Project Order

Proforma 2016

1. Short Project Title

Air, water and soil impacts of hydraulic fracturing: Phase 2

Long Project Title	An intensive monitoring campaign to measure the air, surface water, groundwater and soil impacts of hydraulic fracturing of production wells in the Surat Basin
GISERA Project Number	W.12
Start Date	24 July 2017
End Date	1 February 2019
Project Leader	Melita Keywood

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

Melita Keywood, Principal Research Scientist, CSIRO Oceans and Atmosphere

5. Background

The potential impact on air, surface water, groundwater and soil of hydraulic fracturing (HF) operations in coal seam gas production are of general concern to communities living in gas development regions. The Surat Basin is no different, and members of the Western Downs community want evidence that they will not be subjected to any adverse impacts as HF becomes increasingly used in that region. Community concerns center around disclosure of the nature and type of chemicals used in the HF operations; potential enhanced mobilization of geogenic contaminants (e.g. Rn, Hg, organics) from the coal seam; the environmental fate of HF chemicals and geogenic contaminants; and the potential for impacts on human health and the environment.

The objective of this study is to conduct a comprehensive investigation on the effects of HF on air, water and soil quality. This will involve measurements of contaminant concentrations before, during and after HF at selected sites in the Surat Basin.

The project comprises a Phase 1 Review and Monitoring/Sampling Design (5 months) and a Phase 2, Monitoring and Sampling Program (13 months). Phase 1 was completed by the end of June 2017 under Project Order W-11 and this Project Order concerns the approval of Phase 2 of the project.

This project presents an important opportunity to generate a comprehensive account of the potential for environmental impacts from CSG production including HF. The project presents a unique opportunity to access production wells during an extended HF program. APLNG will allow unrestricted access, where safe, to air, surface water, groundwater and soil in the vicinity of wells being hydraulically fractured for establishing instruments, sample collection and ongoing monitoring. APLNG will also liaise with researchers to maximize data collection during Phase 2.

The intention is to conduct an independent study, however there may be a perceived risk around conflict-of-interest which could present a risk to CSIRO independence associated with this project as APLNG will have involvement in enabling access to the well field. These risks will be mitigated through the engagement of an external Review Panel consisting of four independent external scientists who have reviewed the study designs produced in Phase 1 and who will review the study results and outcomes. In addition, a Stakeholder Panel of local representatives will be engaged through a GISERA 'Knowledge Transfer' session to the study results and outcomes.

CSIRO will oversee the study and GISERA governance; audit procedures of third party air sampling and analysis providers; compile and analyze data; report data; and, make data/reports publicly available on GISERA website with open public access to data.

APLNG will provide CSIRO with information on chemicals used during HF (including a sample of the HF fluid to be collected and analyzed to confirm its composition) and provide information about the HF process; will provide access to the wells during the HF activities; and, ensure a safe work environment and necessary HSE training and PPE.

The study team includes CSIRO Oceans and Atmosphere, CSIRO Land and Water, ANSTO Centre for Accelerator Science, ANSTO Environmental Research, Macquarie University Department of Environmental Science and University of Queensland ENTOX. This proposal includes the rationale, methodologies and budgets for the air quality and the water and soil measurement components of the study.

6. Project Description

The project consists of two phases:

1. Phase 1 - Review, study design for a measurement program and establishment of baseline monitoring/sampling which was completed on 30 June 2017. The study designs for the air quality and water and soil quality components that inform this proposal are currently being peer reviewed.
2. Phase 2 - Implementation of measurement program designed in Phase 1. Approval of Phase 2 is now sought by the Queensland Regional Research Advisory Committee (RRAC).

This project description includes the rationale, methodologies and budgets for the air quality and the water and soil components of the study.

Air Quality Component

The methodology comprises a suite of measurements of atmospheric gaseous and particle species to be undertaken during HF at two sites in the Surat Basin. The objectives of the proposed study are:

- Objective 1- Quantify enhancements in air pollutant levels above back ground that occur during HF operations.
- Objective 2- Provide information on the contribution of HF and non-HF related sources of air pollutants to local air quality at the selected study site
- Objective 3- Provide comparisons of the air quality observed at the site with Australian federal and state air quality objectives, as well as data from other air quality studies undertaken in areas not directly impacted by HF operations both within the Surat Basin and in other locations in Australia.

The proposed sampling and measurement methodologies are designed to target air pollutants identified as being of particular concern in relation to HF. Criteria for selection included pollutants identified in a review of the literature (Keywood and Dunne 2017); if an air quality standard (national or state) exits for the pollutant; if the pollutant is a tracer for specific sources, and if a suitable measurement techniques exist to provide air pollutant data of sufficient quality to meet the study objectives. Current state and federal Ambient Air Quality Standards that apply to pollutants identified for incorporation into this study design are listed in Table 1.

The key pollutants listed in Table 1 represent the minimum that would be reported as part of the proposed study design. The measurement techniques for BTEX (the sum of benzene, toluene, ethylbenzene, and xylenes).and formaldehyde are capable of measuring many other Volatile Organic Compounds (VOCs), aldehydes and ketones. Likewise, the proposed PM_{10} analysis techniques will provide detailed information on the composition of PM_{10} including elemental analysis, and analysis for soluble ions and anhydrous sugars. Additional species from these analyses will be included in reporting if found to be associated with potential negative impacts on air quality associated with HF at the site, or are useful for characterizing the sources of PM, VOCs or other air pollutants at the site.

Table 1 Relevant air quality standards and potential HF sources that could impact air quality. NEPM is National Environment Protection Measure

Pollutant	Ambient Air Quality Standard			Potential HF Sources
	Averaging Period	Max Concentration	Relevant Standard	
Oxides of Nitrogen	1 h 1 year	0.12 ppm 0.03 ppm	Air NEPM Qld EPP Air (2008)	Exhaust from diesel powered equipment & vehicles
Carbon Monoxide	8 h	9 ppm	Air NEPM Qld EPP Air	Exhaust from diesel powered equipment & vehicles
Ozone	1 h 4 h	0.10 ppm 0.08 ppm	Air NEPM Qld EPP Air	Secondary pollutant- No direct emissions Product of reactive processes in air between VOCs and NOx
PM10	1 day 1 year	50 μg/m³ 25 μg/m³	Air NEPM Qld EPP Air	Windborne dust, soil, sand, sea salt. Vehicle exhaust and other combustion emissions. Secondary pollutant -chemical reactions between gases or between gases and other particles in the air.
PM2.5	1 day 1 year	25 μg/m³ 8 μg/m³	Air NEPM	
Benzene Toluene Xylenes	1 year 24 h	0.003 ppm	Air Toxics NEPM Qld EPP	Exhaust and Evaporative emissions from vehicles and equipment Geogenic contaminants in CSG & flowback fluid
Formaldehyde	24 h	0.04 ppm	Air Toxics NEPM Qld EPP (2008)	Exhaust from diesel powered equipment & vehicles Secondary pollutant -Product of reactive processes in atmosphere between VOCs and NOx
PAHs	1 year	0.3 ng /m³	Air Toxics NEPM Qld EPP (2008)	Exhaust from diesel powered equipment & vehicles Geogenic contaminants in CSG & flowback fluid

Mercury	1 year	1.1 µg/m^3	Qld EPP (2008)	Geogenic contaminants in CSG & flowback fluid
Radon				Geogenic contaminants in CSG & flowback fluid

A three-tier hierarchy of air quality monitoring methods for incorporation in the proposed study design will be used. If an air quality monitoring method was not available from the first tier, a subsequent tier was used.

