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Human Health Effects of Coal Seam Gas Activities – A Study Design Framework

Task 4 Report for Health Project (H.1)

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The Gas Industry Social and Environmental Research Alliance (GISERA) undertakes publicly-reported research that addresses the socio-economic and environmental impacts of Australia's natural gas industries.
GISERA was co-founded by CSIRO and Australia Pacific LNG in July 2011. For further information visit gisera.csiro.au.

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Contents

List of Tables

List of Figures

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GISERA is a collaboration between CSIRO, Commonwealth and state governments and industry, established to undertake publicly-reported independent research. The purpose of GISERA is to provide quality-assured scientific research and information to communities living in gas development regions, with a focus on social and environmental topics including: groundwater and surface water, biodiversity, land management, the marine environment, and socio-economic impacts. The governance structure for GISERA is designed to provide for and protect research independence and transparency of research. Visit gisera.org.au for more information about GISERA's governance structure, projects and research findings.

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Glossary

Nomenclature

aldehyde – a class of oxygenated volatile organic compounds including formaldehyde

ambient air – outdoor air

BTEX – benzene, toluene, ethylbenzene, xylenes (a subset of VOCs), found naturally in crude oil and extracted and refined for energy production, emitted during the combustion of fossil fuels and biomass, component of evaporative emissions from diesel and petrol

CSG – coal seam gas; a type of natural gas extracted from coal seams

FIFO – fly-in-fly-out; deployment of personnel to remote locations where they are flown in, spend a period of time working and living at the remote location and are flown out at the end of their shift

geogenic – of geological origin

PAH – polycyclic aromatic hydrocarbons; organic compounds containing numerous carbon atoms joined together to form multiple rings. There are at least 10,000 different PAH compounds.

pH – a scale used to assess the acidity or alkalinity of a solution

quintile – any of five equal groups into which a population can be divided according to the distribution of values of a particular variable

stressor – a chemical or physical agent, environmental condition, external stimulus or an event that causes stress to an organism

tracer – a gas or particle measurement used as a proxy for other atmospheric constituents not directly measured, or used to indicate the likely impact of a specific pollution source

VOC – volatile organic compound; an organic chemical that has a high vapour pressure at room temperature so that it exists in the gas phase

Abbreviations

%DO – percentage dissolved oxygen

ANZECC – Australian and New Zealand Environment and Conservation Council

APLNG – Australia Pacific Liquefied Natural Gas

APPEA – Australian Petroleum Production and Exploration Association

AQMS – Air Quality Monitoring Station

ARMCANZ – Agriculture and Resource Management Council of Australia and New Zealand

BTEX – benzene, toluene, ethylbenzene, xylenes (a subset of VOCs)

CH_4 – methane

CO – carbon monoxide

CO_2 – carbon dioxide

CSG – coal seam gas

EC – electrical conductivity

EHP – Queensland Department of Environment and Heritage Protection

EIS – environmental impact statement

GISERA – Gas Industry Social and Environmental Research Alliance

HIA – Health Impact Assessment framework

N – Nitrogen

$N(NO_x + NH_4)$ – nitrogen comprised of oxides of nitrogen and ammonium

NEPM – National Environment Protection Measure

NH_4 – ammonium

NORM – naturally occurring radioactive material

NO_x – oxides of nitrogen

P – phosphorous

PAH – polycyclic aromatic hydrocarbons

PM_{10} – particulate mass with an aerodynamic diameter of < 10 µm

$PM_{2.5}$ – particulate mass with an aerodynamic diameter of < 2.5 µm

QAEHS – Queensland Alliance for Environmental Health Sciences

SBAAQ Study – Surat Basin Ambient Air Quality Study

STI – sexually transmitted infections

TDS – total dissolved salt

TRH – total recoverable hydrocarbons

TSP – total suspended particles

UNG – unconventional natural gas

VOC – volatile organic compounds

Executive summary

Unconventional natural gas (UNG) production activities in Australia are dominated by coal seam gas (CSG) in New South Wales and Queensland. A 2014 report by the NSW Chief Scientist on managing environmental and human health risks from CSG activities identified potential risks to the environment (air, soil, water) and risks and uncertainties around human health from emissions arising from CSG activities (OCSE 2014). The report concluded that the risks can be managed through regulation and monitoring. Despite this finding, concerns about possible health effects continue to be voiced in communities with CSG development and more widely. Acknowledging the concern over the potential health impacts of CSG activity, CSIRO's Gas Industry Social and Environmental Research Alliance (GISERA) and the Queensland Alliance for Environmental Health Sciences (QAEHS) have funded the first steps of a study design project that will investigate the influence of CSG activity in Australia on human health.

The study design project focuses on a review of the state of knowledge about health impacts of CSG activity, identification of gaps in the knowledge base, and development of a framework that can be used to design a study to address identified gaps. The framework produced in the study design project will be used to develop proposals for one or more future studies across Australia's CSG regions.

The literature review conducted as part of the project highlighted a lack of robust studies around the stressors and health impacts associated with Australian CSG activities. Most available scientific knowledge and data relates to shale gas regions in the United States and does not necessarily translate to the Australian context where CSG industry regulation, geological conditions, and gas extraction methods differ. In particular, current Australian CSG activity has a lower prevalence and intensity of hydraulic fracturing activities. The CSG resource is found closer to the surface than shale gas and does not contain liquefied petroleum material that is often associated with shale gas. The presence of liquefied petroleum material associated with shale gas may result in vaporisation of volatile organic compounds (VOCs) that may contribute to poor air quality. In addition, differences in the gas composition between shale gas and CSG have been observed with the presence of more reactive VOCs (including BTEX chemicals – benzene, toluene, ethylbenzene and xylene) contributing to higher ozone formation potential in shale gas developments (Ahmadi & John 2015; Edwards et al. 2014). With only a few limited studies being carried out in the area of health impacts of CSG activities, the literature review found that there is currently insufficient evidence to conclude whether there are health impacts associated with CSG activities. However, the literature review has revealed methods and approaches that may be applicable to Australian CSG regions.

Understanding community concerns about CSG development and health is fundamental to the design of a potential health study. Community perspectives were collected in Queensland and New South Wales to inform the project. The main factors raised by community stakeholders as warranting investigation and inclusion in a future health study were concerns related to direct chemical and physical hazards, concerns related to social stressors and mental health effects, and benefits related to improved health outcomes for the region.

