Project Order

Proforma 2016

1. Short Project Title

Data-worth analysis and spatial design of groundwater monitoring networks in the Narrabri Gas Project area

Long Project Title	Spatial design of groundwater monitoring networks for early detection and minimizing uncertainty in the prediction of groundwater impacts in the Narrabri Gas Project area
GISERA Project Number	W.8
Proposed Start Date	30 Nov 2016
Proposed End Date	30 Nov 2018 (PhD student 2019)
Project Leader	Sreekanth Janardhanan and Dan Pagendam

2. GISERA Region

- ☐ Queensland
- ☒ New South Wales
- ☐ Northern Territory

3. GISERA Research Program

- ☒ Water Research
- ☐ GHG Research
- ☐ Social & Economic Research
- ☐ Biodiversity Research
- ☐ Agricultural Land Management Research
- ☐ Health

4. Research Leader, Title and Organisation

Sreekanth Janardhanan : CSIRO Land and Water (0.4 FTE)
Dan Pagendam : CSIRO Data61 (0.3FTE)

5. Background

Risks of groundwater pressure and water quality changes occurring in beneficial aquifers that are extensively used by farmers in the Namoi region is one of the biggest concerns of the community. Quantifying the probability of extreme pressure changes and groundwater travel times between coal seams and farmers' bores and other assets can tell us if any of these will be at risk of potential impacts. This will also help in delineating zones within the region where water pressure and quality should be monitored for early detection of any changes in the groundwater system. Such an exercise will help in identifying suitable locations for monitoring bores and identify monitoring strategies that will improve the precision of models and minimize uncertainty surrounding predictions of future changes to the groundwater system.

Permits and licenses for CSG (and mining) exploration and development in NSW require companies to implement groundwater monitoring plans that include two years of baseline monitoring. The recent report from the New South Wales Chief Scientist to the government recommends that companies seeking to mine/extract CSG should, in concert with the appropriate regulator, identify the baseline conditions and install appropriate monitoring infrastructure to detect risks (NSW Government 2014). Accordingly, the **NSW Government plans to invest $23 million for monitoring water impacts** of extractive industries including installation of 70 new monitoring wells in NSW (NSW Government 2015).

This project will develop and extend methods from Bioregional Assessments and GISERA GAB flux projects to identify monitoring strategies that will maximise the likelihood of early detection of groundwater pressure and quality changes in the Namoi region and progressively minimize uncertainty in the prediction of groundwater changes caused by the Narrabri Gas Project

6. Project Description

To address this requirement for monitoring identified by NSW Chief Scientist, our **study will apply state-of-the-science modelling, optimization and uncertainty analysis tools to develop a systematic approach for the optimal design of groundwater bore networks** for monitoring and early detection of groundwater system changes in the Namoi region that may be caused by the gas project. This will be accomplished through consultation with key stakeholders (DPI Water, Santos, CSIRO) to identify monitoring objectives that will be used to couple hydrogeological models with statistical decision theory.

The groundwater modelling task of the project will apply probabilistic methods to quantify the particle travel times to farmers' bores and other economic and ecological assets that should be protected from potential impacts. The optimal design of groundwater monitoring networks sits at the interface of computational statistics and hydrogeology. Optimal design and decision theory are well-advanced niches of statistical science, and in recent years have made strong contributions in the design of measurement networks in many engineering applications (Uciński 2005). In hydrogeology, these techniques have been applied in conjunction with geostatistical models (Nowak *et al.* 2010) and numerical groundwater models (Nowak *et al.* 2012, Sreekanth and Datta 2014).

These methods will be applied to the design of a groundwater monitoring network for the Namoi region and provide a means for early detection of groundwater pressure changes and travel pathways to important environmental and economic assets. In meeting our objective, we aim to demonstrate the effectiveness of optimal design for finding the optimal locations for a finite number of monitoring wells, under the competing demands of protecting multiple assets.

