Project Order

Proforma 2011

1. Short Project Title (less than 15 words)

Project 3: High Performance Groundwater Modelling

Long Project Title	High performance groundwater modelling for risk assessment and management option analysis of large scale injection schemes
GISERA Project Number	W3 1114
Proposed Start Date	July 2011
Proposed End Date	June 2014
Project Leader	Leif Wolf

2. GISERA Research Program

- ☐ Biodiversity Research
- ☐ Marine Research
- ☐ Land Research
- ☒ Water Research
- ☐ Social & Economic Research

3. Research Leader, Title and Organisation

Leif Wolf
Research Team Leader
CSIRO Land & Water
0,62 FTE

4. Summary (less than 300 words)

Injection of reverse osmosis treated production water from the coal seams into surrounding aquifers may provide the most viable measure to dispose of production water. A key advantage of this approach compared with other management options is that a local benefit can be created for Great Artesian Basin groundwater users.

An envisaged scheme is injecting very large quantities of water (approx. 30-80 GL/a) which is of drinking water quality, into aquifers over a large spatial extent of the CSG development, potentially via a large number of tens to hundreds wells. The extent of the scheme combined with the large numbers of users and existing bores in the target aquifers is such that the risk assessment and operational design of the scheme must specifically account for multiple sources and multiple receptors. APLNG is currently performing a set of injection trials to deliver detailed measurements on local impacts. The groundwater modelling exercise proposed within this project will provide the necessary upscaling of the injection trial findings together with the outputs of the three associated studies in the GISERA water sector and use state of the science modelling techniques to investigate risks perceived by communities, regulators and scientists. In summary the project addresses the feasibility of large scale injection schemes.

5. Budget Summary (From Excel Budget Pack worksheet "Project Plan Summary")

Expenditure	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
Labour	358,679	333,900	128,810			821,389
Operating	63,929	42,897				106,826
Total Costs	**422,608**	**376,797**	**128,810**			**928,215**
CSIRO	422,608	376,797	128,810			928,215
Total Expenditure	**422,608**	**376,797**	**128,810**			**928,215**

Expenditure per Task	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
Task 1	70,991					70,991
Task 2	351,617					351,617
Task 3		188,399				188,399
Task 4		188,398				188,399
Task 5			77,286			77,286
Task 6			25,762			25,762
Task 7			25,762			25,762
Total Expenditure	**422,608**	**376,797**	**128,810**			**928,215**

Cash Funds to Project Partners	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
CSIRO	338,086	301,438	103,048		0	742,572
Sub Total	338,086	301,438	103,048		0	742,572
Total Cash to Partners	**338,086**	**301,438**	**103,048**		**0**	**742,572**

Source of Cash Contributions	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
Australia Pacific LNG	338,086	301,438	103,048		0	**742,572**
Total Cash Contributions	**338,086**	**301,438**	**103,048**		**0**	**742,572**

In-Kind Contribution from Partners	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
CSIRO	84,522	75,359	25,762		0	185,643
Total In-Kind Contribution from Partners	**84,522**	**75,359**	**25,762**		**0**	**185,643**

	Total funding over all years	Percentage of Total Budget
Australia Pacific LNG Investment	742,572	80%
CSIRO Investment	185,643	20%
Total Other Investment		
TOTAL	928,215	100%

Gas Industry Social & Environmental Research Alliance

Task	Milestone Number	Milestone Description	Funded by	Participant Recipient	Start Date (mm-yy)	Delivery Date (mm-yy)	Fiscal Year	Fiscal Quarter	Payment $
Task 1	1.1	Project established and reference panel set up	GISERA	CSIRO	1.12.2011	1.6.2012	2011/12	Quarter 4	70,991
Task 2	2.1	Project methodology agreed and tested, input datasets collated, initial model set up	GISERA	CSIRO	1.12.2011	1.6.2012	2011/12	Quarter 4	351,617
Task 3	3.1	Regional scale model set up	GISERA	CSIRO	1.5.2012	1.12.2012	2012/13	Quarter 2	188,399
Task 4	4.1	Upscaling of reinjection response	GISERA	CSIRO	1.5.2012	1.11.2013	2012/13	Quarter 2	188,398
Task 5	5.1	Optimisation & hypothesis testing performed	GISERA	CSIRO	1.5.2012	1.8.2013	2013/14	Quarter 1	77,286
Task 6	6.1	Interim workshops with CSIRO-APLNG for interim reporting and quality assurance	GISERA	CSIRO	1.5.2012	1.10.2013	2013/14	Quarter 2	25,762
Task 7	7.1	Public stakeholder workshop	GISERA	CSIRO	1.6.2013	12.2013	2013/14	Quarter 2	25,762