The project was informed by an Expert Workshop in May 2017. The workshop involved technical experts from government, academia and industry, as well as community-based health professionals. The discussions in the workshop were divided into three topics: stakeholders; information needed for a health study; and potential health study approaches. The importance of community involvement in any future health study was a recurring and fundamental theme that was expressed by participants across all three days of the workshop. Community involvement was seen as critical to the success of work in this area and trust, transparency and independence were criteria considered vital for the success of a future health study (factors that were also raised during the community perspectives research component of the study design project). The workshop participants agreed that a study should address both chemical/physical stressors and social stressors, with research into social stressors focusing on strategies to alleviate the sources of stress.

There was general consensus among workshop participants that the Health Impact Assessment (HIA) framework is an effective and useful framework to evaluate health impacts related to CSG activities.

The study framework proposed here uses the core tenets of the HIA to identify potential health impacts on a population from a CSG development. HIAs generally apply existing knowledge and evidence about health impacts to develop evidence-based recommendations. The framework proposed here is aimed toward generating new, foundational evidence on the possible exposures on residents living in the vicinity of CSG activities in Australia and any associated health impacts.

The framework being offered here has two parallel streams of research:

1. Conducting exposure and health impact assessments for chemical and physical stressors.
2. Identifying CSG activities potentially contributing to social stress and defining effective intervention and mitigation strategies to reduce exposure to these stressors, while maximising benefits in the context of the community's overall resilience.

A series of staged steps are the essence of the framework, with consultation and decision points at each step:

1. A *Scoping and Planning* stage defines the overall structure for a study in a given location, including strategies for involving stakeholders, communicating findings and meeting research ethics requirements. This stage establishes processes to support the quality and legitimacy of the research. Details of the governance principles are included in Section 5 of this report.

2. The *Identification and Screening* stages establish the potential sources of chemical and physical hazards (air, water, soil, noise and light) and other stressors, such as social stressors. They also define how community members near CSG activities might be exposed. These stages compile existing data, assess the data for quality and validity, and establish a data archive. Through these processes, gaps in knowledge are identified. Details of the conceptual model approach that can be used to identify hazards (Stage 2) and sources of data (Stage 3) are included in Section 6 and Section 7 respectively.
3. The *Further Assessment* stage involves in-depth assessments of exposures and risks as well as health outcome assessments. This stage addresses gaps in data in relation to relevant

chemical and physical stressors. This stage also identifies social stress status as well as needs and mitigation opportunities to minimise social stress impact. Details of exposure assessment and health outcome assessment methods are presented in Section 8.

4. The *Recommendations* stage is the final stage in the framework and integrates findings, draws conclusions and makes recommendations, including identifying needs for ongoing monitoring.

The framework is designed around three key principles identified in the Expert Workshop and through discussions with community stakeholders:

1. All aspects of the study should be open and transparent, and outcomes must be publicly available, working within ethical approval guidelines.
2. The study should seek community and stakeholder involvement throughout the process, from scoping to recommendations.
3. The study should result in recommendations to mitigate negative health impacts and promote positive impacts, that is, benefits to the community and individual health.

It is widely recognised that in any Australian CSG region there may be confounding factors to be considered when conducting an investigation using the proposed framework. Confounding factors are extraneous factors that independently affect the risk of developing a health outcome, and their presence can make defining single associations between an exposure and an outcome challenging. These confounding factors include the presence of other industries in a region that may be an alternative source of chemical, physical and social stress. They can also include pre-existing sources of chemical contamination before CSG development commenced. Confounding factors may also include other, non-CSG related social stressors such as how drought can affect agricultural businesses and farmers. These factors may also act as effect modifiers by interacting with CSG development stressors. Ensuring that confounding factors are identified, documented and accounted for in the study design is part of the *Identification* stage of the framework.

Some chemical stressors may be specific to a particular industry, such as pesticides and agriculture. For other stressors, which may come from both CSG activities and other industries (e.g. dust), the study approach may involve designing monitoring strategies to isolate industry-specific sources. Where that is not possible, the total exposure of the community to all sources could be determined and appropriately communicated.

The nature of confounding factors underlies the framework's approach to social stressors. It is not designed to quantify stressors and benefits associated specifically with CSG (or other singular) activities. Rather, it is to identify those aspects of CSG activity that contribute to the overall stress experienced by individuals or communities, and to develop mitigation and amelioration strategies to reduce exposure to these stressors and to support increasing resilience for the region as a whole regardless of the source of the stress. In relation to confounding factors, strategies for interpretation and communication of results will be an important aspect of the communication and community involvement strategies defined in the *Scoping* stage.

The framework described here will require a transdisciplinary project team with expertise ranging from physical and chemical sciences to social science and ethics. A core capability will be communication and knowledge brokering. In addition, while the examples and context given in this report have been developed around current CSG extraction activities in Australia, the framework is equally applicable for all unconventional gas activities.

The staged approach described in the framework includes several decision points. These multiple stages, and participatory decision-making about progression, make it very difficult to estimate the exact timeframe required to carry out an entire health study. However, up to and including Stage 3 *Screening*, one can expect at least 24 months to be required.

1 Introduction

Unconventional natural gas production activities in Australia are dominated by coal seam gas (CSG) in New South Wales and Queensland. For example, annual CSG production in the Surat Basin of Queensland has increased from 8 Mm^3 in 2004/05 to 21,187 Mm^3 in 2015/16 (Queensland Government 2017). Potential human health risks from CSG activities are consistently raised as an issue of concern to the community (OCSE 2014). Directly measuring human health outcomes through epidemiological studies of communities near CSG development is difficult for two main reasons. First is the size of the population exposed to CSG activities. The CSG industry in New South Wales is relatively small, and the rural areas exposed to CSG development in Queensland are not heavily populated. Epidemiological studies involving small populations often do not provide meaningful results due to statistical limitations. They cannot clearly distinguish between disease states or health outcomes that may be caused or aggravated by exposures related to CSG activities and background occurrence of these conditions. Second, some potential health effects of concern may not manifest over shorter time periods. Rather, they emerge after longer periods (many years or decades) of exposure or latency. Thus, direct studies of health outcomes may not be practicable and may not provide meaningful conclusions about the impacts of CSG activity on human health.

Human health risk assessment techniques can provide qualitative, semi-quantitative or quantitative estimates of potential human health risks. The level of quantitative evaluation depends on the type and degree of data that are available regarding the possible chemical exposures and other physical and social stressors experienced by residents in communities near CSG development.

Acknowledging the concern over the potential health impacts of CSG activity, GISERA has funded the study design project to investigate the influence of CSG activity in Australia on human health.

The study design project included a review of the state of knowledge about health impacts of CSG activity, identification of gaps in the knowledge base, and development of a framework that can be used to design a study to address these gaps. The framework produced in the study design project will be used to develop proposals for one or more future studies across Australia's CSG regions.