- Tier 1- Australian Standard Methods as outlined in Schedule 3 of the Ambient Air Quality and Air Toxics NEPMs.
- Tier 2- Appropriate internationally recognised methods or standard techniques.
- Tier 3 – Non-standard methods with appropriate calibration and validation procedures to assess their accuracy and precision. Validation of Tier 3 measurements against Tier 1 and 2 methods will be undertaken where possible.

The suitability of measurement techniques was also assessed in terms of the time resolution required to capture emissions from specific activities within the whole HF process (e.g. chemical mixing, injection, and flowback) which occur on time scales of hours to days. Each measurement method was also assessed in terms of the required method detection limits and measurement uncertainty to provide robust and meaningful information about the concentration of an air pollutant. For instance, if the method detection limit is not significantly lower (i.e. at least 10 x lower) than relevant the NEPM or the QLD air quality standard objective for the pollutant under consideration, the method was deemed inappropriate.

CSIRO will carry out measurements at a minimum of one HF site in the Surat Basin; the final location of the measurement programs will be dependent on the access to the sites and provision of power at the sites. At the time of the preparation of this proposal the targeted HF site is Combabula.

Concentration of NEPM criteria gases pollutant concentrations and VOCs will be compared with simultaneous data collected as part the SBAAQ Study.

The proposed measurement approach for the Combabula site is comprised of two parts- a fixed AQMS located within the HF field and four battery powered perimeter monitoring stations located around the boundary of the property (perimeter monitoring sites). The Combabula site under consideration for inclusion in the project contains 26 wells, 13 of which started HF in August 2017.

In general Tier 1 and 2 methods will be used in the AQMS while Tier 3 method will be used in the perimeter monitoring stations. The list of pollutants and measurement methods include continuous measurements of NEPM criteria pollutants, methane, black carbon aerosol as well as

VOCs by Proton Transfer Reaction Mass Spectrometry (PTR-MS) and integrated sampling of VOCs and particles.

A highlight of the Combabula campaign will be the first deployment in an Australian unconventional gas field of the PTR-MS which continuously measures the concentration of VOC's, including NEPM Air Toxics BTEX and formaldehyde. This technique is ideal for tracking short duration HF events and has been successfully utilized in studies of unconventional oil and gas in the US and Canada (e.g. Warneke et al 2015, Li et al 2017).

An additional highlight of the Combabula monitoring program will be the collection of a large number of particle samples on filters at the AQMS that will undergo several analytical procedures to determine the mass and detailed composition of the particles. This information will be used to assess the contribution of HF and non-HF sources to total particle load. This methodology was recently successfully used to investigate the sources of airborne particles in a coal mining region in the Upper and Lower Hunter Particle Characterization Studies (Hibberd et al 2013, 2015).

Instrumentation will be installed and commissioned, with measurements occurring ~ 28 days during HF activities. Baseline and post-HF data will be derived from 21 days of measurements made before and 21 days after HF activity in this study.

Continuous measurements will occur at the AQMS and perimeter monitoring stations over ~70 days resulting in approximately 31,000 days of data (across 47 parameters). Integrated samples will be collected at the AQMS and perimeter monitoring sites resulting in the collection of 788 samples that will undergo 6 analytical procedures to determine the concentration of at least 74 pollutants.

Other data that will be utilized in the air quality component of the study include previous air quality studies conducted as part of Industry Environmental Assessments, HF well completion reports, simulation impact monitoring data, site activity schedules and wider industry data. This information will be used to assess the applicability of the results observed in this study to improved understanding of the potential impacts of HF on air quality at other sites. The potential for emission of air pollutants from HF fluids (injectate and flowback waters) via evaporation, volatilization, or aerosol formation is poorly understood. The analysis of flowback waters and injectate collected as part of the water and soil component of this study will be utilized to screen for pollutants that may have a pathway from HF fluids to air. Assessments of the source potential of HF fluids will be compared with the observed air quality during periods where the air measured was likely to have been impacted by the potential source i.e. during chemical mixing, injection and flowback.

In addition, in October 2016 APLNG with advice from CSIRO initiated a program of passive monitoring of VOCs at 4 locations within the Condabri field, and at 3 locations in a neighboring field that contains 5 wells that underwent HF in November 2016. The passive samplers are deployed by SGS Leeder Chinchilla for a period of two weeks and are analyzed by SGS Leeder in Mitcham, Melbourne. Three types of passive samplers have been deployed at each site: one for VOCs including BTEX, one for aldehydes including formaldehyde and one for hydrogen sulfide (H_2S). This VOC monitoring will end in late 2017 and the data will be incorporated into reporting for this HF study, providing critical longer term information on the levels of VOCs before, during and after HF activities at a second site.

The Condabri site is located within the air quality monitoring network operating as part of the GISERA Surat Basin Ambient Air Quality (SBAAQ) Study being undertaken by the project team. The network comprises 5 ambient air quality monitoring stations measuring NEPM criteria pollutants and in some cases methane as well as 10 sites at which volatile organic compounds (VOCs) are being monitored by passive samplers.

Overall, the proposed methodology represents the most detailed study of the impact of HF on air quality to be undertaken in Australia. While the focus of this study is the use of HF for CSG extraction, the proposed study will provide a proof of concept for a comprehensive approach to measuring air quality impacts of HF at other locations and in other unconventional gas resources (tight gas, shale gas) in Australia.

A description of how these data will be used to address the air quality component objectives is presented below.

Objective 1 - Quantify enhancements in air pollutant levels above background that occur during HF operations. The data from the proposed methodology will be used to address objective 1 by:

a. Comparison of data from the HF site with measurements taken at the site prior to HF operations
b. Comparison of data from the HF site with simultaneous measurements at other AQMS in SBAAQ study network.