Importance and necessity

It has been well-established that coal seam gas development will result in significant changes in groundwater pressure in the target coal seams.. Evidence from predictive modelling and ongoing operations in Queensland indicate that groundwater pressure changes in the coal seams may propagate horizontally and vertically through different aquifer and aquitard formations. It is critical to monitor such changes in the groundwater system for both detecting these changes and also to provide useful data for minimizing uncertainty in the predicted impacts. Management decisions on groundwater changes/impacts caused by gas development should be underpinned by evidence provided by good quality monitoring data. The gas industry of Australia is bound to monitor the changes in natural environment and inform regulatory agencies. At present, the amount of deep groundwater monitoring data currently available for the Namoi region is sparse, highlighting the importance of investing in collecting groundwater data before, during and after the operation phase of gas industry.

We **propose to develop Bayesian statistical methods and tools** for undertaking optimal design of groundwater monitoring networks used for early detection of groundwater changes and also to provide useful data for minimizing uncertainty in the prediction of future impacts. Given that assets like farmers bores are spatially distributed over multiple areas and there is considerable uncertainty about the groundwater flow and particle travel times and travel paths between CSG wells and these bores, a probabilistic approach is required to maximize the chance of identifying groundwater changes in the region.

Bayesian statistical methods provide a framework for conducting rigorous probabilistic analyses whilst incorporating information from various data sources (i.e. past studies, expert opinion, observational data etc). Bayesian methods can be used for designing robust monitoring networks, whilst acknowledging uncertainties in hydrogeological and geostatistical parameters, model outputs, observational data and expert opinions. Bayesian approaches incorporate existing knowledge as priori probabilities in the analysis of new observations, in this case from new wells. The new data updates the priors to generate new estimates of probabilities that are optimal in terms of all of the available information. The approach integrates hydrogeological information pertaining to stratigraphy, geological structure and hydraulic properties into the decision making process and acknowledges uncertainties in model outputs and parameters. A variety of data required for accomplishing this have already been collated through various projects of CSIRO (including the Bioregional Assessment program), Santos and the New South Wales government for the Surat and Gunnedah basins, where we propose to develop the approach.

Existing groundwater models for the Namoi region (developed and improved in Bioregional Assessment and GISERA projects) would be used to drive a Bayesian hierarchical statistical model (e.g. Cressie and Wikle, 2011) and to identify sources of uncertainty in model parameters governing prediction of pressure changes in the aquifer and groundwater travel times. In addition, workshops for consultation with key stakeholders would be run in order to identify the environmental and economic assets at risk of water quality impacts, and objectives of monitoring. Using CSIRO's supercomputing facilities, many runs of the groundwater models would be used to identify regions/formations and patterns in probable pressure changes and other variables like groundwater travel times. Using these model runs, we would use stochastic optimization to identify monitoring well locations that provide a high probability of early detection of changes in the groundwater system.

The optimal monitoring network design would also draw upon other useful spatial layers regarding:
(i) regions or assets that may be at high risk of groundwater pressure/quality changes (information obtained from Bioregional Assessment Programme and workshops with key stakeholders); and
(ii) locations that are easily accessible (e.g. close to roads, within the CSG tenements/government land etc.).

These spatial information layers will help to identify practically accessible locations where investing in further groundwater data will improve confidence around predicted groundwater impacts, and help minimize the risk of environmental damage.

7. Budget Summary

Expenditure	2016/17	2017/18	2018/19	Total
Labour	21,039	171,560	-	192,599
Operating	35,000	21,000	-	56,000
Subcontractors	-	-	-	-
Total Expenditure	**56,039**	**192,560**	**-**	**248,599**

Expenditure per Task	2016/17	2017/18	2018/19	Total
Task 1	56,039	-	-	56,039
Task 2	-	51,334	-	51,334
Task 3	-	52,873	-	52,873
Task 4	-	88,353	-	88,353
Total Expenditure	**56,039**	**192,560**	**-**	**248,599**

Source of Cash Contributions	2016/17	2017/18	2018/19	Total
GISERA Industry Partners (25%)	14,010	48,140	-	62,150
- Santos (12.5%)	7,005	24,070	-	31,075
- AGL (12.5%)	7,005	24,070	-	31,075
NSW Government (25%)	14,010	48,140	-	62,150
Federal Government (25%)	14,010	48,140	-	62,150
Total Cash Contributions	**42,029**	**144,420**	**-**	**186,449**