The methodology employed in this initial scoping effort is shown in Figure 1. Included in this methodology is a literature review, consultation with the community and an Expert Workshop during which conceptual models of the hazards associated with CSG activities were identified. The literature review, community consultation perspectives, a summary of the Expert Workshop and a description of the conceptual models have been the subject of previous reports (Aylward et al. 2017; Keywood et al. 2017). The report presented here is the final report (Task 4) for GISERA Project Number H.11. It presents the framework that will be used to design studies to investigate the influence of CSG activity on human health.

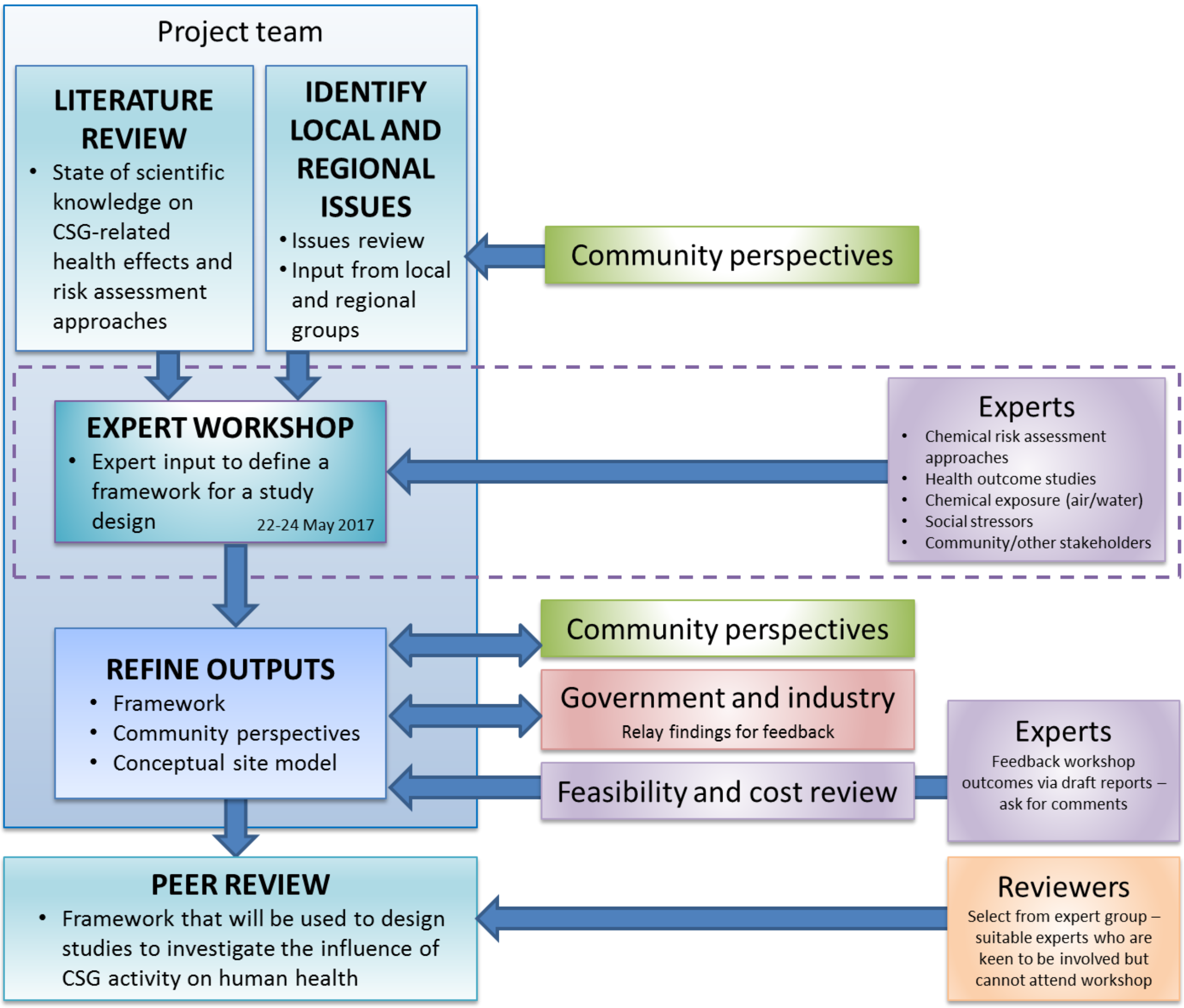


Figure 1 Methodology used in this study

2 Key insights/conclusions from previous activities

In this section we summarise the key points from the literature review, community engagement and Expert Workshop that are relevant for the framework. Details of these activities are found in Aylward et al. (2017) and Keywood et al. (2017).

2.1 Insights from community stakeholders

2.1.1 Health issues to investigate in a future health study

Three sets of factors related to health and CSG development were identified by community stakeholders as warranting investigation and inclusion in a future health study. They were:

- concerns related to direct chemical and physical hazards
- concerns related to social stressors and mental health effects
- benefits related to improved health outcomes for the region.

These are summarised in Figure 2.

Concerns related to effects of chemical and physical hazards

- Water contamination
- Air quality impacts including dust and methane seeps
- Soil contamination
- Noise and light impacts

Concerns related to social stressors and mental health effects

- Uncertainty - especially over the long term
- Farmer specific – stress related to managing the relationship, feeling intimidated and powerless, potential impact on water, property values
- Cumulative effects – on top of other stressors, such as dealing with other impacts at the same time (inland rail, pipeline construction, water buyback schemes as part of the Murrat Darling Basin plan, drought), heavy work loads, loss of spouse, low socioeconomic issues, poor health
- Town related issues – worries about boom-bust effects
- Polarised views – very strong emotions that unfold in public or social media; strains friendships, social networks, and community cohesion; effects of 'scare mongering', people feel pressured, confused, worried about who to believe

Benefits related to improved health outcomes in the region

- Improved safety culture at work - extends to the wider community
- Improved services or community programs through corporate support
- Economic benefits to local enterprises

Figure 2 Summary of health issues identified by community stakeholders to consider in a future health study

Concerns related to direct chemical and physical hazards

As depicted in Figure 2, health concerns from chemical and physical hazards included: possible effects of *water contamination* on health; *air quality effects* from combustion (flaring) and fugitive emissions of methane, dust, and odour associated with CSG operations or related infrastructure; possible *soil contamination* and subsequent effects on animals and human health; and the impact of *noise* and *light*. Although participants were unsure of the exact nature of possible health effects, they were aware of claims of nose bleeds, headaches and skin rashes associated with CSG development, particularly in the Surat Basin.

