Gas Industry Social & Environmental Research Alliance

Project Order

Proforma 2015

1. Short Project Title (less than 15 words)

Constraining groundwater flow rates in the Surat Basin through environmental tracer and hydrochemical data.

Long Project Title	Constraining conceptual/numerical groundwater flow models for aquifers in the Surat Basin through environmental tracer and hydrochemical data
GISERA Project Number	W6
Proposed Start Date	01 January 2016
Proposed End Date	30 June 2017 (28 Feb 2019 for PhD student)
Project Leader	Henning Prommer

2. GISERA Research Program

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

3. Research Leader, Title and Organisation

Henning Prommer
Winthrop Research Professor, University of Western Australia
Team Leader, CSIRO Land and Water
(Joint appointment)

4. Summary (less than 300 words)

Groundwater flow models are routinely used to gain a better quantitative understanding of groundwater systems and provide the basis for important water resources management decisions.

Calibration of such models, including those investigating CSG impacts in the Surat Basin, are not typically constrained using environmental tracers (e.g. ^{2}H, ^{18}O, ^{3}H, ^{85}Kr, ^{39}Ar, ^{14}C, ^{36}Cl, ^{81}Kr, stable noble gases) although the use of such data can significantly reduce predictive uncertainties. These additional sources of information can also improve conceptualisation of flow systems and the quantification of groundwater fluxes. Further model constraints that can reduce model uncertainty may be provided by a joint simulation of the key geochemical processes that control large-scale groundwater hydrochemical evolution. These include reactions induced by weathering, diffusive exchange with aquitards and similar changes in the hydrochemical patterns within aquifers along the inferred flow paths and with increasing residence times. Integrated into a comprehensive reactive transport modelling framework, this approach also allows direct quantification of the impact of multiple geochemical processes on the fate of specific environmental tracers and thereby reduce model non-uniqueness. In contrast to the current OGIA model, which provides a state of the art numerical groundwater flow model, ***the main objective of this project is to use solute and reactive transport modelling techniques to further evaluate and improve the current model conceptualisation.*** To achieve this goal, new data will be gathered during field work in the eastern recharge areas and the deeper Precipice Sandstone to complement existing environmental tracer and major ion chemical data. Existing and new data will be jointly used as constraints for an assemblage of surrogate numerical models that can represent sub-system behaviour in terms of flow, multi-species environmental tracer transport and geochemical reaction behaviour. The initial focus of the modelling study will most likely be the Hutton aquifer and its connection to the Walloon Coal Measures and the surrounding aquitards.

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

Expenditure	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	
Labour					99,611	212,346		311,957
Operating					174,000	103,000		277,000
Total Costs					**273,611**	**315,346**		**588,957**
CSIRO					273,611	315,346		588,957
Total Expenditure					**273,611**	**315,346**		**588,957**

Expenditure per Task	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	
Task 1					5,000			5,000
Task 2					134,943	91,859		226,802
Task 3					42,389	68,436		110,825
Task 4					91,279	155,051		246,330
Total Expenditure					**273,611**	**315,346**		**588,957**

Cash Funds to Project	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Total

Partners	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	
CSIRO						394,269		394,269
Sub Total						394,269		394,269
Total Cash to Partners						**394,269**		**394,269**

Source of Cash Contributions	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	2016/17 Year 6	2017/18 Year 7	Total
GISERA						394,269		394,269
Total Cash Contributions						**394,269**		**394,269**

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	2016/17 Year 6	2017/18 Year 7	Total
CSIRO					273,611	-78,922		194,688
Total In-Kind Contribution from Partners					**273,611**	**-78,922**		**194,688**

	Total funding over all years	Percentage of Total Budget
GISERA Investment	$394,269	67%
CSIRO Investment	$194,688	33%
Total Other Investment		
TOTAL	**$588.957**	**100%**

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	Stakeholder workshop (and interactions)	GISERA	CSIRO	02-16	03-16	15/16-	1	0
Task 2	2.1	Collection and analysis of age tracer data	GISERA	CSIRO	01-16	08-16	15/16-16/17	1	152,283.6
Task3	3.1	Hydrogeological and hydrochemical data compilation and processing.	GISERA	CSIRO	01-16	08-16	15/16-16/17	1	74,050.2
Task 4	4.1	Integrated age tracer/reactive transport model	GISERA	CSIRO	03-16	06-17	15/16-16/17	1	167,934.9