Objective 2 - Provide information on the contribution of HF and non-HF related sources of air pollutants to local air quality at the selected study site. The data from the proposed methodology will be used to address objective 2 by:

c. Comparison of temporal variations in pollutant levels observed by continuous measurement systems, with meteorological parameters in particular wind direction, and activities occurring upwind of the monitoring system on site and in the surrounding area.
d. Investigation of the detailed composition measurements of particulate and gaseous pollutants and relationships between pollutants which can be used to estimate contribution of different sources to air pollutant load. For instance, the Al/Si ratio in elemental composition analysis of PM10 can be used to estimate

contribution of soil (Al) and sand (Si) including proppant to total PM10 load. Likewise, that ratio of benzene to CO differs between diesel exhaust and wood smoke emissions; levoglucosan can also be used as a tracer for woodsmoke.

e. Statistical analysis methods will be applied to the whole dataset to investigate pollutant sources. This may include analyses such as positive matrix factorisation assuming an adequate number of samples of sufficient quality are successfully collected.

Objective 3- Perform comparisons of the data with Australian federal and state air quality objectives, as well as data from other air quality studies undertaken in areas not directly impacted by HF operations both within the Surat Basin and in other locations in Australia. The proposed methodology will be used to address objective 3 by:

f. Employing where possible, Australian Standard measurement techniques (Tier 1) and properly validated Tier 2 and 3 techniques to provide data that are directly comparable to NEPM and Qld EPP ambient air quality guidelines.

g. Providing compatible data from HF site for comparison measurements taken simultaneously at other AQMS in SBAAQ study network.

h. Providing compatible data for comparison with measurements taken simultaneously at other locations not impacted by CSG activities, including other areas of Queensland via data from the Qld EPA ambient air quality network.

i. Providing compatible data for comparison with historical measurements at other locations, not impacted by CSG activities, where CSIRO has deployed similar instrumentation.

Water and Soil Component

The objectives of water and soil quality component of the study are

- Objective 1-To quantify the impacts of HF operations on the concentrations of contaminants in nearby surface waters, groundwater and soil
- Objective 2- To assess the concentrations of HF chemicals and geogenic contaminants in flowback and produced waters resulting from CSG HF operations
- Objective 3-To check compliance of contaminant concentrations in the collected water and soil samples with relevant Australian water and soil quality guidelines
- Objective 4- To conduct a laboratory assessment of various spill scenarios involving spillage of HF chemicals and flowback waters onto soils types representative of the Surat Basin.

The study will involve the collection of samples of surface waters, groundwater, flowback water from the HF operations, produced water and soil samples from the HF site operations area. Sampling will be conducted at APLNG sites located at Combabula and Condabri.

Details of the sampling plan are provided here for the Condabri site. However, it is likely that some of the Condabri sampling program may be moved to Combabula depending on APLNG's HF program, which is subject to change. Sampling locations and the timing will be finalized through consultation with APLNG. It is also anticipated that refinements to the sampling plan will be made as the project progresses and water and soil quality information is accumulated. Hence the program outlined below is a preliminary program that will evolve as more information on the HF program to be carried out at Combabula becomes available.

All water and soil samples will be collected and analysed using internationally accepted sampling and analysis protocols. Where possible sample analyses will be conducted in NATA accredited laboratories and will be subject to rigorous quality control. CSIRO staff will make at least three site visits during the course of the study in order to undertake specialist sampling, oversee sampling conducted by contractors and gain familiarity with the study sites.

The sample types and proposed number of samples are summarised in Table 2. The collection of 108 water samples and 40 soil samples is planned, these samples will undergo 22 analytical procedures to determine the concentration of more than 150 pollutants.

The proposed water and soil quality parameters to be analyzed and the analytical procedures to be applied are shown in Table 3. This list covers both inorganic and organic chemicals that may be potential contaminants of soil and waters. Note that the list of analytes includes tracers such as fluorobenzoic acid which are deliberately added to the HF fluids in order to provide a means of tracing the fate of the fluids.

Surface water sampling

The major surface water resources within the Condabri study area are Dogwood Creek and a number of farm dams (Figure 1). Upstream of the study site, Dogwood Creek flows through the township of Miles and receives inputs from the town's sewage treatment works. It is therefore important to include a Creek sampling location upstream of the study site. Samples will be collected at Dogwood Creek (four sites: upstream, downstream and two locations at the study site) and at three farm dams. There will be four sampling events: before, during (two occasions) and after fracking operations.

Groundwater bore samples

More than 10 Department of Natural Resources and Mining registered water bores are located within a 5 km radius of the proposed fracturing operations at Condabri and one water bore is within the study area (Figure 2). Instantaneous contamination of the boreholes is highly unlikely given the travel time required for chemicals to reach the locations. Nevertheless, samples will be taken as confirmatory evidence. Three nearby boreholes will be sampled prior to, during and on two occasions after the HF operations have ceased. A CSIRO groundwater specialist will oversee the groundwater sampling program and provide advice on sampling when required.

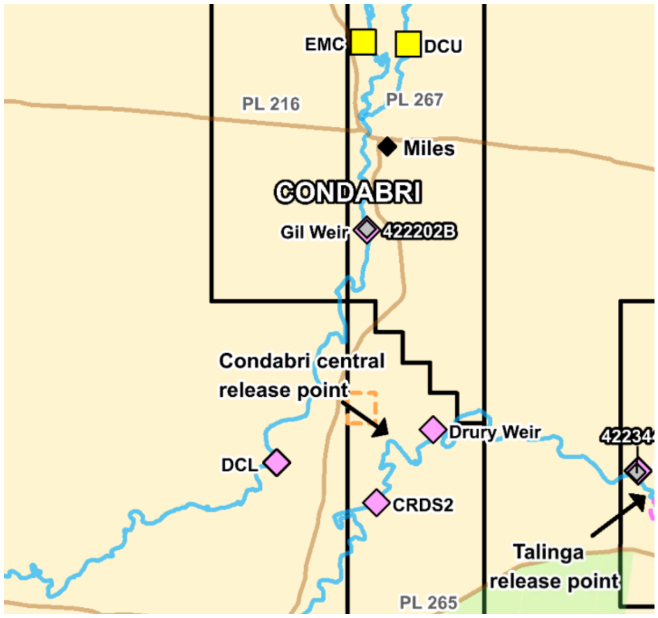

Figure 1. Map of the Condabri region showing existing surface water monitoring sites.