6. Other Researchers (include organisations)

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organization
Dr Leif Wolf	0.62 FTE	Model concept & risk assessment, project management & capacity building	>12	CSIRO
Dr Catherine Moore	0.97 FTE	Uncertainty groundwater modelling, project management	>20	CSIRO
Malcolm Hodgen	0.34 FTE	Geospatial data analyst specialising in raster analysis, ArcHydro & project spatial data acquisition & spatial data management.	>20	CSIRO
Unknown Groundwater Modeller	1.30 FTE	Groundwater modelling, report preparation, data management, coordinating field work for projects 1-4		CSIRO
Dr Declan Page	0.15 FTE	Water quality risk assessment	>10	CSIRO
Dr. John Doherty	ca. 0.1 FTE	A pioneer of inverse parameter estimation and uncertainty modelling	>30	Watermark Computing
Dr Henning Prommer	00.12 FTE	Reactive transport modelling;	>20	UWA

7. GISERA Objectives Addressed

The broad goal of the surface and groundwater portfolio of research is to improve the understanding of regional groundwater flows and management of groundwater impacts. Specific objectives of this project include:

- addresses CSG's environmental & social challenges & opportunities
- benefits industry, relevant communities & broader public
- fosters collaboration by industry, government, universities, stakeholders
- synthesises data & knowledge to enable regional & cumulative perspectives
- provides non-exclusive & mutual leverage opportunities

8. Program Outcomes Achieved

Details are provided in *Section 13. Project Objectives and Outputs*

9. Program Outputs Achieved

Details are provided in *Section 13. Project Objectives and Outputs*

10. What is the knowledge gap that these research outputs will address?

The research outputs from this project will improve and extend the capacity to assess the environmental risks and opportunities associated with groundwater re-injection arising from CSG-LNG development, by improving re-injection models.

11. How will these Research outputs and outcomes be used in State Government and other water managers to achieve Adaptive Management of Water Resources?

Providing information to government, regulators and policy-makers on key issues regarding policy and legislative framework for the CSG-LNG industry; particularly in the area of model based risk assessment, which underpin adaptive management processes.

12. Project Development (1 page max.)

The project was developed in consultation between Australia Pacific LNG (Andrew Moser, Ryan Morris, and Rebecca Pickering) & CSIRO. Current activities of the Queensland Water Commission and DERM were considered and discussion with Randall Cox and Sanjeev Pandey (QWC) confirmed the need for improved groundwater modelling exercises.

Current public discussion centres on the remaining uncertainty in groundwater impact predictions which result from the inevitably incomplete knowledge about the underground geology. It is of key importance to demonstrate, which risks can be confidently excluded because of physical laws, which risks are possible but have a low probability and which risks are likely. Based on this knowledge, adaptive management strategies can be developed.

The project was developed to respond to the widespread concern about potential impacts of CSG related activities on existing groundwater users and hydraulically connected surface waters. Much of this concern (shared by local communities, gas companies and regulators alike) is related to the uncertainty of the model outputs which are used as the foundation of the adaptive management policy being developed to manage these impacts. Adaptive management policies are inherently risk based policies, whereby some resource use is allowed, where the risk of any significant adverse impacts is acceptably low. Defining risk requires a probabilistic description of model outputs, yet this requires a range of mathematical and computational developments before such probabilistic descriptions are possible for large scale groundwater modelling problems within the CSG context. In summary, this research focuses on advanced methods to allow for hypothesis testing and quantitative assessments of the confidence intervals from groundwater modelling. The objectives of this research are to contribute to the societal need for sound impact assessments to advance modelling methodologies in general.

The novelty of the proposed approach in this work is the explicit incorporation of parameter uncertainty in order to inform decisions regarding risks to other groundwater users and ecosystems considering interconnections between the multilayer aquifer systems which impact on travel times. The project provides a best-practice example of modelling complex multi-layer aquifer systems, with multi-phase components, within the context of large scale CSG development. Outputs of the project include modelling developments to determine robust upscaling of hydraulic properties and processes at the regional scale and incorporating these into a hypothesis testing framework. By benchmarking model confidence with statistical approaches, advancements in the model due to additional data availability can be clearly assessed and confusion regarding multiple numerical modelling exercises is avoided.