6. Other Researchers (include organisations)

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Axel Suckow	0.1FTE	Multiple environmental tracer measurement & interpretation	25	CSIRO
Andrew Taylor	0.15FTE	Environmental Tracer Sampling, organization of field trip	13	CSIRO
Megan Lefournour	0.1FTE	Environmental Tracer sampling & measurement	26	CSIRO
Phil Davies	0.05FTE	GIS Applications	18	CSIRO
Arne Kersting	0.2FTE (not in CCF)	$^{39}Ar/^{81}Kr$ measurement, preparation	3	Uni Heidelberg (+visiting scientist CSIRO)
Matthias Raiber	0.4FTE	3D geological modelling and hydrochemistry	11	CSIRO
Sreekanth Janardhanan	0.4FTE	Flow modelling and uncertainty analysis	7	CSIRO
Henning Prommer	0.2FTE (not in CCF)	Solute and reactive transport modelling	25	CSIRO/UWA (joint appointment)
Ursula Salmon	1.0FTE	Reactive and environmental tracer modelling	14	UWA (+visiting scientist CSIRO)
PhD student (tbd)	3.0FTE (not in CCF)	Reactive and environmental tracer modelling		UWA/CSIRO

7. GISERA Objectives Addressed

Research to extend knowledge of social and environmental impacts and opportunities of CSG-LNG projects for the benefit of the CSG-LNG industry, the relevant community and the broader public.

Informing government, regulators and policy-makers on key issues regarding policy and legislative framework for the CSG-LNG industry.

8. Program Outcomes Achieved

Stakeholders and CSG industry will use the new conceptual and quantified understanding of the groundwater flow in the Surat basin resulting from environmental tracer data and numerical modelling. Among the stakeholders there is recognition of the value and necessity of an integrated approach that considers multiple lines of evidence (tracers, geochemistry, modelling) for the understanding of aquifer systems. They are aware of the magnitude of CSG impact on the groundwater resources in the Hutton and Precipice Sandstone aquifers.

9. Program Outputs Achieved

A more complete range of environmental tracer data will be provided for new locations in the Hutton and Precipice Sandstone aquifers. Models for subdomains of the current OGIA groundwater flow model will simulate hydrogeochemical and environmental tracer transport processes. The comparison between measured data and simulation results will provide an evaluation of the current conceptualisation and quantification of groundwater flow within the Hutton and Precipice Sandstones and water/mass fluxes from and to aquitards.

Site-specific outputs that this project will provide include (i) improved estimates for the effective transmissivity of the Hutton Sandstone (ii) better understanding of the dual porosity characteristics of the Hutton Sandstone (iii) improved estimates of the vertical exchange fluxes between Precipice Sandstone and Hutton Sandstone and Walloon Coal Measures and possible constraints on these fluxes (iv) flux estimates from the eastern outcrop of the Hutton Sandstone to the centre of the Mimosa Syncline and (v) revised estimates for groundwater recharge rates and basin-wide fluxes within the Precipice Sandstone.

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

The main knowledge gap that this project addresses is the integration of different data types within a quantitative framework. Relying on the joint model-based interpretation of newly collected and existing data and models (such as the OGIA models), this approach is aimed at improving the conceptual understanding of the flow system in the Hutton Sandstone (both flow directions and quantity), and potentially a revised quantification of the main components of the water budgets of the Hutton and Precipice Sandstone aquifers, due to, for example, a revised net recharge to the deeper parts of the flow system.

The research addresses both site-specific knowledge gaps (and/or uncertainties) and it will develop state-of-the-art methods/approaches that are transferrable to a wide range of other water management problems in larger-scale basins.

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

The expected results will allow for a revised assessment of flow rates and volumes of usable groundwater resources in the Hutton and Precipice Sandstone aquifers. This has important implications as the work impacts predictions of extractable water quantities, drawdown due to CSG production and consequences of re-injection into these aquifers. The improved characterisation and quantification of the dual-porosity behaviour of the Hutton will constrain the usable amount of water and explain observed drawdowns. Constraining vertical fluxes will lead to an improved quantification of the impact of CSG extraction on underlying aquifers. Quantifying the fluxes in the Precipice allows determining the extractable amount of water and the impact of CSG water re-injection. The outcomes of this project will be used to inform and improve future generations of the OGIA model and thus have a direct impact on groundwater management of the Surat Basin.