In-Kind Contribution from Partners	2016/17	2017/18	2018/19	Total
CSIRO (25%)	14,010	48,140	-	62,150
Total In-Kind Contribution from Partners	**14,010**	**48,140**	**-**	**62,150**

	Total funding over all years	Percentage of Total Budget
GISERA Investment	$62,150	25%
NSW Government Investment	$62,150	25%
Federal Government Investment	$62,150	25%
CSIRO Investment	$62,150	25%
Total Other Investment	-	
TOTAL	**$248,599**	**100%**

Task	Milestone Number	Milestone Description	Funded by	Start Date	Delivery Date	Fiscal Year Completed	Payment $ (excluding CSIRO contribution)
Task 1	1.1	Project establishment and status review of the existing groundwater monitoring in the Namoi region	GISERA	30 Nov 2016	30 Mar 2017	2016/17	42,029
Task 2	2.1	Calibration constrained stochastic simulation of groundwater pressures and particle tracks to delineate target monitoring zones (shared with milestone 3)	GISERA	1 July 2017	30 Jan 2018	2017/18	38,500
Task 3	3.1	Data-worth analysis (shared with milestone 2)	GISERA	1 July 2017	30 Jan 2018	2017/18	39,655
Task 4	4.1	Optimising the design of groundwater monitoring network and application for Namoi	GISERA	1 July 2017	30 Mar 2018	2017/18	66,265

8. Other Researchers (include organisations)

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Sreekanth Janardhanan	40	Groundwater modelling, uncertainty analysis	10	CSIRO
Dan Pagendam	30	Statistics, Optimization	10	CSIRO
Trevor Pickett	15	Software Engineering	10	CSIRO
Matthias Raiber	10	Geology and Hydrogeology	12	CSIRO
PhD student	-	Groundwater modelling/optimization		CSIRO/(UQ/QUT)

9. Subcontractors

Subcontractors (clause 9.5(a)(i))	Subcontractor	Role
	None	

10. Project Objectives and Outputs

The project will deliver a method for the optimal spatial design of groundwater monitoring networks. By applying the method it will also deliver a set of monitoring locations that would be ideal for sentinel wells and allow for early detection of groundwater system changes caused by CSG development and protection of important environmental and economic assets in the Namoi. The methods developed in this project could also be used as a basis for designing groundwater monitoring networks in other regions of NSW.

The project idea has been communicated with NSW Government's DPI Water. The current timelines for the drilling project by NSW Government favours possible uptake of the knowledge from this project for informing the drilling decisions for the Namoi region. In order to accomplish this DPI water representatives will be included in the Technical Reference Group to enable ongoing consultations with DPI staff who have knowledge of the local hydrogeology and prompt transfer of knowledge generated by the project.

11. GISERA Objectives Addressed

Carrying out of research and improving and extending knowledge of social and environmental impacts and opportunities of unconventional gas projects for the benefit of the Gas Industry, the relevant community and the broader public.

Informing government, regulators and policy-makers on key issues regarding policy and legislative framework for the Gas Industry.