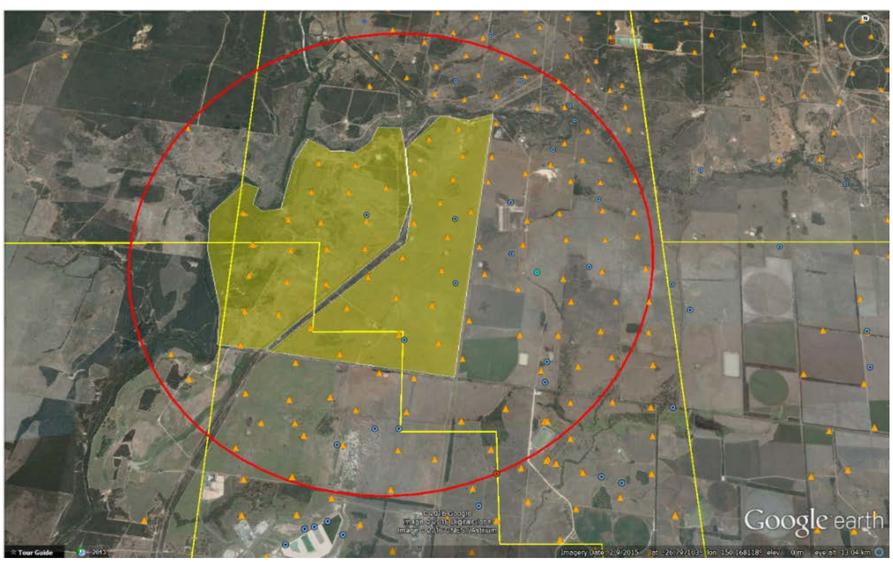

Figure 2 Map showing the location of registered water boreholes (blue dots) in the study region.

Hydraulic fracturing operations

Hydraulic fracturing fluid

The chemical formulation of the HF fluid to be used will be provided by APLNG. In addition six samples of the HF fluid (one per each well to be monitored) will also be collected and analysed by CSIRO to confirm its composition.

Flowback waters

A critical aspect of the study will be the sampling of wells before during and after HF. One well will be studied in detail with 12 samples taken over the duration of the fracturing operation (typically one week). A further five wells will be sampled at five time points over the duration of flowback water collection. Ancillary data (e.g. volume of flowback water, temperature etc.) will be collected for each fracturing operation in order to assist data interpretation.

Produced waters

Produced waters will be sampled from the six wells that were sampled for flowback water during the production phase. Samples will be taken from the gas-liquid separator well head. The well that was intensively sampled during HF will be intensively sampled during production (six samples taken over a six month period). For the remaining five wells there will be three sampling events per well. The exact timing of the sampling events will be determined following the completion of HF and commissioning of each well.

Water treatment facility (WTF) waters

Samples of raw water, post treatment water and reject brines will be taken at the Condabri WTF on three occasions over the study period (total of nine samples). It should be noted that the WTF receives and treats water from locations across the Condabri gas field. The data generated will therefore give a general view of water treatment operations rather than specific information relating to the study area.

Soil Quality

Field study

Unless there is a spill of HF fluid, flowback or produced water, it is highly unlikely that soil quality will be impacted. Soil samples will be collected at five points across the well pad at four wells before and after HF activities. This will lead to a total of 40 soil samples, that will be subjected to the same chemical characterization as the water samples following suitable sample preparation/extraction of the soil. Additional soil samples from each well pad will be collected and archived for later analysis (e.g. if contamination is detected).

Impact of HF chemicals on soil quality

Given the difficulties of sampling soils for spills and other contamination a laboratory scenario study will also be conducted. This will involve exposing soil samples representative of soil types found across the Surat Basin to HF fluids and flowback waters. The degradation and stability of the added contaminants will then be measured with time. Biological indices such as respiration will also be measured. This study will provide key information on the consequences of chemical spills on soil health. Further details of this study may be found in Appendix A.

Table 2 Summary of the proposed water and soil sampling program

Sample type	Samples to be collected	Number of samples	Notes
Surface waters			
Local Creek	Water	16	Samples will be collected at 4 sites: upstream, downstream and two locations at the study site). Four sampling events: before, during (2 occasions) and after fracking operations.
Farm dams	Water	12	3 farm dams sampled. Four sampling events: before, during (2 occasions) and after fracking operations.
Water bores	Groundwater	12	The nearby active boreholes will be sampled prior to, during and on two occasions post hydraulic fracturing operations.
Hydraulic fracturing	HF fluid sample	6	Mixed HF fluid sample to be provided to CSIRO
	Flowback waters	37	One well (12 sampling events), 5 wells (5 sampling events)
Production phase waters	Produced waters	21	One well (6 sampling events), 5 wells (3 sampling events)
Wastewater treatment facility	Incoming water	3	3 sampling events
	Post-treatment	3	3 sampling events
	Brine	3	3 sampling events
Soils	Samples from the well pad and adjacent areas	40	Soil samples will be collected at 5 points across the well pad at four wells before and after fracking activities. Additional soil samples from each well pad will be collected and archived for potential later analysis (if contamination is detected).

Table 3 Water and soil quality parameters to be analysed

Parameter	Typical Limit of Detection (3σ) for water samples
Dissolved: Al, Ag, As, Ba, Be, Bi, Cd, Ca, Ce, Co, Cr, Cu, Cs, Dy, Er, Eu, Fe, Ga, Gd, Hf, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Os, Pd, Pt, Pr, Rb, Re, Rh, Ru, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, W, Y, Yb, V, Zn & Zr	0.01-1 µg/L
Total: Al, Ag, As, Ba, Be, Bi, Cd, Ca, Ce, Co, Cr, Cu, Cs, Dy, Er, Eu, Fe, Ga, Gd, Hf, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Os, Pd, Pt, Pr, Rb, Re, Rh, Ru, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, W, Y, Yb, V, Zn & Zr	0.01-1 µg/L
Total Hg	1 ng/L
Dissolved Organic Carbon (DOC)	0.5 mg/L
Alkalinity as CaCO3	5 mg/L
Sulfate (SO4) & Chloride	1 mg/L
Phosphate, nitrate, nitrite, ammonia	1 mg/L
Electrical conductivity	
Ra-226	1 mBq/L
Ra-228	1 mBq/L
Th-230 & Th-232	1 mBq/L
U-234 & U-238	1 mBq/L
Gross alpha and beta	50mBq/L
Total suspended sediment (TSS) and pH	1 mg/L
Fracking additives e.g. fluorobenzoic acid tracers; butoxyethanol, biocides etc. depending on the fracking fluid composition	low µg/L
Geogenic organic chemicals: Phenols (inc. phenol, methylphenols, dimethylphenols) PAHs (inc. naphthalene and substituted naphthalenes, acenaphthene, anthracene, benzopyrenes, fluoranthene, fluorene, phenanthrene) VOCs- Volatile organic carbons (including BTEX compounds) TRHs- Total recoverable hydrocarbons THMs -Trihalomethanes	low µg/L
Non-target compounds- unknowns (semi-quantitative)	low µg/L

Phase 2 Air measurement program total cost $1,158K
CSIRO contribution: $448K
GISERA contribution $0k
Industry contribution $710k
Costs for external providers of air sampling and analytical services (including ANSTO and Macquarie University), $236K included in price

Phase 2 Surface water, groundwater and soil measurement program total cost $953K
CSIRO contribution: $378K
GISERA contribution $0k
Industry contribution $575k
Costs for external providers $283K included in price

Importance and necessity

- While the use of HF is currently not widespread in the Surat Basin HF is likely to be increasingly employed as CSG production from high permeability coal seams peaks and future reserves are dominated by lower permeability coal seams which necessitates HF for CSG extraction.
- With an increase in HF operations in the Surat Basin, the level of community concern about the impact of the CSG industry on human health and the environment is likely to persist or increase
- The independent study will provide detailed knowledge about the likely impact of HF for CSG extraction on air, surface water, groundwater and soil quality which will inform future management, regulatory and community actions
- Measurements of air, surface water, groundwater and soil quality at HF sites will be reported and made available to the public.