12. Project Development (1 page max.)

This project is based on the experience gathered within the GISERA projects "*Geochemical response to re-injection*", "*High-Performance groundwater modelling*" and "*Geochemical Baseline Monitoring*". These projects provided the basic understanding for the area but also exhibited the existing knowledge gaps that will be addressed in this project. The project "*Geochemical Baseline Monitoring*" demonstrated the usefulness of the environmental multi-tracer approach to groundwater systems and to quantify groundwater flow within the Hutton Sandstone to assess the historic flow system. A part of this project was a detailed study of using quartz as proxi for pore water helium concentrations, deducing pore water velocities in aquitards on the formation scale and quantifying fluxes between aquifers in the coal seam gas area. These projects also demonstrated the lack of knowledge in the Precipice Sandstone in general, concerning recharge and overall flow direction and quantification. They demonstrated the lack of understanding of the Hutton Sandstone in its role as regional contributor to the GAB flow system and the lack of environmental tracer data in the northern and south-eastern parts of the infiltration area.

Detailed studies by Raiber et al. (2015) demonstrated the usefulness of hydrochemical data interpretation to inform the conceptual understanding of groundwater systems in the Clarence-Moreton and Surat basins. In particular, the integration of hydrochemistry and environmental tracers with 3D-modelling of the geologic geometries of the multi-aquifer systems provided valuable insights and understanding of the aquifer conceptualization, including the delineation of flow paths and zones where different aquifers are likely to be connected. A recent study by Duvert et al. (2015) in the Clarence-Moreton Basin showed how using different ion ratios combined with stable isotope data can provide insights into recharge processes and inter-aquifer connectivity.

The modelling approaches developed in the "*High-Performance groundwater modelling*" project relied on the OGIA model and explored various upscaling approaches that allowed the use of the local-scale information gathered in the "*Geochemical response to re-injection*" project for larger-scale model predictions and uncertainty analysis. All project results were discussed regularly with stakeholders of the impacted CSG areas. Project results were presented on various workshops with stakeholders and industry and were discussed both controversially and constructively. First ideas for this project were discussed within CSIRO, and in close exchange with OGIA.

In parallel to these GISERA activities, recent work in the joint CSIRO/UWA Reactive Transport Modelling Team has demonstrated the use of reactive transport modelling to track the impact of geochemical reactions on the fate of ^{14}C and the associated impact on groundwater ages [Salmon et al., 2015]. Ongoing work on simulating ^{14}C fate within the large-scale Perth Regional Aquifer Modelling System [Salmon, in prep.] has investigated a variety of modelling approaches and discretisation requirements. Finally, ongoing collaborative work with Prof. Olivier Atteia (University of Bordeaux, France) on developing hybrid numerical/analytical model for effectively simulating biodegradation-induced enhanced NAPL dissolution in finely-layered aquifers suggests that similar type models could also be constructed for the simulation of environmental tracer transport in larger-scale aquifer/aquitard systems [Atteia et al., 2005].

The initial plans for this new project were developed in discussions between the project team and Origin (Andrew Moser/Ryan Morris). Since then, feedback to earlier versions of the proposal was provided by the RAC. As a result additional discussions were held with OGIA, Origin, QGC (Patrick McKelvey), UQ Centre for Coal Seam Gas (Jim Undershultz) and GA (Andrew Feitz) to ascertain that the proposed work will be well based on and well aligned with the ongoing OGIA modelling work.

Atteia, O., L. Andre, A. Dupuy, *and* M. Franceschi *(*2005*)*, Contributions of diffusion, dissolution, ion exchange, and leakage from low-permeability layers to confined aquifers, Water Resour. Res., 41, *W09412, doi:*10.1029/2003WR002593.

Duvert, C., Raiber, M., Owen, D., Cendón, D., Batiot-Guilhe, C. and Cox, M.E. (2015). Hydrochemical processes in a shallow coal seam gas aquifer and its overlying stream–alluvial system: implications for recharge and inter-aquifer connectivity. Applied Geochemistry, 61, 146-159.

Raiber, M., Cui, T., Rassam, D. and Janardhanan, S. (2015). Hydrochemical evolution of Coal Seam Gas groundwaters and implications for inter-aquifer connectivity: examples from the Clarence-Moreton and Surat basins. American Association of Petroleum Geologists (AAPG) workshop on "Opportunities and Advancements in Coal Bed Methane in the Asia Pacific", Brisbane, February 2015.