13. Project Objectives and Outputs

- Upscaling and synthesis of findings from (a) geochemical modelling (b) managed aquifer recharge (MAR) operational modelling and clogging studies (c) isotope monitoring & hydrochemical baseline study. Upscaling will account for data scarcity and the degree to which such data impacts on predictive reliability. The focus of the synthesis will be on communication, and improvement of, the reliability of model scenarios underpinning decisions on CSG production water reinjection. Identify information support needed for modelling framework and evaluate available data for which parametric statistical distributions can be derived to constrain model characteristics and enhance predictive reliability.
- For selected scenarios quantitatively evaluate the value of investment in data acquisition in relation to model predictive uncertainty and identify priorities for future data acquisition.
- Predict cumulative impacts of injection strategies in the Surat & Bowen Basins
- Predictions of short and long term changes to groundwater quality, both the areal extent of possible changes and the time to equilibrium in terms of general impacts within the basin.
- Predictions of short and long term pressure changes and their areal extent and the time frame over which they would occur in terms of general impacts within the basin.
- Improving MAR risk assessment procedures for cumulative impacts on hydraulic heads and travel times to extraction wells through the use of probability based modelling
- Model the performance of different layout options for large scale injection to identify suitable well locations/spacing
- Optimum target aquifers in recognition of risk/benefit
- Demonstrate state of the art uncertainty modelling
- Demonstrating methodologies for fact based decision making in context with data uncertainty, e.g. via exploring whether the hypothesis of contamination of a potable water supply well can be rejected at a 99% confidence level, and if not, exploring which alternative management option will allow such confidence.

The demonstration of innovative uncertainty modelling is envisaged to impact on decision making processes in groundwater management by providing a best practice example. If the project can demonstrate the feasibility of large scale injection schemes in CSG water management, this will impact beneficially on Great Artesian Basin water resources.

14. Project Plan

14.1 Project Schedule

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Project set up & management	Leif Wolf	2011	2013	
Task 2	Risk assessment framework	Leif Wolf	2011	2012	
Task 3	Model basis and local and regional scale model development	Catherine Moore	2011	2012	
Task 4	Upscaling of reinjection response	Catherine Moore	2012	2013	
Task 5	Hypothesis testing	Catherine Moore	2012	2013	
Task 6	CSIRO-APLNG workshops	Leif Wolf	2011	2013	
Task 7	Public stakeholder workshop	Leif Wolf	2013	2013	

Task 1.

TASK NAME: Project set up & management
TASK LEADER: Leif Wolf
OVERALL TIMEFRAME: 2011/12

- Establish a project reference panel
- Collate available input data on the Surat Basin from CSIRO, Geoscience Australia, Department of Environment and Heritage Protection, QWC, Australia Pacific LNG.
- Refine work plan according to bi-annual Australia Pacific LNG-CSIRO discussions

Task 2.

TASK NAME: Risk assessment framework - Project methodology agreed and tested, input datasets collated, initial model set up
TASK LEADER: Leif Wolf, Declan Page
OVERALL TIMEFRAME: 2011/2012

- Write document on project methodology and optimization goals
- Obtain critical input datasets and initial model set up

- Specify risk assessment criteria and thresholds for health risk/environmental risk/economic risk for CSG water injection schemes according to current regulatory and stakeholder positions.
- Identify information support needed for modelling framework.
- Select no more than five key predictive targets specific in time and space to represent key risks identified. These five simulations will be used as the focus of tasks 3-6.

Task 3.

TASK NAME: Model basis and local and regional scale model development

TASK LEADER: Catherine Moore

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The local and regional scale models to be used throughout this project need to be developed with high computational efficiency, yet with maximal model functionality with which to represent the detail of the processes important to the analysis of CSG impacts. Currently the newly developed and soon to be released MODFLOW USG package (Unstructured grid package) appears to offer the most promising features in terms of relevance to the CSG context. MODFLOW USG offers many of the advantages of finite element packages, potentially without some of the drawbacks e.g. long model run times, compromised ability to interrogate flux terms etc. MODFLOW USG also supports the conduit package which will be important for analysing the impacts of fault representations within the Surat Basin. Similarly the NWT package with its ability to de-rate pumping with decreasing heads will assist in the representation of the de-pressuring rates required for CSG. A series of numerical experiments will be required to assess the worth of the enhanced process detail in model codes, in terms of analysing the uncertainty of a preselected suite of target predictions. The selected software platforms will then be used to develop the local and regional scale models for the Gubberamunda aquifer, which are to be used in the project. The models will be based upon available information from existing Australia Pacific LNG and QWC models and other available sources.

