays.

TASK OBJECTIVES: Application of state-of-the-art seismic detection methods to map the seismic activity of the region.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Time of the detected events, histogram plots (e.g., Activity vs time).

Task 7: Seismicity – Initial Event Location

OVERALL TIMEFRAME: October 2024 – March 2025

BACKGROUND: After detection of earthquakes or any other activity, it is critical to precisely locate the origin of the activity. However, this requires a precise subsurface model to produce maps of activity with low uncertainty.

TASK OBJECTIVES: Initial estimation of the locations of the earthquakes that were detected previously using the existing velocity models in the region and evaluate the quality of results.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: 2D Maps showing the location of earthquakes, a catalogue of events with timing information, spatial coordinates depth estimate and uncertainty.

Task 8: Local Velocity Model Integration

OVERALL TIMEFRAME: April 2025 – January 2026

BACKGROUND: In seismic event location and seismic imaging problems, accurate initial subsurface seismic models are crucial for achieving modelling convergence. In this task, the team will not conduct additional studies to create a subsurface model. Instead, the team will utilise the outputs of another GSWA project that will commence simultaneously with this project (subject to final approval).

TASK OBJECTIVES: Improving and utilisation of a model in 4D imaging and seismic locations.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: An improved seismic velocity model to be used in the next steps.

Task 9: Final Estimation of the locations of Seismic Events and Catalogue Building

OVERALL TIMEFRAME: July 2025 – January 2026

BACKGROUND: Seismic velocity models play a key role in reducing the spatial uncertainty in the detected and located seismic activity.

TASK OBJECTIVES: Re-run the location algorithm with the new velocity model to improve the accuracy of the seismic event locations.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A final catalogue of seismic activity will be constructed with uncertainty information.

Task 10: Interim Report 2

OVERALL TIMEFRAME: February 2025 – March 2025

BACKGROUND: The passive seismic data from WA Array is analysed systematically to detect ground water changes in an unprecedented temporal and spatial resolution. The same dataset is also used to detect and located any seismic activity in the region.

TASK OBJECTIVES: Provide a summary of the progress seismic event detection-location and preliminary subsurface velocity changes in a clear format.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A written report, with the spatial information presented with two spatial maps showing velocity changes.

Task 11: Final Report

OVERALL TIMEFRAME: December 2025 – January 2026

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

TASK OBJECTIVES: A final report with the findings of the discrete analyses, written in a format that will be comprehensible by public as well as the scientific community. Methods, assumptions, limitations, and new insights will be discussed in the report.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

A written report outlining the final results. Also, two GIS layers will be produced (water level changes and seismicity), that will be provided to the team for the other GISERA project – 'Assessment of potential conflicts of subsurface resources development in the North Perth Basin'.

Task 12: Communicate project objectives, progress and findings to stakeholders

OVERALL TIMEFRAME: Full duration of project

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, a 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. Engagement with an established technical reference group
2. Knowledge Transfer Session with relevant government/gas industry representatives.
3. Presentation of findings to community stakeholders such as identified business and/or community groups in a workshop (virtual or face-to-face).
4. Preparation of an article for the GISERA newsletter and other media outlets as advised by GISERA's communication team.
5. 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.
6. Peer-reviewed scientific manuscript ready for submission to relevant journal.

Project Gantt Chart

		2023/24				2024/25												2025/26						
Task	**Task Description**	**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**	**Jul 25**	**Aug 25**	**Sep 25**	**Oct 25**	**Nov 25**	**Dec 25**	**Jan 26**
1	Water Level Monitoring – Preprocessing	■	■																					
2	Water Level Monitoring – Data Analysis			■	■	■	■	■	■	■	■													
3	Water Level Monitoring – 4D Mapping of WL Changes											■	■	■	■	■	■	■	■	■	■	■	■	
4	Interim Report 1					■																		
5	Seismicity - Preprocessing		■																					
6	Seismicity – Event Detection			■	■	■	■	■																
7	Seismicity-Initial Event Location								■	■	■	■	■	■										
8	Local Velocity Model Integration														■	■	■	■	■	■	■	■	■	■
9	Final Estimation of the Locations of Seismic Events and Catalogue Building																	■	■	■	■	■	■	■
10	Interim Report 2												■											
11	Final Report																						■	■
12	Communicate project objectives, progress and findings to stakeholders	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