Concerns related to social stressors and mental health effects

Social stress and mental health impacts were described as the most prevalent health issue associated with CSG development, with differing effects experienced among residents within a region. As summarised in Figure 2, for some residents it is anxiety related to the *uncertainty* of the industry; for *farmers and land owners* it is stress related to possible on-farm impacts, managing the relationship with a CSG company, and a sense of powerlessness; the *cumulative effect* of CSG development in conjunction with other stressors such as drought and long work hours; *town related* issues associated with housing impacts and effects on local businesses from boom-bust effects; and the effect of *polarised views* about CSG development. Social pressure to adopt polarised views about gas was described as a cause for stress within some parts of the community, and individuals who held either strong oppositional views or strong pro-gas views also described stress associated with feeling bullied or maligned on social media, which could then impact their families.

Benefits related to improved health outcomes for the region

Community stakeholders also indicated a health study needs to recognise any beneficial effects as well as addressing negative impacts. Three main types of benefits associated with the industry identified from the data were:

- improved safety culture at work that extends to the wider community and local businesses
- improved health and social services through corporate support of community programs and local services that support health related initiatives
- reduced financial stress from economic benefits to local enterprises – both farm businesses and local town businesses.

2.1.2 Guiding principles and considerations for the design of any future study

Community stakeholders identified a range of considerations important for meeting their expectations of a good study design and for generating trust and acceptance in the findings of any future health study. These considerations are detailed in Table 1 and included:

- the importance of *trust* and *independence*
- the significance of establishing *baseline measures of environmental and health parameters*
- the importance of considering context when investigating possible health effects, especially *cumulative effects* and the impact of *confounding factors.* For example, factors associated with impacts from other non-gas activities, such as agriculture; pre-existing environmental issues, such as those associated with Linc Energy (DEHP 2017); and the social determinants of health and lifestyle factors that may affect an individual's physical health, such as housing type and location
- the need to take a *long-term perspective* and *make use of existing knowledge*, especially local knowledge

- the importance of an *action and communication* plan, including the ongoing *involvement of community* and *managing expectations* with respect to the limitations of a health study.

Community stakeholders also raised a range of important questions to consider in the design of a future health study. These include:

- What will be the actions if risks are found – management approaches, commitment from industry – and how will this be communicated?
- How will chemical health effects be differentiated from psychosomatic effects?
- What about people who work in the industry – are there any health effects?
- In the case of Queensland – how will dealing with the 'here and now' be addressed in a health study when the industry is already started?
- How will you separate out the effects of CSG from other factors – for example, pre-existing environmental factors, other industries, individual health/mental health situations?
- How will other industries be involved in a future health study if findings potentially implicate other (non-CSG) industries as potential causes of health effects (e.g. health effects related to agriculture)?
- What was the basis of making one decision over another when designing the study?

Overall, there was support for conducting a health study, though concerns were raised about possible ramifications of an adverse finding for agriculture and how issues related to the possible impact on agriculture would be managed. There was acknowledgement among community stakeholders of the importance for communities to understand the potential health effects associated with CSG development.

Table 1 Community perspectives on guiding principles and considerations for the design of a future health study

Theme	Notes
Trust is paramount	• Findings need to be substantiated with 'real' data wherever possible – e.g. medical results, exposure measurements – Trust in qualitative data very low as this could reflect biased views about gas • Need to build trust in industry measurements and modelling if going to rely on industry data – e.g. test reliability by comparing with other data sources, repeated measures • Publicly available and transparent data and processes very important – e.g. live data streams; continuous, and accessible good quality data • Use legitimate and credible sources – e.g. national toxicity standards, scientifically qualified experts • Peer review – one option is for different interest groups to nominate a suitably qualified candidate as part of the peer review process

Independence is key and underpins trust and credibility	• Problems with 'who do you trust' – everyone seen to have a vested interest – pro-gas groups, anti-gas groups, and government – particularly in Queensland where CSG development is seen as rushed with concerns that adaptive management not always working
	• Clear, independently developed terms of reference could help credibility
	• Independent committee to oversee project
	• Mixed views regarding industry funding of a future study
	  – Some concerned about 'tainted' money and that such a study would not be deemed independent
	  – Others were less concerned and expressed pragmatism – where will the money come from if not funded in part by industry?

	– Some believed industry *should* be funding a study and bearing the costs of determining health effects – Whatever the view about funding, all agreed the study needs to be **conducted independently**
Baseline studies critical	• Before any increased CSG activity occurs, gather baseline data – to identify natural variation in air, dust, noise, water
Context is very important	• Consider *cumulative* effects – e.g. the effects of a stressor related to CSG activity adding to a farmer's stress already experienced due to the impact of drought • Consider all *confounding* factors – e.g. factors associated with other non-gas activities such as intensive agriculture and coal mines in the area (dust and chemical use) that may confound the findings; pre-existing issues (Linc energy issues); social determinants of health and lifestyle factors at the individual level
Need to take a long-term perspective	• Risks and possible effects need to be understood **over the long term especially where the science is uncertain**
Make use of existing knowledge	• Use existing knowledge and data sources to feed into a possible study design and the focus of investigation– e.g. overseas studies, research from surrogate industries, report from NSW Chief Scientist (2014), learnings from Queensland Health (2013) • Listen to local knowledge and involve local health service providers – check local hospital data, check for incidence of learning disabilities
Action and communication plan important component of any future study	• An action and communication plan needs to be part of any health study design • Communities need to be involved in any study – e.g. through key special interest groups, local councils, local health services and stakeholder reference groups • Concerns that an adaptive management approach has not necessarily worked as a way to manage emergent issues in Queensland • Comparisons of risks could be useful as a way to communicate the findings
Overall, support for conducting a health study	• Overall, there was support for conducting a health study even from those who weren't concerned about health effects • A health study seen as one of the last areas of research to be done; however, needs to be managed carefully to ensure all confounding factors considered so that accurate outcomes are achieved • Needs to be **able to withstand scrutiny** from special interest groups • Important to be inclusive and allow participation of people who are concerned or worried about their health and CSG development in the study

2.2 Key conclusions from the literature review

A literature review conducted as part of the project highlighted a lack of robust studies around the stressors and health impacts associated with Australian CSG activities (Aylward et al. 2017). Most available scientific knowledge and data relate to shale and oil gas regions in the United States, and do not necessarily translate to the Australian context where CSG industry regulation, geological conditions, and gas extraction methods differ. In particular, current Australian CSG activity has a lower prevalence and lower intensity of hydraulic fracturing activities. The natural gas resource is found closer to the surface than shale gas. Also, CSG does not contain liquefied petroleum material that is often associated with shale gas. With only a few limited studies being carried out in this area, the literature review found that there is currently no conclusive evidence of health impacts associated with CSG activities. Specifically:

- Overall, while chemicals and activities associated with CSG development may have the potential to cause health effects, whether such chemicals are reaching nearby residents in sufficient concentrations to cause noticeable health effects has not been established in the research literature and is likely highly jurisdiction- and site-specific. More data from coordinated, in-depth studies are required from Australian CSG regions to understand whether there are risks or not.