Salmon, S.U., Prommer, H., Park, J., Meredith, K., Turner, J.V. and McCallum, J.L. (2015). A general reactive transport modeling framework for simulating and interpreting groundwater 14C age and δ13C. Water Resour. Res., DOI: 10.1002/2014WR015779.

13. Project Objectives and Outputs

The project will provide new data and develop a modelling approach that allows a quantitative comparison between model simulations and data. This will complement the existing state of the art modelling effort by OGIA and will allow to test and improve conceptual models of groundwater flow and hydrochemical evolution for this important aquifer system. In contrast to previously developed models it will jointly use multiple data types (heads, hydrochemistry, environmental tracers) to constrain a refined understanding and quantification of both groundwater resources and CSG impact. The development and testing of the conceptual/numerical modelling technique will provide benefits beyond the site-specific information gain as it will pave the way for future applications of the methodology to other large groundwater systems within Australia and elsewhere.

14. Project Plan

14.1 Project Schedule

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
1	Stakeholder workshop and interactions	Matthias Raiber, Sreekanth Janardhanan, Axel Suckow, Henning Prommer	1 Feb 2016	30 June 2016	
2	Sampling and analysis of environamental tracer data and their interpretation.	Axel Suckow	1 Jan 2016	31 Aug 2016	1
3	Hydrogeological and hydrochemical data compilation and conceptual modelling	Matthias Raiber	1 Jan 2016	31 Aug 2016	1
4	Integrated age tracer/reactive transport and flow models	Henning Prommer / Sreekanth Janardhanan	1 Mar 2016	31 July 2017 (31 January 2019 for proposed PhD study)	2,3

TASK 1

TASK NAME: Stakeholder workshop

TASK LEADER: Matthias Raiber, Sreekanth Janardhanan, Axel Suckow, Henning Prommer

OVERALL TIMEFRAME: Jan 2016

BACKGROUND: The proposed project strongly builds on existing data and models such as the OGIA models. To allow an effective integration of these data and models into the proposed work a workshop will be held at the start of the project. The workshop will provide a communication platform between the project team and key stakeholders such as OGIA, Origin, QCG, UQ, GA and CSIRO.

TASK OBJECTIVE: The main objective of the workshop is

- to ascertain that all existing data, models and knowledge is adequately incorporated into the project and that key stakeholders have the opportunity to provide additional feedback on the data collection strategy and the modelling approach
- to review and, if needed, to adapt the focus aquifers of this project, i.e., the Hutton and Precipice aquifer
- to establish a longer-term connection between the researchers of this new project and the stakeholders and to coordinate interactions and a communication platform that will ascertain close interactions throughout the remainder of the project

TASK OUTPUTS: Refined project plan

SPECIFIC DELIVERABLES: 1-day workshop to be held at CSIRO laboratories Dutton Park.

TASK 2

TASK NAME: Collection and analysis of age tracer data

TASK LEADER: Axel Suckow

OVERALL TIMEFRAME: Jan 2016 – Aug 2016

BACKGROUND: The predecessor GISERA project "*Geochemical Baseline Monitoring*" has successfully applied multi-tracer techniques for a characterization of flow direction, flow velocity and effective flow thickness in the Hutton Sandstone. It was confirmed and quantified that groundwater flow in the Hutton takes place only on a small fraction of the effective thickness of the stratigraphic layer. This was only possible by combining measurements of a suite of environmental tracers (^{2}H, ^{18}O, ^{3}H, ^{14}C, ^{36}Cl, noble gases) in a joint interpretation.

Open questions, however, remain:

- Is the Hutton Sandstone an entry point to the Great Artesian Basin (GAB) flow system and dewatering into the Eromanga Basin, as previously assumed, or does it decompose into small local flow systems, each tributary to the Dawson River and hardly contributing to the GAB water balance?
- What is the *net* contribution of the recharge areas in the far north of the Hutton outcrop and in the south-eastern branch of the outcrop to the regional deep flow system?
- Is there a local flow system within the eastern branch directly to the Dawson River where it breaks through the outcrop area?
- Is the Precipice Sandstone a double porosity system as well as the Hutton Sandstone?

- What are the magnitudes of recharge to the Precipice, its flow times and velocities?
- How vulnerable is the Precipice Sandstone against extraction and CSG injection, as it is regarded the future, and more important, source of farm water supply than the Hutton Sandstone?
- Can we quantify the contributions of groundwater influx from the Clarence-Moreton Basin to the Surat Basin?
- Can we quantify vertical fluxes between Hutton Sandstone, Precipice Sandstone and Walloon Coal Measures by calibrating numerical models to geochemistry and environmental tracer data?