TASK OBJECTIVE: Assess suitable modelling software platforms and develop local and regional scale reinjection models.

TASK OUTPUTS: Analysis of optimal modelling frameworks for local and regional scale model platforms in this project (this will incorporate a number of numerical experiments for this purpose), and development of local scale and regional scale models of the Gubberamunda aquifer throughout the basin. Technical transfer will be achieved by reporting on results of model software platform selection.

SPECIFIC DELIVERABLES: Local and regional scale models, and model development report.

Task 4.

TASK NAME: Upscaling of reinjection trial geochemical and hydraulic response to the regional context

TASK LEADER: Catherine Moore

OVERALL TIMEFRAME: 2012/13

BACKGROUND: Develop upscaling approach to ensure robust representation of reinjection trial geochemical and hydraulic responses at the regional model scale. The complexity of geochemical and fine scale distributed hydraulic models leads to long model run times and at times questionable numerical stability, both which compromise the calibration of regional modelling and the analysis of predictive uncertainty at the regional scale. Using a methodology for paired complex and simple surrogate models (based on Doherty and Christensen 2011) allows the uncertainty associated with upscaling to be quantified, and allows optimal levels of upscaling to be assessed to reduce any upscaling derived bias to a minimum. This methodology will be extended to the context of hydraulic response in reinjection trials. Appropriate 'upscaling' will be assessed in terms of impacts on predictive reliability and specifically in terms of the 5 key predictive simulations identified in task 2. Technology transfer will be achieved by project reporting.

TASK OBJECTIVE: Demonstration and extension of robust upscaling methodologies, allowing robust determination of uncertainty at the regional scale, and information that can be used to ensure this uncertainty is minimised.

TASK OUTPUTS: Determination of upscaling bias and variance terms required for predictive uncertainty analysis, and its adjunct hypothesis testing and data worth analyses.

SPECIFIC DELIVERABLES: Technical report, progress presentation at project workshops and submission of paper demonstrating the methodology.

Task 5.

TASK NAME: Hypothesis testing

TASK LEADER: Catherine Moore

OVERALL TIMEFRAME: 2013/14

BACKGROUND: It is important to be able to demonstrate the probability extremes around predictions underpinning decisions, to ensure a robust level of confidence. One uncertainty analysis method that has particular suitability for testing the probability extremes of groundwater models is an hypothesis testing method, as implemented via a pareto front (e.g. as outlined in Moore et. al. 2009). The pareto front can be used to define the tension between a hypothesized extreme prediction, and its likelihood. Furthermore the algorithm that is used to define this pareto front is targeted to find any parameter combination that would allow the hypothesized prediction to occur, which makes it a very efficient tool in terms of model runs necessary for the analysis. Technology transfer of enhancements of this method in the CSG context will be via demonstrations in workshops and in a submitted paper.

TASK OBJECTIVE: Use hypothesis testing methods for specific regional targets to assess and communicate water level and travel time risks related to reinjection. For example the hypothesis that the 2m or 5m drawdown triggers will not occur at specified points if reinjection "make good" efforts are implemented can be explored and rejected or accepted at a 95% or 99% confidence level. Similarly the risk of a migration of analytes from a reinjection scenario to potable water supply wells can be explored and rejected or accepted. In summary the work aims for:

- Quantification of the risk of hypothesised impacts occurring. These risks will relate to the five key predictive simulations identified in task 2 (geometries of geological strata, spatial distribution of hydraulic parameters, reinjection scenarios) on the model results using an advanced theoretical concept
- Specification of confidence intervals (95%, 99%).

TASK OUTPUTS: Prediction of solute travel times and water level responses for a set of regional scenarios. Analysis of risk of various reinjection options.

SPECIFIC DELIVERABLES: Technical report and progress presentation at project workshops.

Task 6.