- The literature to date provides frameworks and methods for health risk assessment, identifies challenges in conducting epidemiological studies, and highlights gaps in knowledge in various relevant areas. Detection of specific health effects and the ability to relate them to the chemical, physical and social stressors in various communities is challenging due to:

  – the multi-factorial nature of human disease

  – the limitations in data on both exposure and outcomes

  – the challenges inherent in studying small populations.

  Additional research is needed to address identified information gaps and challenges in establishing causal relationships between exposure and health outcomes.

- Social stressors are key factors potentially affecting the health of communities in the vicinity of CSG activities. While established metrics are generally available to measure exposure to social stressors, studies linking exposure to associated health effects in the CSG context are lacking. Social stressors may exacerbate the effects of co-occurring chemical stressors, but cumulative impacts are generally unquantified.

2.3 Key conclusions from the Expert Workshop

The Expert Workshop was held in Brisbane, Queensland on 22–24 May 2017. The goal of the workshop was to share information and insights from a range of health and related experts and to formulate a plan to study the potential human exposures, health risks and potential health effects of CSG activities. A detailed summary of the workshop is reported in Keywood et al. (2017).

The workshop was attended by 36 participants from research and government organisations, including CSIRO, Queensland Government, New South Wales Government, several universities, and other experts including community-based health professionals.

The focus of this workshop was to gather scientific and governmental expertise and viewpoints related to the scientific methods and design considerations of a health study. Information about community concerns was incorporated into the workshop through presentations regarding the research presented in Section 2.1 above, as well as contributions from workshop participants who were involved in CSG communities.

Three key workshop topics

1. Stakeholders
2. Information sources and conceptual models
3. Health study approaches

The discussions in the workshop were divided into three key topics: stakeholders; information needed for a health study; and potential health study approaches. In discussions about stakeholders, the importance of community involvement in any future health study was a recurring and fundamental theme that was expressed by participants across all three days of the workshop. Community involvement was as seen as critical to the success of work in this area.

Information sources and conceptual models for a health study were discussed and explored. Workshop participants provided their input to generating lists of possible data sources relevant to a future health study. They also helped to identify a range of possible hazards that might be found around four different site scenarios.

The workshop participants agreed that a study should address both chemical/physical stressors and social stressors, with research into social stressors focusing on strategies to alleviate the sources of stress.

In discussing various health study approaches, there was a general positive consensus among workshop participants regarding the effectiveness and applicability of the Health Impact Assessment (HIA) framework to evaluate health impacts related to CSG activities. Generally, HIAs are used to incorporate health issues into planning processes. The framework combines procedures, methods and tools to predict or evaluate potential health outcomes for a population arising from an action (e.g. policy, program, or project) (Taylor & Quigley 2002). The HIA is generally made up of several stages – screening, scoping, identification and assessment of impacts, decision-making and recommendations, and evaluation, monitoring and follow-up. The HIA framework forms the basis for the framework that is presented in Section 4 of this report.

3 Insights from the process

3.1 Key principles

Three key principles were identified in the Expert Workshop and through discussions with community. These became the core tenets of the proposed framework for a future study:

- All aspects of the study should be open and transparent and outcomes publicly available, working within ethical approval guidelines.
- The study should seek community and stakeholder involvement throughout the process, from scoping to recommendations.
- The study should result in recommendations to mitigate negative health impacts and promote positive impacts.

A significant outcome of the workshop was the acknowledged ubiquity of social stressors in CSG communities. It was also recognised that CSG development can bring social benefits to individuals and communities that can serve to ameliorate adverse health outcomes from social stressors. However, sub-populations can be disproportionately affected by positive and negative social impacts (i.e. 'winners' and 'losers' may not be the same groups) and it was considered by some that net overall stress at a community level is likely. Given the ubiquity and complexity of social stressors, it was proposed that resources were better directed towards defining and implementing intervention and mitigation strategies to reduce this stress, rather than undertaking detailed assessments of stress/benefit levels and associated mental health outcomes. To this end, the proposed framework has two parallel, and somewhat independent, streams of research:

- Understanding exposure and health risks associated with chemical and physical stressors, through exposure and health impact assessments.
- Identifying CSG activities contributing to social stress and defining effective intervention and mitigation strategies to reduce exposure to these stressors, while maximising benefits to enhance the community's overall resilience.

3.2 Confounding factors

It is widely recognised that in any Australian CSG region there may be confounding factors to be considered when conducting an investigation using the proposed framework. Confounding factors are extraneous factors that independently affect the risk of developing a health outcome, and their presence can make defining single associations between an exposure and an outcome challenging. These confounding factors include, for example, the presence of other industries in a region that may be an alternative source of chemical, physical and social stressors, and pre-existing sources of chemical contamination before CSG development commenced. They also include other, non-CSG related, social stressors such as how drought can affect agricultural businesses and farmers. These factors may also act as effect modifiers by interacting with CSG development stressors.

Before the commencement of the study, key confounders, independent risk factors for identified health outcomes and potential effect modifiers could be identified using directed acyclic graphs and data collected purposively during the study (Williamson et al. 2014). Directed acyclic graphs are visual representations of causal assumptions that are increasingly used in modern epidemiology. They can help to identify the presence of confounding factors or mediation for the causal question being explored.

Ensuring that confounding factors are identified, documented and accounted for in the study design is a key aim of the *Identification* stage of the framework.

The study approach to confounding factors will be shaped by the type of factors identified in the region. Some chemical or physical stressors may be specific to a particular industry, such as pesticides and agriculture, and therefore the stressors and the potential health impacts that they may be associated with can be separately identified in the study assessments. For other stressors, which may come from both CSG activities and other industries (e.g. dust), the study approach may involve designing monitoring strategies to isolate industry-specific sources. Where that is not possible, the total exposure of the community to all sources will be determined and appropriately communicated.

The nature and expected presence of confounding social factors is behind the framework's approach to social stressors. The framework is not designed to quantify stress associated specifically with CSG (or other singular) activities. Rather, it is to identify those aspects of CSG activity that contribute to the overall stress experienced by individuals or communities and to develop mitigation and amelioration strategies to reduce exposure to these stressors and to support increasing resilience for the region as a whole regardless of the source of the stress. In relation to confounding factors, strategies for interpretation and communication of results will be an important aspect of the communication and community involvement strategies defined in the *Scoping* stage.