The project will address some of these questions and/or provide the underlying science to address these questions that are important for water supply and CSG impact assessment. Sampling and analysis will be performed for a suite of environmental tracers (e.g. ^{2}H, ^{18}O, ^{3}H, ^{85}Kr, ^{39}Ar, ^{14}C, ^{36}Cl, ^{81}Kr, ^{87}Sr, noble gases) in those areas where the existing dataset is incomplete (north Hutton Sandstone outcrop, east-southeast Hutton Sandstone outcrop, Precipice Sandstone outcrop, deep Precipice Sandstone bores). Cooperation with University of Heidelberg and contributions of a PhD student (Arne Kersting) will provide unique tracer measurements of radioactive noble gas isotopes (^{85}Kr, ^{39}Ar, ^{81}Kr) to calibrate the geochemically sensitive tracer systems ^{14}C and ^{36}Cl. The new data will be jointly interpreted with the existing datasets, with the necessary geochemical background information and used to constrain the conceptualisation of this multi-aquifer system and to calibrate numerical models of groundwater flow and multi-component reactive transport.

TASK OBJECTIVE: Determination and selection of sampling sites in the Hutton Sandstone and Precipice Sandstone suitable for environmental tracers. Sampling, analysis and interpretation of the applied multi-tracer suite. Improvement of the conceptual understanding of the flow systems of Hutton, Precipice and between them in the Mimosa Syncline. The environmental tracer data will subsequently be used as constraints for the numerical model calibration within the present project. In addition, these data will be available as "public good" data for future use by other projects that investigate the impact of CSG-related activities.

TASK OUTPUTS: Improved and more detailed conceptual understanding of the general flow system of the Hutton Sandstone. First environmental tracer assessment of the Precipice Sandstone flow system in the area of the Mimosa Syncline. Contribution of environmental tracers and geochemistry to the understanding of sub-regional flow and transport processes.

SPECIFIC DELIVERABLES: Environmental tracer data and initial qualitative interpretation. Initial versions of revised conceptual model(s) of the flow system within the Hutton Sandstone and Precipice Sandstone aquifers, to be tested and refined by the numerical model. Technical report.

TASK 3

TASK NAME: Hydrogeological and hydrochemical data compilation and conceptual modelling

TASK LEADER: Matthias Raiber

OVERALL TIMEFRAME: Jan 2016 – Aug 2016

BACKGROUND: The current conceptual understanding of groundwater flow directions in the northern Surat Basin is based on a relatively limited number of hydraulic head measurements, which suggests that groundwater flow directions are highly variable, and that discharge from the Hutton Sandstone and the Precipice Sandstone to the Dawson River occurs.

In this task, hydrochemical data will be used as an independent line of evidence to test the current conceptual understanding of regional groundwater flow and recharge patterns in the Hutton Sandstone and Precipice Sandstone in the northern Surat Basin. The key to enable the use of hydrochemical data to assess intra and inter-aquifer flow patterns and hydrochemical processes from the recharge area to the deeper parts of the Surat Basin and to avoid misconceptions is the reliable knowledge of the source aquifer from which the sample was collected. As the aquifer membership of bores in the current version of the QLD groundwater database is often incorrect and the screened intervals source water from different aquifers than stated in the database, perceived within-aquifer changes of hydrochemistry might indeed represent differences between different aquifers. To avoid such issues and resulting misconceptions, an existing 3D geological model of the aquifer boundaries (formation tops) developed by OGIA together with an updated and improved version of the groundwater database (incorporating the latest OGIA aquifer assignments) will be used to verify that only water chemistry records are included in the assessment of spatial patterns where the aquifer membership can be determined with a high level of confidence. For the identification of hydrochemical changes along inferred flow-paths, multivariate statistical techniques will be applied and major ion ratios will be assessed, aiming to identify hydrochemical differences within the Hutton Sandstone and Precipice Sandstone aquifers along inferred flow paths and their controlling factors (e.g. hydrochemical processes or inter-aquifer mixing). Throughout the different stages of the project (e.g., planning, initial data screening and interpretation stages), on-going communication with OGIA and researchers from the Centre of Coal Seam Gas at the University of Queensland will ensure that the proposed work builds upon existing knowledge.