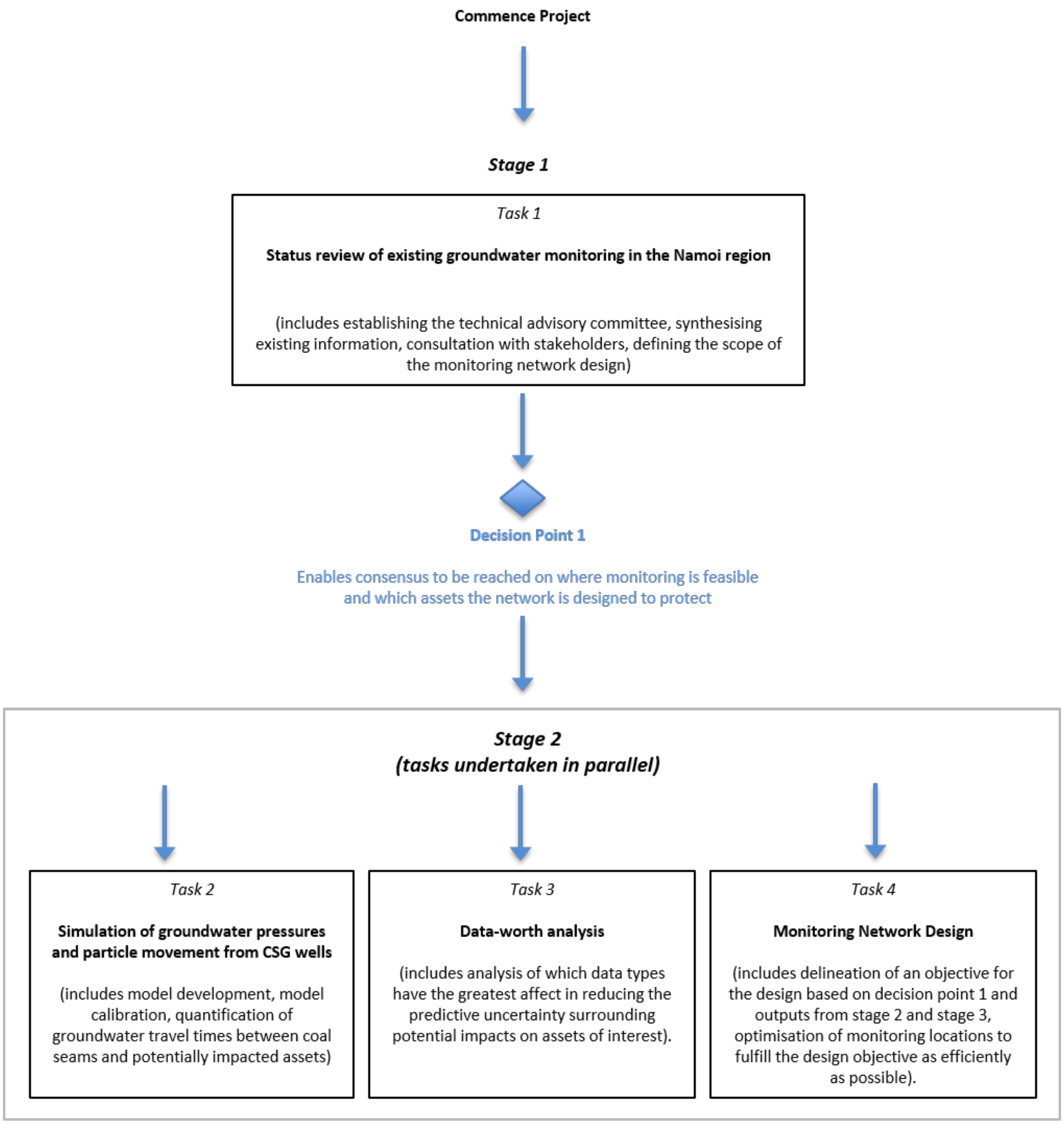
12. Project Development (1 page max.)

The project idea was scoped based on the requirement identified in NSW Chief Scientist's report for installation of appropriate monitoring infrastructure to monitor risks posed by coal seam gas development in NSW. It was also identified from the currently ongoing studies like Bioregional Assessments where only sparse amount of deep groundwater data is available of the Namoi region and is clearly insufficient for monitoring impacts from gas development in the Namoi region. The project idea was further discussed with DPI Water, Government of NSW. Groundwater modelling work undertaken in Bioregional Assessments and GISERA GAB flux project will help to improve the conceptual understanding of the groundwater system in the Namoi region and probability extremes of changes in groundwater pressure and flow volumes in the GAB aquifers. The project will further expand this work to explore other predictions like groundwater particle travel times between the CSG wells and farmers' bores and other assets. The work will also integrate the data/knowledge from these multiple predictions to help make decision regarding where to install monitoring bores to best monitor the impacts and minimize uncertainty in predictions. Synergies with the current research and development activities in this area are listed in the following:

1) **NSW government initiative for installing 70 new monitoring bores in NSW**: The spatial design of monitoring bores by this proposed project can aid in the identification of suitable locations for drilling groundwater monitoring in the Narrabri Gas Project area. Initial discussions with NSW Government's DPI water identified that the proposed study may be useful for the government monitoring initiative.
2) **GISERA GAB Flux project and Bioregional Assessment Programme**: Namoi sub-region; The flow models developed and improved in the GISERA flux project and Namoi BA would be used to build on the travel time simulation model modPATH-3DU for doing the stochastic particle travel time analysis required for this project. These models and/or their surrogates will be coupled with an optimization routine to identify optimal monitoring locations.
3) **OWS project of Faults and aquitards (FAM project)**: The improved characterization of structural features by the FAM project will help to identify the structures and aquitard properties that will be used to characterize the advective transport pathways in this project.