3.3 Future study priorities and fundamental gaps in knowledge that need to be addressed

A number of knowledge gaps and other considerations have been identified that are relevant to any future study of health impacts associated with CSG activities. The following points should be kept in mind when planning and conducting a study in Australia.

Proposed prioritisation strategy for future studies

While it is recognised that there is an existing body of data related to previous and ongoing monitoring activities, an in-depth heath impact study has yet to be conducted in an Australian CSG region. Any future study conducted using this framework will therefore provide foundational new knowledge on exposures and possible related health effects that may be associated with the Australian CSG industry. Every CSG site is unique; however, there will be many commonalities between different Australian CSG regions, particularly with respect to the types of stressors and the exposure pathways. A prioritisation strategy for (initial) future studies is proposed as follows:

- A **high-activity, established CSG region** is identified to undertake the inaugural study using the framework (which may comprise a suite of studies working collaboratively). Detailed knowledge from this site will inform, with the intention of simplifying and streamlining, future studies in other regions.

- A **new region** is identified where CSG activities are planned but not commenced. The study framework would be applied to undertake a baseline assessment of existing chemical, physical and social stressors in the region, including, as appropriate, an archiving program of relevant environmental and human samples. This study would provide the baseline levels of stressors against which on-going monitoring in the region once CSG activities have commenced can be assessed. As with the high-activity site, data from the baseline study site would provide detailed knowledge to inform future studies in other regions.

In addition, prioritisation may be required to work within a given budget. This may result, for example, in breaking a future study up into a suite of smaller studies to be undertaken as budgets permit.

Chemicals used and emitted by the Australian CSG industry and their related toxicological information

While a co-ordinated database of chemicals used by the Australian CSG industry is not currently available, industry makes available the material safety data sheets for all chemicals used during drilling and hydraulic fracturing (e.g. https://www.aplng.com.au/about-us/compliance/material-safety-data-sheets.html). However, information on the quantities used and locations of use are not publicly available. In addition, information on chemicals used in US shale activities (where hydraulic fracturing is used extensively and chemical regulation differs) is often cited by the community as a concern. A key task in any future study is to establish and make available Australian chemical information either as data provided by industry and/or determined/validated through non-target analysis (i.e. screening for unknown chemicals) of environmental samples.

Inventories of emissions resulting from the CSG extraction process including VOCs, NORM, metals, and salts are also required. This includes fugitive emissions to air and water from chemicals during their handling, transport and storage, as well as species emitted from petrol and diesel engines during combustion.

An assessment of toxicological information (dose-response assessment) for Australian CSG chemicals would be part of the Hazard Assessment phase of an enHealth Risk Assessment Framework, a nationally recognised approach to environmental health risk assessment (enHealth 2012). Overseas studies suggest that relevant, reliable toxicological information for specific health endpoints is only available for a small fraction of chemicals used. Similarly, data relating to dose-response relationships for social stressors, as well as mixtures of chemical stressors and social/chemical stressors, are limited or non-existent. In the absence of reliable toxicity data (which may be translated to regulatory guideline values for human exposure, e.g. as dietary intake limits) and/or dose-response relationships, a risk assessment is not possible. This may be a limitation of future health impact studies in Australia.

Establishing relationships between exposure and health impacts in small populations

The literature review highlighted that human health outcome studies, such as epidemiological studies, in CSG regions are very limited, and both in the scope of the outcomes that have been examined and in the extent to which associations between exposures and health have been independently studied and/or replicated. Furthermore, social stressor-related health impacts have seldom been considered and approaches to establish causal relationships between social stress and health impacts are not well defined in the literature. Australian CSG regions pose additional challenges due to the generally small population sizes living in the vicinity of CSG production infrastructure. It is often not possible to make statistically sound inferences based on small population data. This may limit the effectiveness of future health outcome studies in Australia.

Availability of existing and future monitoring and health data

A key outcome of the Expert Workshop, which was also been voiced in community discussions, is that existing monitoring and health data from Australian CSG regions, if validated, are of high value to any future health impacts study. Such data may provide an indication of baseline levels and/or temporal trends in stressor and health levels. While some data are publicly available, not all data can be accessed due to, for example, patient confidentiality or industry commercial-in-confidence considerations. Moreover, previous data may have been collected for other purposes and not be useful as data for a health study. Strategies to access previously restricted data which are often held by stakeholders in the CSG and health arena (e.g. through de-identification of data) are an important consideration for the planning of future cost-effective studies. Likewise, a key component of any future study under the proposed framework is to ensure that all outcomes of the study are made publicly available and that the data and associated samples are archived in a public repository for future use. This will allow retrospective assessment of exposures and health.

4 Study design – recommended framework

An approach to undertaking robust, comprehensive and conclusive studies of potential health impacts from CSG activities is proposed here. The study framework uses the core tenets of the Health Impact Assessment (HIA), an existing framework used widely in Australia to identify potential impacts of a development on a population.

The main output is an evidence-based set of recommendations that propose practical ways to remove or minimise potential or realised negative impacts on health and wellbeing. It also addresses health inequalities that may arise or exist as a result of the development, as well as promoting potentially positive health impacts (Taylor & Quigley 2002).

HIAs generally apply existing knowledge and evidence about health impacts to develop evidence-based recommendations. The framework proposed here is aimed toward the design of studies that will generate new, foundational evidence on the potential impacts of CSG activities on the health of Australian populations living in the vicinity of CSG activities.

The tailored framework (referred to as the framework from here on) incorporates assessment of both chemical and physical hazards related to chemicals in air, water and soil, as well as noise and light. Social stressors (and/or benefits) associated with changes in a region due to CSG activities are also addressed, such as significant social and economic changes accompanying a temporary construction boom, factors that may have consequent negative (or positive) effects on human physical or mental health.

As outlined in Section 3.1, the framework has two streams of research:

- Conducting exposure and health impact assessments for chemical and physical stressors
- Identifying CSG activities contributing to social stress and defining effective intervention and mitigation strategies to reduce exposure to these stressors, while maximising benefits to enhance the community's overall resilience.

These will be staged approaches with consultation and decision points about subsequent phases.

Key outcomes of the Expert Workshop were the acknowledgement of the ubiquity of social stress in CSG communities, and the difficulty of researching cumulative social impacts, for example, stress from drought added to CSG-related changes, and other confounding factors. These considerations resulted in a proposal that resources be directed toward defining and implementing intervention and mitigation strategies to reduce this stress and support increased resilience and adaptive capacity within the community, rather than undertaking highly complex, detailed assessments in search of specific sources or impacts of mental health outcomes.