As part of this hydrochemical assessment, we will also evaluate if the hydrochemical patterns can inform a refinement of the 3D geological model boundaries and properties within the proposed environmental tracer sampling and groundwater model domain. For example, within-aquifer hydrochemical gradients may be indicative of geological heterogeneity that could justify and inform a further sub-division of the aquifers.

This task will be linked iteratively to Task 2: For example, the initial hydrochemical assessment conducted as part of Task 3 will help to decide on the optimal environmental tracer sampling locations, and the hydrochemical data collected as part of the sampling will then feedback to improve the understanding of hydrochemical processes. The refined conceptual models or alternative conceptual models and together with the OGIA 3D geological model will then inform Task 4 by providing the model structure and calibration target.

TASK OBJECTIVE: Compilation and quality-checking of hydrochemical and geological data; use of hydrochemical data to test current conceptual models of groundwater flow paths and recharge mechanisms in the northern Surat Basin; update existing, or develop alternative, conceptual models.

TASK OUTPUTS: Refined or alternative conceptual models of groundwater flow processes in Hutton Sandstone and Precipice Sandstone.

SPECIFIC DELIVERABLES: Technical report on hydrochemical assessment and conceptual model development.

TASK 4

TASK NAME: Integrated environmental tracer/reactive transport and flow models

TASK LEADER: Henning Prommer / Sreekanth Janardhanan

OVERALL TIMEFRAME: March 2016 - June 2017

BACKGROUND: This task will translate the (qualitative) conceptual models developed in Tasks 1 and 2 and test them within a quantitative framework using previously existing and newly collected data as model calibration constraints. As a simple extension of the existing OGIA 3D flow models for the Surat Basin to a fully three-dimensional reactive transport model is currently not feasible due to the associated excessive computational demands, a suitable modelling strategy that relies on hybrid numerical/analytical surrogate models will need to be developed. The surrogate models will be models that, possibly at a lower lateral grid resolution, integrate the full suite of reactive transport processes required to simulate the fate of the environmental tracers and of the major ion chemistry. However, individual surrogate models will be constructed for the Hutton and Precipice Sandstone and only include the underlying/overlying aquitards that can act as sources/sinks for solutes (i) from diffusional fluxes and (ii) from advective fluxes due to leakage. Besides diffusion and advective fluxes to or from aquitards, mineral weathering reactions may also affect solute concentrations and appropriate concentration increases will occur along the main flow direction. The construction of the surrogate models will be informed by the improved conceptualisation of the Hutton and Precipice Sandstone aquifers obtained from Task 2 and Task 3. The models will be calibrated using an inverse modelling approach in which measured heads, environmental tracer data and hydrochemical data serve as joint calibration constraints. The joint calibration exercise will be used to test hypotheses on model structure and conceptualisation of net recharge into these aquifers. Any failure to successfully calibrate the models with a plausible parameterisation would indicate structural model errors and a rejection of the underlying conceptual model. This approach enables testing of multiple conceptual models and to select only models that jointly honour measured heads, tracer and hydrochemical data. Initially vertical leakage fluxes may be treated as unknowns in the surrogate models whereby the fluxes simulated in the current OGIA 3D flow model may be used for initial estimates. The output derived from the calibration of the surrogate models will be used to inform revisions and future generations of the current 3D flow models for the Surat Basin. Depending on model run times and practical consideration, the feedback between surrogate models and 3D flow models may be achieved through direct coupling of the models. The modelling results will be communicated through scientific papers and through direct communication with stakeholders.

TASK OBJECTIVE: Development of a suitable modelling approach for a computationally effective, integrated simulation of groundwater flow, environmental tracer fate and hydrogeochemical processes. Application of the approach for evaluating the conceptual models developed in Tasks 1 and 2.

TASK OUTPUTS: Integrated numerical surrogate models for the Precipice and Hutton Sandstone that honour observed heads and the major patterns of observed environmental tracer and hydrochemical data.

SPECIFIC DELIVERABLES: Numerical models and technical report describing the development of the models and their application to the Hutton and Precipice Sandstone.