13. Project Plan

The research is designed to proceed in four stages. The first stage will be completed in the first six months and will include the establishment of the project and technical reference group and a status review of groundwater monitoring in the Namoi region around the Narrabri Gas Project area. Tasks 2, 3 and 4 will be undertaken in parallel.



13.1 Project Schedule

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Project establishment and status review of the existing groundwater monitoring in the Namoi region	Sreekanth Janardhanan	Nov 2016	March 2017	None
Task 2	Calibration constrained stochastic simulation of groundwater pressures and particle tracks to delineate target monitoring zones	Sreekanth Janardhanan	July 2017	Jan 2018	Task 1
Task 3	Data-worth analysis	Sreekanth Janardhanan	July 2017	Jan 2018	Task 1, 2
Task 4	Bayesian optimal design of monitoring network and application for Namoi	Dan Pagendam	July 2017	March 2018	Task 1, 2

Task 1

TASK NAME: Project establishment and status review of existing groundwater monitoring in the Namoi region

TASK LEADER: Sreekanth Janardhanan

OVERALL TIMEFRAME: 4 months

BACKGROUND: This task is intended to establish the project scope and review the status of current groundwater monitoring undertaken by NSW Government and Santos for the Narrabri Gas Project area. The task will also align this project to the companion project on GAB flux in terms of the inputs from the BA/GISERA modelling work that will provide the basis for further groundwater particle tracking modelling and monitoring network design tasks that will be undertaken in this project. The technical advisory committee will be established in consultation with stakeholders (DPI water, Santos and CSIRO). The scope of monitoring network design will be established based on the synthesis of existing information and consultations with the stakeholders.

TASK OBJECTIVE: Establish and finalise the project scope and objective(s) of monitoring network design

TASK OUTPUTS: This task will establish the current status of groundwater monitoring in the Narrabri Gas Project area and identify the scope of the proposed design.

SPECIFIC DELIVERABLES: Status review report on current monitoring in the Namoi region.

Task 2

TASK NAME: Calibration constrained stochastic simulation of groundwater pressures and particle tracks to delineate target monitoring zones

TASK LEADER: Sreekanth Janardhanan

OVERALL TIMEFRAME: 6 months

BACKGROUND: In this task a state-of-the science groundwater model developed and improved as part of the Bioregional Assessments and GISERA GAB flux projects will be used as a basis for building models for particle tracking simulations and further calibration of the models using latest available groundwater data. The state-of-the-science groundwater modelling platform MODFLOW-USG will be used for the flow modelling task and the model will be calibrated using the PEST suite of software. In addition to this a recently developed software tool mod-PATH3DU will be used for undertaking particle tracking simulations. The flexibility of using unstructured grids permitted by this tool enables to simulate particle tracks with higher precision near CSG development area. Particle tracking simulations will be performed to quantify the groundwater travel times between coal seams and multiple aquifer/aquitard formations and assets like farmers' bores. The calibration constrained Monte Carlo simulation method called Null-Space Monte Carlo will then be employed to make predictive simulations of groundwater pressure changes and travel times to selected assets.

TASK OBJECTIVE: Develop and calibrate the model basis that can be used to predict groundwater pressure changes and travel times and further perform calibration constrained uncertainty analysis to delineate monitoring zones.

TASK OUTPUTS: The task will deliver the modelling and uncertainty analysis framework that are required for monitoring network design.