7. Budget Summary

Expenditure	2022/23	2023/24	2024/25	2025/26	Total
Labour	$0	$75,069	$254,559	$177,226	$506,854
Operating	$0	$2,000	$5,000	$5,000	$12,000
Subcontractors	$0	$0	$0	$0	$0
In-kind	$0	$239,400	$399,000	$0	$638,400
Total Expenditure	**$0**	**$316,469**	**$658,559**	**$182,226**	**$1,157,254**

Expenditure per task	2022/23	2023/24	2024/25	2025/26	Total
Task 1	$0	$27,500	$0	$0	$27,500
Task 2	$0	$16,333	$64,685	$0	$81,018
Task 3	$0	$0	$84,645	$87,527	$172,172
Task 4	$0	$0	$10,132	$0	$10,132
Task 5	$0	$12,034	$0	$0	$12,034
Task 6	$0	$16,333	$31,004	$0	$47,337
Task 7	$0	$0	$33,986	$0	$33,986
Task 8	$0	$0	$14,908	$0	$14,908
Task 9	$0	$0	$0	$58,268	$58,268
Task 10	$0	$0	$15,132	$0	$15,132
Task 11	$0	$0	$0	$26,191	$26,191
Task 12	$0	$4,869	$5,067	$10,240	$20,176
In-kind	$0	$239,400	$399,000	$0	$638,400
Total Expenditure	**$0**	**$316,469**	**$658,559**	**$182,226**	**$1,157,254**

Source of Cash Contributions	2022/23	2023/24	2024/25	2025/26	Total
Federal Govt (24.83%)	$0	$42,690	$143,775	$100,939	$287,404
Total Cash Contributions	**$0**	**$42,690**	**$143,775**	**$100,939**	**$287,404**

In-Kind Contributions	2022/23	2023/24	2024/25	2025/26	Total
CSIRO (20%)	$0	$34,379	$115,784	$81,287	$231,450
Geological Survey of WA (55.17%)	$0	$239,400	$399,000	$0	$638,400
Total In-Kind Contributions	**$0**	**$273,779**	**$514,784**	**$81,287**	**$869,850**

	Total funding over all years	Percentage of Total Budget
Federal Government investment	$287,404	24.83%
Geological Survey of WA investment	$638,400	55.17%
CSIRO investment	$231,450	20.00%
Total Expenditure	**$1,157,254**	**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	Water Level Monitoring – Preprocessing	GISERA	Mar-24	Apr-24	2023/24	$15,233
Task 2	2.1	Water Level Monitoring – Data Analysis	GISERA	May-24	Dec-24	2024/25	$44,877
Task 3	3.1	Water Level Monitoring – 4D Mapping of WL Changes	GISERA	Jan-25	Dec-25	2025/26	$95,369
Task 4	4.1	Interim Report 1	GISERA	Jul-24	Jul-24	2024/25	$5,612
Task 5	5.1	Seismicity - Preprocessing	GISERA	Apr-24	Apr-24	2023/24	$6,666
Task 6	6.1	Seismicity – Event Detection	GISERA	May-24	Sep-24	2024/25	$26,221
Task 7	7.1	Seismicity-Initial Event Location	GISERA	Oct-24	Mar-25	2024/25	$18,826
Task 8	8.1	Local Velocity Model Integration	GISERA	Apr-24	Jan-25	2024/25	$8,258
Task 9	9.1	Final Estimation of the Locations of Seismic Events and Catalogue Building	GISERA	Jul-24	Jan-25	2024/25	$32,276
Task 10	10.1	Interim Report 2	GISERA	Feb-25	Mar-25	2024/25	$8,382
Task 11	11.1	Final Report	GISERA	Dec-25	Jan-26	2025/26	$14,508
Task 12	12.1	Communicate project objectives, progress and findings to stakeholders	GISERA	Mar-24	Jan-26	2025/26	$11,176

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)	Offer GSWA non-exclusive royalty free licence of project (CSIRO) IP for the delivery of information portal only. No further distribution rights.			
Distribution of Commercialisation Income (clause 13.4)	All income derived from commercialisation of the project IP is owned by CSIRO.			
Commercialisation Interest (clause 13.1)	**Party**		**Commercialisation Interest**	
	CSIRO		N/A	

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