15. Budget Justification

Data collection:
Multi-tracer analyses like the one envisaged (^{2}H, ^{18}O, ^{3}H, ^{85}Kr, ^{39}Ar, ^{14}C, ^{36}Cl, ^{81}Kr, ^{87}Sr, noble gases) require total analysis cost of ≈$4k per sampled well, depending on the tracers applied. The radioactive noble gas isotopes (^{85}Kr, ^{39}Ar, ^{81}Kr) are the most expensive analysis, but also most robust and reliable tracers for their respective time scales. Only the combination of these tracers allows assessing the age distribution of groundwater on the time-scale of many millennia to one million years. The CSIRO environmental tracer laboratory (ETL) operates the only mass spectrometric noble gas facility on the southern hemisphere to analyse He, Ne, Ar, Kr, Xe and the only gas preparation system on the southern hemisphere to extract the Ar and Kr fractions for analysis of ^{85}Kr, ^{39}Ar, ^{81}Kr.

Staff Task 2:
Axel Suckow has 25 years of experience in the application of environmental multi-tracer studies, is co-author and editor of a guidebook on dating old groundwater by isotope tracer methods and is managing the ETL at CSIRO. His team, here including ***Arne Kersting*** (joint PhD student with University of Heidelberg), and at CSIRO ***Andrew Taylor***, ***Megan Lefournour*** and ***Phil Davies*** have demonstrated their capability to perform multi-tracer studies in the GISERA predecessor project.

Staff Task 3:
Matthias Raiber is a Research Scientist at CSIRO with more than 10 years experience in the development of 3D geological models and the interpretation of hydrochemical and isotopic tracer data to study complex multi-aquifer-aquitard systems in Australia and New Zealand. During the last 2.5 years, he has worked on the development of 3D geological models of the Clarence-Moreton and Surat basins.

Staff Task 4:

Sreekanth Janardhanan is a Research Scientist in CSIRO and has over 7 years experience in groundwater modelling. He has lead the completed GISERA project "*High Performance Groundwater Modelling*" over the period 2013 to 2015. **_Ursula Salmon_** is a Research Assistant Professor within the joint CSIRO/UWA Reactive transport modelling team. She has 14 years experience on assessing and modelling geochemical processes and has for the last 3 years worked on the development of environmental tracer transport modelling approaches and is currently applying those to the Perth Regional Aquifer System (PRAMS) model. **_Henning Prommer_** is a Winthrop Research Professor in a joint position between the University of Western Australia and CSIRO Land Water. He is leading the Reactive Transport Modelling Team within the Environmental Contaminant Mitigation and Technologies Program. He has lead the GISERA project on *Geochemical response to re-injection*. He has 25 years of numerical modelling experience and worked for the last 20 years on the development and application of reactive transport models. A PhD project at the University of Western Australia will be linked to Task 3.

16. Project Governance

After the start of the project and a short initial phase of reviewing existing data and models a workshop (Task 1) with key stakeholders (OGIA, Origin, QCG, UQ, GA, CSIRO) will be hold to refine the project plan and modelling strategy. A second meeting will take place after the collection of data and an initial assessment of the newly collected environmental tracer data has occurred. The GISERA director will be regularly briefed by the project and task leaders.

The data collection, processing and modelling is split into three separate tasks (Tasks 2-4) that will be coordinated by the respective task leaders while the project leader will coordinate the interaction between these three tasks, with key stakeholders and with scientific collaborators. Task 2 (Collection and analysis of age tracer data) will be coordinated by Axel Suckow. The budget of this tasks is mostly determined by the cost for sampling and the risk of delays is relatively low. Task 3 (Hydrogeological and hydrochemical data compilation and conceptual modelling) will be lead and performed by Matthias Raiber, who has through his current work a good knowledge of the existing and of required data. Task 4 (Integrated environmental tracer/reactive transport and flow models) will be jointly lead by Henning Prommer and Sreekanth Janardhanan, whereby the central parts of this task will be performed by Ursula Salmon. In addition a PhD study will also contribute to the outcomes of this task. Through his previous GISERA work Sreekanth has a good understanding of the Surat basin aquifer system and of the existing numerical flow models, which is essential for the development of a suitable solute and reactive transport modelling approach. Task 4 provides some significant technical and scientific challenges and the level of modelling detail that can be achieved within the available time and budget will need to be carefully adapted during the project.

17. Communications Plan

General communication will be managed by GISERA.

18. Risks

Risks: At this stage no major risks particular to this project are foreseen. However, due to the short timeframe and the reliance on previous experience good progress relies on the availability of all named key researchers.

Capacity to deliver: The project and task leaders have individually sufficient experience to lead and supervise the various activities and ascertain the key research outcomes.