Community benefits -access to independent information on the potential impacts of HF

Industry benefits- social licence through acknowledgement of community concerns, engagement of independent scientific institutions, transparency in relation to chemicals and processes employed in HF and provision of access to industry sites.

References

Hibberd, M., Keywood M, et al. (2015). Lower Hunter Particle Characterisation Study (Vol. 4th Progress Report (Summer)). CSIRO: Prepared for the NSW Environmental Protection Authority.
Hibberd, M., Selleck P, et al. (2013). Upper Hunter Valley Particle Characterization Study. Report to NSW OEH. 40p. http://www.environment.nsw.gov.au/resources/aqms/UHFPCSFinal.pdf.
Keywood M and E. Dunne (2017). State of the knowledge about the potential sources of air pollutants associated with CSG extraction using hydraulic fracturing. Report Milestone 2.1 of GISERA project W.11 in review.
Li, L. J., L. Qi, et al. (2017). "Contribution of methyl group to secondary organic aerosol formation from aromatic hydrocarbon photooxidation." Atmospheric Environment **151**: 133-139.
Warneke, C., P. Veres, et al. (2015). "PTR-QMS versus PTR-TOF comparison in a region with oil and natural gas extraction industry in the Uintah Basin in 2013." Atmospheric Measurement Techniques **8**(1): 411-420.

7. Budget Summary

Expenditure	2016/17	2017/18	2018/19	Total
Labour	0	1,199,777	156,460	1,356,237
Operating	0	262,238	8,294	270,532
Subcontractors	0	469,287	15,000	484,287
Total Expenditure	0	1,931,302	179,754	2,111,056

Expenditure per Task	2016/17	2017/18	2018/19	Total
Task 1	0	621,133	0	621,133
Task 2	0	358,175	137,480	495,655
Task 3	0	0	41,480	41,480
Task 4	0	54,376	794	55,170
Task 5	0	457,421	0	457,421
Task 6	0	286,143	0	286,143
Task 7	0	154,053	0	154,053
Total Expenditure	**0**	1,931,301	179,754	2,111,056

Source of Cash Contributions	2016/17	2017/18	2018/19	Total
GISERA (0%)	0	0	0	0
Industry (61%)	0	1,174,821	110,179	1,285,000
APLNG	0	1,174,821	110,179	1,285,000
Total Cash Contributions	**0**	**1,174,821**	**110,179**	**1,285,000**

In-Kind Contribution from Partners	2016/17	2017/18	2018/19	Total
CSIRO (39%)	0	756,481	69,575	826,056
Total In-Kind Contribution from Partners	**0**	756,481	69,575	826,056

	Total funding overall years	Percentage of Total Budget
GISERA Investment	$0	0%
Industry Investment	$**1,285,000**	61%
CSIRO Investment	**$826,056**	39%
TOTAL	**$2,111,056**	

Costs and contributions indicated above are inclusive of all taxes but exclusive of GST.

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	Air quality measurement program report	CSIRO / Industry	July 2017	Dec 2017	2017/18	$380,744
Task 2	2.1	Air Quality draft report	CSIRO / Industry	Dec 2017	Oct 2018	2018/19	$303,829
Task 3	3.1	Air Quality final report	CSIRO / Industry	Nov 2018	Dec 2018	2018/19	$25,427
Task 4	4.1	Water and Soil Quality field measurement report	CSIRO / Industry	July 2017	Dec 2017	2017/18	$33,295
Task 5	5.1	Water and Soil analysis report	CSIRO / Industry	Aug 2017	Jun 2018	2017/18	$276,050
Task 6	6.1	HF chemical fate in soils lab study report	CSIRO / Industry	Aug 2017	June 2018	2018/19	$172,685
Task 7	7.1	Water and Soil Quality final report	CSIRO / Industry	July 2018	Dec 2018	2018/19	$92,970

8. Other Researchers (include organisations)

Researcher	Time Commitment (Phase 2)	Principle area of expertise	Years of experience	Organisation
Melita Keywood	30 days	Air quality science leader	20	CSIRO O&A
Erin Dunne	180 days	Air quality scientist and measurement techniques	7	CSIRO O&A
Jason Ward	90 days	Air quality measurement techniques	15	CSIRO O&A
James Harnwell	70 days	Air quality measurement techniques	25	CSIRO O&A
Suzannah Molloy	50 days	Air quality measurement techniques	10	CSIRO O&A
Min Cheng	100 days	VOC analysis	20	CSIRO O&A
Paul Selleck	100 days	DNPH and PM10 analysis, receptor modelling	25	CSIRO O&A
Jennifer Powell	30 days	Air quality measurement techniques	25	CSIRO O&A
Simon Apte	36 days	Water quality	30	CSIRO L&W
Rai Kookana	71 days	Water & soil quality	30	CSIRO L&W
Mike Williams	57 days	Water & soil quality	6	CSIRO L&W
Joshua King	35 days	Water quality	5	CSIRO L&W
Sonia Grocke	4 days	Soil quality	15	CSIRO L&W
Adelle Craig	227 days	Soil quality	5	CSIRO L&W
Chad Jarolimek	14 days	Water quality	20	CSIRO L&W
Jun Du	29 days	Organic analysis	15	CSIRO L&W
James Kear	20 days	Hydraulic fracturing		CSIRO Energy

9. Subcontractors

Subcontractors (clause 9.5(a)(i))	Subcontractor	Role
	ANSTO (Radon group)	Perform Radon measurement
	ANSTO (IBA	Perform analysis of elements using ion beam analysis on PM10 filters

	ANSTO (environmental radiochemistry)	Radionuclide analysis on water and soil samples
	Macquarie University	Perform Mercury measurements
	University of Queensland	Perform PAH analysis
	Ecotech	Supply, install and move air quality station to house PTRMS and two other AQMS's
	National Measurement Institute (NMI)	Analysis of selected organic compounds in water and soil samples

10. Project Objectives and Outputs

Objectives for Phase 2

1. Quantify enhancements in air, water and soil pollutant levels above back ground that occur as a consequence of HF operations.