TASK NAME: CSIRO-Australia Pacific LNG workshops

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2013/14

TASK DESCRIPTION: Twice a year, CSIRO-Australia Pacific LNG workshops will be held with the project reference panel.

TASK OBJECTIVE: Review project progress, identification of necessary adjustments to the workplan. The workshops will be used to summarize knowledge for the GISERA reporting duties.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Workshop results documented and distributed to project partners.

Task 7.

TASK NAME: Public stakeholder workshop

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2014

TASK DESCRIPTION: After mature project results are generated, a public stakeholder workshop will be held in Brisbane

TASK OBJECTIVE:

- To disseminate results to a wider audience of scientists, industry, regulators and consultants.
- To identify new research needs

TASK OUTPUTS & SPECIFIC DELIVERABLES: Workshop results documented and distributed to project partners, Summary paper presented at a scientific conference.

15. Budget Justification

The budget for this project has been approved by GISERA's Research Advisory Committee and Management Committee.

16. Project Governance

Project management tasks and disseminations activities are specified in item 14.

17. Communications Plan

General communication will be managed by GISERA.

The pathway to impact for this project includes:

- The modelling work in this project will inform the cumulative impacts of injection strategies in the Surat Basin and the feasibility of large scale injection schemes.
- The research in this project is being carried out in cooperation with APLNG experts, who oversee the groundwater impact assessments of the Surat and Bowen Basins and manage injection trials. By this means the work is directly informing existing industry trials and is building industry science capacity.
- The modelling work will predict the long term evolution of water levels and describe long term risks to water quality for the Gubberamunda sandstone as it is an aquifer that is most used in the Surat Basin for irrigation and stock water.
- This project will integrate results from three other GISERA projects by performing upscaling and synthesis of findings from (a) geochemical modelling (b) MAR operational modelling and clogging studies (c) isotope monitoring & hydrochemical baseline study.
- Regulators such as the Queensland Water Commission (QWC) are in need for improved groundwater modelling on coal seam gas impacts and have indicated their interest in the outcomes of this work in a number of meetings between CSIRO and QWC. The groundwater modelling performed in GISERA will be based on the cumulative groundwater impact model of QWC and will return improved parameter sets and quantifications to the QWC.
- This work will inform updates and application of regulations like the CSG Water Management – Injection Guidelines which was recently drafted by the Queensland Department of Environment and Heritage Protection and also future updates of the Underground Water Impact Report drafted by the QWC. Existing relationships with the regulator will be used to ensure that they are kept informed of project results as the project progresses.
- By this means, the work is poised to extend its impact to the CSG-LNG industry as a whole, across a broader commercial and geographic base.
- The modelling undertaken in this project will enable results from trials of limited duration to be extended to much longer time frames. This provides a key public good benefit in that it will enable robust estimations of potential impacts to be made well before they have become apparent. Consequently, the project will be informing environmental risk management decisions well ahead of long term monitoring programs.

- The openly published project reports will quantify the uncertainty of the predictive modelling. This will supplement the modelled estimates that have been used to derive existing guidelines.
- Transparent quantification of uncertainty in the modelling process using innovative mathematical concepts seeks to increase public trust in the impact assessments.
- Direct technical cooperation with the industry experts in the planning of the trials, the collection of samples and the analysis of the results ensures effective knowledge transfer.
- For broader public benefit, stakeholder workshops with government agencies, interested communities and GISERA representatives will be organised.
- The results will be disseminated at national and international conferences as well as a number of peer reviewed journal papers.
- PhD students will be integrated into the work program to allow for direct capacity building. Project team members are providing lectures to the National Centre for Groundwater Research and Training (NGCRT) on groundwater modelling and managed aquifer recharge in CSG. Furthermore, CSIRO is currently negotiating to provide scientific support to NGCRT researchers on the topic of data worth analysis.
- The datasets and models employed in this project will also contribute to fundamental science on the upscaling from local scale water quality modelling to the impact on regional groundwater flow systems. This was recently recognised in the award of a competitive OCE-Postdoctoral Fellowship which will further support the project.

18. Risks

Close public interest in the results and in particular any discrepancies between this and other studies, and being able to explain such discrepancies should they arise, may be an important component in managing project risks.

Capacity to deliver:

Currently, the project relies on the specialised expertise of Catherine Moore. To mitigate the risk associated with this dependency, a new groundwater modeller is to be recruited and skilled up in uncertainty based groundwater modelling.