SPECIFIC DELIVERABLES: Report on stochastic modelling and data-worth analysis

Task 3

TASK NAME: Data-worth Analysis

TASK LEADER: Sreekanth Janardhanan

OVERALL TIMEFRAME: 6 months

BACKGROUND: In this task we will study the relative contribution of different data types in reducing uncertainty in the predicted impacts at selected assets. This will be calculated using the sensitivity of the prediction to different model parameters and evaluating it in relation to the sensitivity of the model to different observations. Data-worth will be calculated in two different ways by: (i) calculating the increase in predictive uncertainty by removing observations from the model calibration suite; and (ii) calculating the decrease in predictive uncertainty by addition of new observations.

TASK OBJECTIVE: To quantify the relative worth of different data types in informing selected model predictions.

TASK OUTPUTS: The task will provide knowledge on the type of data sets that will be most useful for reducing uncertainty in the predicted impacts.

SPECIFIC DELIVERABLES: Report on stochastic modelling and data-worth analysis

Task 4

TASK NAME: Bayesian optimal design of monitoring network and application for Namoi

TASK LEADER: Dan Pagendam

OVERALL TIMEFRAME: 9 months

BACKGROUND: In this task, many runs of the groundwater quality model will be performed with a variety of parameter combinations and potential water quality impacts. These runs will then be used with a stochastic optimisation algorithm, such as Simulated Annealing to find an optimal spatial network for monitoring wells, i.e., one that has the greatest potential of protecting all identified assets through early detection of water quality contamination from extractive industry. The project will make use of CSIRO's super computing facilities to thoroughly explore the range of potential impacts and potential monitoring sites.

TASK OBJECTIVE: To determine the optimal locations for a set of groundwater monitoring wells using many stochastic runs of a groundwater quality model.

TASK OUTPUTS: This task will deliver an optimally designed groundwater monitoring network for the Namoi region and also a methodology for the design of groundwater quality monitoring networks that can be used for other regions in New South Wales. The methods developed and the application to the Namoi region would be written up as a scientific journal publication.

SPECIFIC DELIVERABLES: The specific deliverables from this task would be: (i) the optimal locations for placing groundwater quality monitoring bores in the Namoi region; (ii) computer code for computing an optimal design using a groundwater model; and (iii) a scientific journal paper explaining the methods developed and the steps taken to apply the method in the Namoi region.

14. Communications Plan

Communication of the results of the project will be managed in accordance with GISERA's communication strategy. This may include presentations at community and industry meetings, conferences and publication of reports, scientific articles and factsheets. In addition, communication with relevant state and federal government departments including NSW Department of Primary Industries Water (DPI Water), NSW Chief Scientist Office will be maintained to ensure that they are aware of the outcomes of the research and possible policy implications.

The project will establish a Technical Reference Group (TRG) aimed at seeking advice on contextual matters and to discuss research needs as well as outputs as the project progresses. The TRC will include the project leader and a group of different stakeholders, as appropriate (noting NSW Chief Scientist Office have been approached and declined).

15. Intellectual Property and Confidentiality

<table>
<tr><td rowspan="4">Background IP (clause 11.1, 11.2)</td><td>Party</td><td>Description of Background IP</td><td>Restrictions on use (if any)</td><td>Value</td></tr>
<tr><td>CSIRO</td><td>Groundwater model</td><td>None</td><td>$</td></tr>
<tr><td>Santos</td><td>Leapfrog Geological model</td><td>None</td><td>$</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Ownership of Non-Derivative IP (clause 12.3)</td><td colspan="4">CSIRO</td></tr>
<tr><td>Confidentiality of Project Results (clause 15.6)</td><td colspan="4">Project Results are not confidential.</td></tr>
<tr><td>Additional Commercialisation requirements (clause 13.1)</td><td colspan="4">Not applicable</td></tr>
<tr><td>Distribution of Commercialisation Income (clause 13.4)</td><td colspan="4">Not applicable</td></tr>
<tr><td rowspan="4">Commercialisation Interest (clause 1.1)</td><td colspan="2">Party</td><td colspan="2">Commercialisation Interest</td></tr>
<tr><td colspan="2">Santos</td><td colspan="2">NA</td></tr>
<tr><td colspan="2">AGL</td><td colspan="2">NA</td></tr>
<tr><td colspan="2">CSIRO</td><td colspan="2">NA</td></tr>
</table>

REFERENCES

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