2. Provide information on the contribution of HF and non-HF related sources of air, water and soil pollutants to local environmental quality at the selected study site

Outputs

The project timeline and milestones are shown in Section 6. Proposed deliverables are

1. Reports on data capture of the air quality and water and soil quality components

2. Draft final reports on air quality and water and soil quality components for peer review

3. Final reports on air quality and water and soil quality components

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

This project is the succession to Phase 1 which has reviewed the state of the knowledge about the potential sources of air, surface water, groundwater and soil pollutants associated with HF and developed peer reviewed study designs for a measurement program to provide enhanced information of the impacts of HF on air, surface water, groundwater and soil quality. The project proposed here is for Phase 2, to carry out the studies designed in Phase 1.

This project was developed through consultation between APLNG and CSIRO O&A. Given the significant community concern associated with HF, CSIRO O&A then approached GISERA to consider including the project in the GISERA umbrella. Stakeholder engagement in Phase 1 also connected the project to other potential industry partners.

CSIRO GISERA Gas Industry Social and Environmental Research Alliance

13. Project Plan

13.1 Project Schedule

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Air Quality field measurement report	Melita Keywood	24 July 2017	1 December 2017	
Task 2	Air Quality draft report	Melita Keywood	1 December 2017	30 October 2018	
Task 3	Air Quality final report	Melita Keywood	1 November 2018	23 December 2018	
Task 4	Water and Soil Quality field measurement report	Simon Apte	24 July 2017	1 December 2017	
Task 5	Water and Soil analysis report	Simon Apte	1 August 2017	1 June 2018	
Task 6	HF chemical fate in soils lab study report	Rai Kookana	1 August 2017	1 June 2018	
Task 7	Water and Soil Quality final report	Simon Apte	1 June 2018	23 December 2018	

13.2 Payment Schedule

Invoice to	Date invoice to be issued	Amount
APLNG	24-Nov-17	$720,333
APLNG	1-Feb-18	$564,667

It is important to note that:

- payment is to be received from APLNG prior to completion of milestones. Payment will reside in GISERA's Bank WBS until the GISERA Director is satisfied that each milestone has been completed.
- APLNG's financial contribution to this project is separate from their contribution for membership to GISERA.

Task 1

TASK NAME: Air quality measurement program report

TASK LEADER: Melita Keywood

OVERALL TIMEFRAME: 24 July 2017 to 1 December 2017

BACKGROUND: Phase 1 of the study involved the development of a peer reviewed study design to investigate the impacts of HF on air quality in the Surat Basin. The study design comprises a suite of measurements of atmospheric gaseous and particle species to be undertaken during HF at a two sites in the Surat Basin.

A three-tier hierarchy of air quality monitoring methods was identified in the study design, ranging from high quality Australian Standard methods (Tier 1) to appropriate internationally recognised methods or standard techniques (Tier 2) to non-standard methods with appropriate calibration and validation procedures to assess their accuracy and precision (Tier 3).Validation of Tier 3 measurements against Tier 1 and 2 methods will be undertaken where possible.

The suitability of measurement techniques was also assessed in terms of the time resolution required to capture emissions from specific activities within the whole HF process (e.g. chemical mixing, injection, and flowback) which occur on time scales of hours to days. Each measurement method was also assessed in terms of the required method detection limits and measurement uncertainty to provide robust and meaningful information about the concentration of an air pollutant. For instance, if the method detection limit is not significantly lower (i.e. at least 10 x lower) than relevant the NEPM or the QLD air quality standard objective for the pollutant under consideration, the method was deemed inappropriate.

Measurements will be undertaken at two sites in the Surat Basin (notionally Condabri and Combabula). Measurements at Combabula will be made at air quality stations (AQMS) and using battery powered perimeter monitoring stations located around the boundary of the property (perimeter monitoring sites) at Combabula. Continuous measurements will occur at the AQMS and perimeter monitoring stations over ~75 days resulting in approximately 6,100 days of data (across 47 parameters). Integrated samples will be collected at the AQMS and perimeter monitoring sites resulting in the collection of 788 samples that will undergo 6 analytical procedures to determine the concentration of at least 74 compounds.

TASK OBJECTIVE: To carry out measurements of air quality parameters using methodologies identified in the peer reviewed study design at two sites in the Surat Basin.

TASK OUTPUTS: Report documenting a meta-data summary of the Air Quality field measurement program including methodologies employed, data capture rates, number of samples collected. The report will also include an analysis of the VOC baseline data collected at Condabri between October 2016 and May 2017

SPECIFIC DELIVERABLES: Report documenting a meta-data summary of the Air Quality field measurement program including methodologies employed, data capture rates, number of samples collected. The report will also include an analysis of the VOC baseline data collected at Condarbri between October 2016 and May 2017.

Task 2

TASK NAME: Air Quality draft report

TASK LEADER: Melita Keywood

OVERALL TIMEFRAME: 1 December 2017 to 30 October 2018

BACKGROUND:
The draft report will present an analysis of data collected during the air quality field measurement campaign. The report will

- Quantify enhancements in air pollutant levels above back ground that occur during HF operations.
- Provide information on the contribution of HF and non-HF related sources of air pollutants to local air quality at the selected study site
- Provide comparisons of the air quality observed at the site with Australian federal and state air quality objectives, as well as data from other air quality studies undertaken in areas not directly impacted by HF operations both within the Surat Basin and in other locations in Australia.

The report will undergo peer review.

TASK OBJECTIVE: To report the air quality impacts of HF at two locations in the Surat Basin

TASK OUTPUTS: A draft report final report on air quality impacts of HF at two locations in the Surat Basin

SPECIFIC DELIVERABLES: A draft report final report on air quality impacts of HF at two locations in the Surat Basin

Task 3

TASK NAME: Air Quality final report

TASK LEADER: Melita Keywood

OVERALL TIMEFRAME: 1 November 2018 to 23 December 2018

BACKGROUND:
The draft final report from Task 2 will undergo peer review by external reviewers (international and Australian). In this task the reviewer's comments will be addressed and the final report produced. In addition stakeholder engagement and a Knowledge Transfer Session will be undertaken to communicate the study findings.

TASK OBJECTIVE: To report the air quality impacts of HF at two locations in the Surat Basin and to communicate outcomes of the study to stakeholders (industry, government and community).

TASK OUTPUTS: A final report on air quality impacts of HF at two locations in the Surat Basin and stakeholder engagement activities

SPECIFIC DELIVERABLES: A final report on air quality impacts of HF at two locations in the Surat Basin, fact sheets, stakeholder meetings where appropriate and Knowledge Transfer Session.