The framework involves a series of stages:

1. A ***scoping*** and ***planning*** stage defines the overall project structure and strategies for involving stakeholders, communicating findings and meeting all ethics requirements. A major aim of this stage is to establish processes and governance that will support the legitimacy and quality of the research. The research objectives and project team are established in this stage.
2. The ***identification*** stage establishes the potential sources of chemical and physical hazards (chemicals in air, water and soil, plus noise and light) and other stressors, such as social stressors, and the pathways by which the community may be exposed to the hazards. This is done by developing a site-specific conceptual model of hazard and risk identification. At the end of this stage a decision is made about whether a chemical or physical hazard poses a health risk and whether further screening and assessment is required.
3. The ***screening*** stage involves the collection of all existing data (physical, chemical, social and health) and establishes the quality of existing data sets. Gaps in data are identified and new data may be collected if required to understand key exposure and health factors for the study location.
4. The ***further assessment*** stage involves in-depth exposure and risk assessments, as well as health outcome assessments. This stage addresses any gaps for relevant chemical and physical stressors. A health needs assessment approach would be used to further investigate and mitigate social stressors.
5. The final ***recommendations*** stage integrates findings, draws conclusions and makes recommendations including any need for ongoing monitoring.

It is important to note that this framework:

- can begin before an industry activity has commenced (i.e. at environmental impact assessment phase) or once it has been established
- seeks community and stakeholder involvement throughout the process
- results in recommendations to mitigate negative health impacts and promote positive impacts
- is applicable to chemical, physical and social stressors since there is common ground for Stage 1 and Stage 2, which then branches out to chemical/physical and social stressors for Stage 3. Social and chemical/physical hazards are, however, identified in different ways.

Assessment in the framework refers to the process of considering all the available information on potential health impacts gathered during the Identification step of the framework. For the purposes of this report, we focus here on specific health effect studies that may be conducted in a community, and which may contribute to the overall assessment of potential health impacts. For example, Witter et al. (2013) used air monitoring data as part of their HIA to estimate health risks from exposure to air pollutants for residents living in proximity to wells in a community undergoing natural gas development.

During the *Further Assessment* stage, selection of a specific study design or designs will be driven by a number of factors. One of the major considerations in selection of a study design is the specific health endpoint(s) of concern to be studied. Identification of the health endpoints of interest is likely to be influenced both by the concerns of the specific community as well as by examination of health effects identified as potentially associated with CSG or unconventional natural gas (UNG) activity in previous studies. A second category of factors affecting study design selection is the specific characteristics of a given community, including the population size and the demographics of the population. Finally, study design selection will also be affected by the financial resources available to conduct the study. Note that while the examples and context given in this report have been developed around current CSG extraction activities in Australia, the framework is equally applicable for all UNG activities.

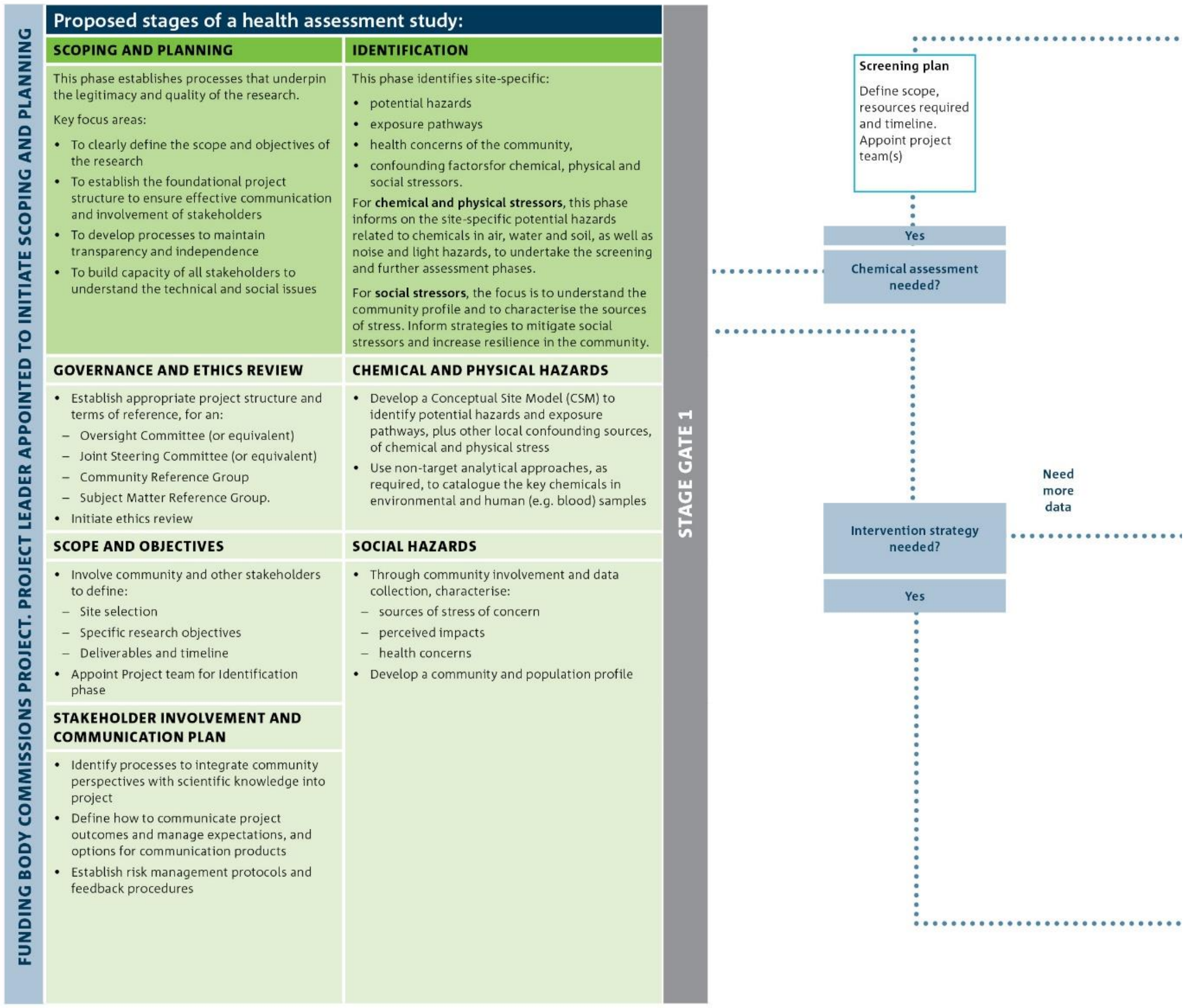
An overview of the framework, with a description of the key steps, is given in Figure 3.