Task 4

TASK NAME: Water and Soil Quality field measurement report

TASK LEADER: Simon Apte

OVERALL TIMEFRAME: 24 July 2017 to 1 December 2017

BACKGROUND: Phase 1 of the study involved the development of a peer reviewed study design to investigate the impacts of HF on water and soil quality in the Surat Basin. This task involves execution of the sampling program. APLNG have also provided CSIRO with background monitoring data for the field sites which requires analysis and interpretation.

TASK OBJECTIVE: To collect water and soil samples from the study sites in the Surat Basin using methodologies identified in the peer reviewed study design

TASK OUTPUTS: Water and soil samples collected and transported to CSIRO laboratories for chemical analysis. Report documenting a summary of the water and soil quality field measurement program including methodologies employed, field observations, number of samples collected. The report will also include an analysis of the water and soil baseline data collected at the relevant field sites between October 2016 and May 2017

SPECIFIC DELIVERABLES: Report documenting the water and soil quality field measurement program including methodologies employed, number of samples collected and field observations. The report will also include an analysis of the water and soil baseline data collected at the relevant field sites between October 2016 and May 2017

Task 5

TASK NAME: Water and Soil analysis report

TASK LEADER: Simon Apte

OVERALL TIMEFRAME: 1 August 2017 to 1 June 2018

BACKGROUND:
The water and soil samples collected during the field sampling campaign will be subjected to a range of chemical measurements. The data will need to be collated in the form of a data report.

TASK OBJECTIVE: To analyse the water and soil samples for a range of chemical constituents (see Table 1) and report the water and soil quality data

TASK OUTPUTS: A detailed data report describing the concentrations of various chemical constituents present in the water and soil samples collected during the field sampling campaign.

This will include quality assurance data.

SPECIFIC DELIVERABLES:
Data on the concentrations of various chemical constituents present in the water and soil samples collected during the field sampling campaign.

Task 6

TASK NAME: HF chemical fate in soils lab study report

TASK LEADER: Rai Kookana

OVERALL TIMEFRAME: 1 August 2017 to 30 June 2018

BACKGROUND:
Given the difficulties of sampling soils for spills and other contamination a laboratory scenario study will also be conducted. This will involve exposing soil samples representative of soil types found across the Surat Basin to HF fluids and flowback waters. The degradation and stability of the added contaminants will then be measured with time. Biological indices such as respiration will also be measured. This study will provide key information on the consequences of chemical spills on soil health.

TASK OBJECTIVE: To conduct a laboratory based study on HF chemical mobility and degradation in soils from the Surat Basin, generate an externally peer reviewed report on the study and to communicate outcomes of the study to stakeholders (industry, government and community).

TASK OUTPUTS: An externally peer reviewed final report on the fate and degradation of HF derived chemicals in soil types found across the Surat Basin, Stakeholder presentations will be conducted as needed.

SPECIFIC DELIVERABLES: A final report on water and soil quality impacts of HF at two locations in the Surat Basin, fact sheets, stakeholder meetings where appropriate and Knowledge Transfer Session.

Task 7

TASK NAME: Water and Soil Quality final report

TASK LEADER: Simon Apte

OVERALL TIMEFRAME: 1 June 2018 to 23 December 2018

BACKGROUND: A large quantity of field and analytical data will be generated during the study and this will need to be interpreted and reported.

TASK OBJECTIVE: To prepare a comprehensive report on the study and to communicate outcomes of the study to stakeholders (industry, government and community).

The draft final report from Task 5 will undergo peer review by external reviewers (international and Australian). In this task the reviewer's comments will be addressed and the final report produced. In addition stakeholder engagement and a Knowledge Transfer Session will be undertaken to communicate the study findings.

TASK OUTPUTS: A final, externally peer reviewed report on water and soil quality impacts of HF at the study sites. Stakeholder engagement that will enhance knowledge transfer.

SPECIFIC DELIVERABLES: Detailed report on water and soil quality impacts of HF at locations in the Surat Basin, fact sheets, stakeholder meetings where appropriate and Knowledge Transfer Session.

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 will be maintained to ensure that they are aware of the outcomes of the research and possible policy implications.

The project will continue to engage with the Technical Reference Group (TRG) established during Phase 1 of the project. The TRG enables the project team to seek peer-to-peer technical advice on contextual matters and to discuss research needs as well as outputs as the project progresses. The TRG includes the project leader and a group of different stakeholders as appropriate.

15. Intellectual Property and Confidentiality

<table>
<tr><td rowspan="3">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></td><td>Not Applicable</td><td></td><td>$</td></tr>
<tr><td></td><td>Not Applicable</td><td></td><td>$</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="3">Commercialisation Interest (clause 1.1)</td><td colspan="2">Party</td><td colspan="2">Commercialisation Interest</td></tr>
<tr><td colspan="2">APLNG</td><td colspan="2">NA</td></tr>
<tr><td colspan="2">CSIRO</td><td colspan="2">NA</td></tr>
</table>

16. Approval from Project Parties

In signing this document you are committing your organisation to provide the specified funds, personnel and the required in-kind contributions.

At date of signing, this Project Order approves Phase Two only of this project and commits CSIRO and industry to completing milestones associated with Phase Two, specifically Tasks 1 - 7 on page 21 of Item 13.1 'Project Schedule' and the ‘Payment Schedule’ set out in 13.2.

Appendix A: Impact of HF chemicals on soil quality

Background

A recent assessment (Patterson et al. 2017 – Environ Sci Technol (in press) DOI:10.1021/acs.est.6b05749) of potential exposure pathways for contamination of soils with chemicals established that spills of HF fluids and flowback water are among the most polluting and plausible pathways of exposure (Table A1). Spills, however, are unpredictable and are very site- and event-specific and therefore conducting a field-based soil contamination study may not yield meaningful information that can be extrapolated to other locations.

Considering the above, a scenario based assessment, mimicking the exposure via spills of HF and flowback water (under controlled conditions) is proposed to be a more appropriate approach as it will generate useful information on the potential fate of HF chemicals in soils that could be used to inform future management of chemicals.

Table A1. Common sources of soil contamination and their relevance/controls to the current study site

Contamination source	Relevance and control	Relative importance
Drill cutting piled on site or reused for rehabilitation	Not stored on site Not used for rehabilitation	Not likely to be significant source
Fraccing fluid is prepared on site	Some chemical blending and handling occurs during the fracking process	Spill of the chemicals could be an important source
Flowback water stored in pits	Flowback water goes into tanks or to wastewater plant via pipeline	Leakage from pits is not relevant Spills from tanks or leakage from pipe can contaminate soil
Chemical stored on site	Chemicals not stored on site	Not likely to be significant source
Disposal of solids from flowback water	Proppants and sediments are not buried or stockpiled on site	Not likely to be significant source
Untreated flowback or produced water reuse	Only treated water (RO) is reused	Not likely to be a contamination source. Untreated flowback water will represents greater risk
Transport of chemicals to and from the site	Transport is essential but carried out under great care	Accidental spill can be an important source. May be similar to those in HF fluid.
Spills, flowline failure, equipment failure	Relevant to the site, unpredictable	Can be a significant source – spills is a key source specific to hydraulic fracturing

The objectives of the study are:

(i) To establish the likely fate in the soil environment of key chemicals that may be accidently introduced to soil via the spill of HF fluids and flowback waters.
(ii) To assess the mobility of a selected suit of high risk chemicals through the soils
(iii) To better understand the potential impacts of soil contamination of HF and flowback waters on soil health (through microbial assays) and potential groundwater contamination.

To cover the exposure and impact pathways as a result of a spill of HF and flowback water on soils and groundwater, three aspects will be covered in this study include

(i) the degradation (persistence) of chemicals in HF and flowback water in soils
(ii) the mobility of HF and geogenic chemicals through soils to shallow groundwater
(iii) the potential impact of the spill on soil microbial health

Methodology

Chemical sources: Two types of fluids are seen as the main contributor to the potential contamination of soil via spills during various operation including transport, namely the HF fluid and the flowback water. The main difference between the two sources is that the flowback water is likely to be highly saline and contain geogenic chemicals (both organic and inorganic) in addition to those present in HF. While some chemicals present in HF fluids may have been attenuated during the HF process, others may remain largely unchanged and in similar concentrations in the flowback water. The chemical composition of the source waters will be characterised.

Soil types:
Five soils types chosen from different geomorphic units occurring in Surat Basin were selected to represent diversity of soil type in the region. These are listed in table A2.

Table A2. Dominant Geomorphic units and soils types in Surat Basin (after Biggs et al. 2012[#]) (* - soils selected in this study)

Geomorphic unit	Dominant soil type	Key features
Alluvia	Black and grey Vertosols*	Clay rich (> 35%)
Basalt	Vertosols, Ferrosols, Dermosols*	Deep clay soils Dermosol – low in free iron
Quartzose sandstones	Chromosols*	Sandy texture contrast soils
Unweathered to moderately weathered non-quartzose sedimentary rocks	Vertosols, Texture contrast Sodosols*, Kandosols	Sodosols - Sodic B Horizon
Moderately to strongly weathered non-quartzose sedimentary rocks	Texture contrast Sodosols, Chromosols, Rudosols*, Tenosols	Rudosols – Sandy loams Chromosols – Sandy over clayey B horizon

[#] Biggs, AJW, Witheyman, SL, Williams, KM, Cupples N, de Voil CA, Power, RE, Stone, BJ, (2012). Assessing the salinity impacts of coal seam gas water on landscapes and surface streams. August 2012. Final report of Activity 3 of the Healthy HeadWaters Coal Seam Gas Water Feasibility Study. Department of Natural Resources and Mines, Toowoomba.

Experimental procedure: All experiments will be conducted under controlled laboratory conditions to avoid any confounding factors in the field. Homogenised soil samples will be subjected to a known volume of chemical sources (two types of fluids) as well clean water. The volume will be determined based on the amount of fluid required to saturate the soil representing a scenario where the spill was adequate to fully saturate the soil and any excess fluid either leached through to deeper layers or migrated through surface runoff. The saturated soil will be allowed to dry and reach a moisture content that is equivalent to 60-70% of maximum water holding capacity before the commencement of experiment. For mobility study, uncontaminated soils will be used.

Experimental details:
Degradation study: The experimental conditions will be based on published relevant studies (e.g. McLaughlin et al. 2016 Environ Sci Technol, 50:6071; DOI:10.1021/acs.est.6b00240). Soil will be incubated under constant temperature and moisture conditions representative of Surat Basin. The soils containers will kept open to atmosphere, as is the case under field conditions.

Mobility study: The study on mobility of selected chemicals in soils will be carried out using the batch method of sorption. It is noteworthy that intact cores are very site specific (due to presence of biopores and soil structure) and hence do not allow extrapolation to other sites. Hence a batch method that will result in more generic assessment is preferred here. The chemicals will be selected based on their persistence and their equilibrium sorption coefficients (Kds) will be measured. This will provide an assessment of their mobility (i.e. retardation factor) in comparison with water flow. This information together with degradation will allow an assessment of their potential of contaminating groundwater as a result of a spill.

Microbial health of soil: The soils exposed to HF and flowback water will be tested for microbial functions in soils. Tests will be conducted to represent carbon turnover (microbial respiration), nitrogen cycling (nitrification) and general microbial diversity. Three standard tests will be carried out. These are OECD 307 Substrate Induced Respiration test (to establish if the general diverse range of bacteria are functioning well), OECD 216 Substrate Induced Nitrification Test (to assess if the specialist bacteria involved in nitrification are affected) and terminal restriction fragment length polymorphism (tRFLP) test to establish any effect on the bacterial diversity in soils.

Chemical analysis: The fate of key chemicals present in source waters will be established by a time series of soil analysis. Three HF and three geogenic chemicals will be included in the study. The sampling times will be 0, 1, 3, 7, 14, 28. 56 and 90 days following commencement of experiment.

Number of treatments: (number of soil samples involved in assays)

Chemical sources – n = 3 (HF and flowback water) + control (RO Water)

Soil types
n= 10 (Vertosol, Dermosol, Sodosol, Chromosol and Rudosol) – 5 surface and subsurface soils (B Horizon)

Number of chemicals
For residue analysis – broad suit depending of what is in HF fluid and in flowback waters.

For sorption study = n= 6 chemicals
(to be identified based on HF fluid composition and flowback water.

Time series for analysis – n= 8 (0, 3, 7, 14, 30, 60 and 90 days) – the last sampling events may depend on earlier results from the experiment.
Number of replicates: 3

Total number of samples:
For degradation study
3 sources x 10 soils x 7 times x 3 replicates = 630 samples (90 samples each time)
For microbial health study
3 sources x 10 soils x 5 times x 3 replicates = 450 samples (90 samples each time)
For mobility study
10 soils x 6 chemicals x 8 concentrations = 480 samples (80 samples for each chemical)

Output:
The study will provide the following:

- Quantification of how rapidly the chemicals in spills are degraded in soils
- Prediction of how the chemicals in spills are likely to move through soil to groundwater.
- Identification of any contaminant that may persist and potentially pose impact on soil microbial health.
- Data and information that is useful for management of spills to avoid contamination.