The study framework is designed around three key principles:

a. All aspects of the study should be open and transparent, and outcomes publicly, within ethical guidelines;
b. The study should seek community and stakeholder involvement throughout the process, from scoping to options; and
c. The study should result in options to mitigate negative health impacts and promote positive impacts

Important notes:

- Prioritisation may be required to work within a given budget. This may result, for example, in breaking a future study up into a suite of smaller studies to be undertaken as budgets permit.
- Although the framework is illustrated as sequential steps, some steps may be efficiently undertaken in parallel
- Project plans will need to adapt as new information becomes available
- Information and findings will be communicated throughout the project via explainers and fact sheets
- The project will work in collaboration with existing programs, studies and initiatives



The framework includes two Stage Gates (1 and 2), which represent decision points on whether to continue to the next stage or to finalise the study. The decision point considers the information and outcomes of the study to that point.

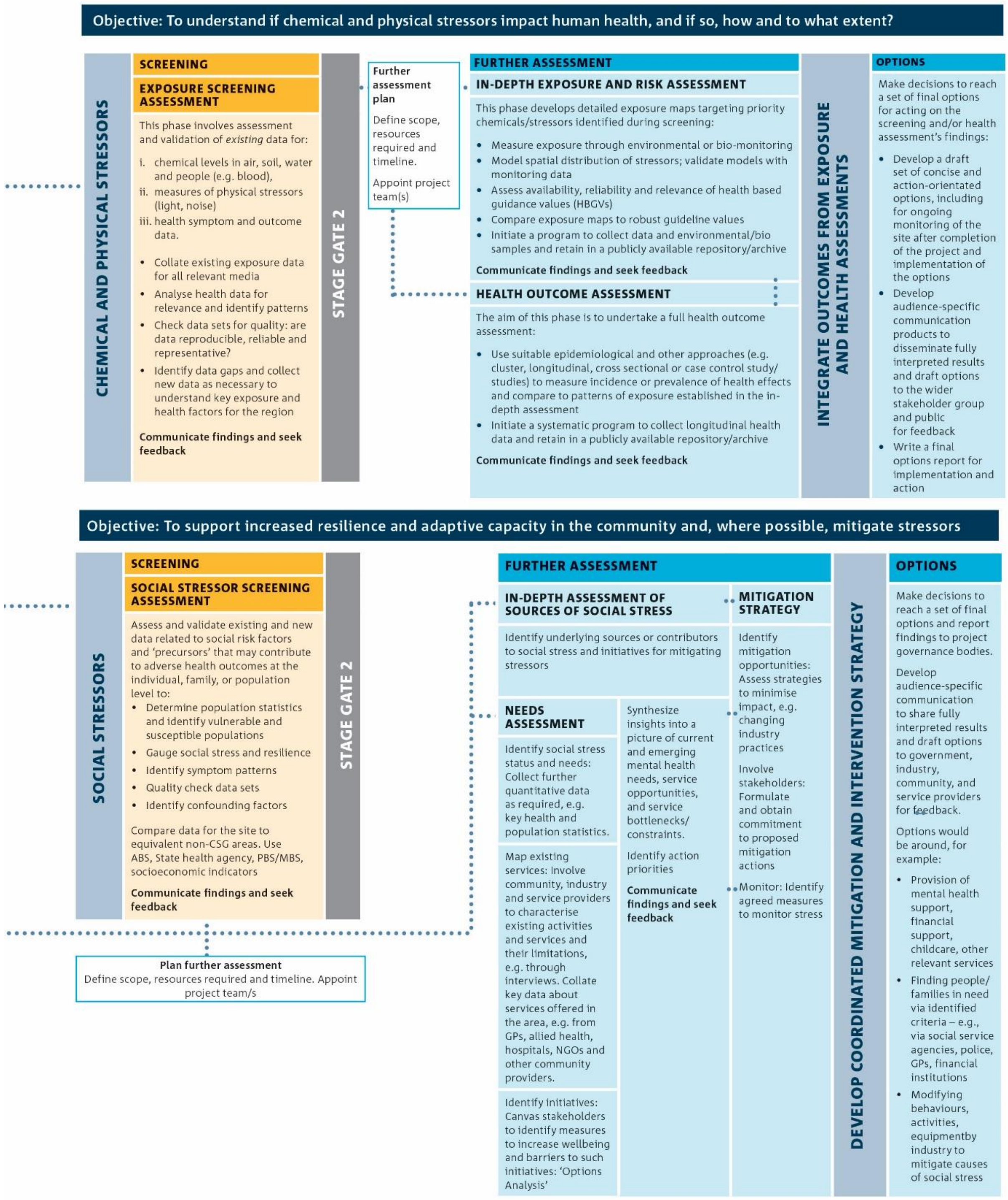


Figure 3 Proposed framework to design studies to investigate the influence of CSG activity on human health

5 Community involvement and governance considerations (Stage 1)

5.1 The importance of community involvement

Community involvement in health-related research is widely recognised as an important component of a successful project. It provides valuable input into the way research is framed, how the research is conducted, and how the results are communicated and translated into improved policy and programs (NHMRC 2016; Payne et al. 2011). Such involvement can help to bring about enhanced health outcomes. In Australia, the *Statement on Consumer and Community Involvement in Health and Medical Research* (NHMRC 2016) outlines the benefits that community involvement can bring to both the research process and its outcomes by helping to ensure the quality and relevance of the research, and by supporting public confidence in the research findings. In addition, international research identifies inclusion of community stakeholders in decision-making about managing risks associated with environmental issues as essential for success, especially in situations where there are emerging technologies, uncertainty and heightened perceptions of risk, such as around unconventional gas (National Research Council 2008; North et al. 2014; van der Vegt 2017).

Context of CSG in Australia

The context of CSG development can be characterised as follows:

- Relatively new industry and technology with high levels of perceived uncertainty about environmental, health and social impacts
- Risk perceptions are high in those places that could be facing CSG development
- A distinct concern exists for latent risks that may unfold over time
- Trust levels are low, both in CSG governing bodies and CSG companies
- A range of views about CSG development exist within and between communities
- A sense of agency and community empowerment is low with communities not feeling heard or listened to and not feeling involved in decision-making around CSG development (Leonard et al. 2016; Walton & McCrea 2017; Walton et al. 2016)

Done well, community involvement helps to improve the quality and legitimacy of decisions, and the capacity of those involved in decision-making (National Research Council 2008; Schroeter et al. 2016). This results not only in better outcomes but also in enhancing trust and understanding among the entities. Quality of decisions is improved through the inclusion of values and concerns of community stakeholders (interested and affected parties) combined with scientific and technical knowledge from experts about the issues. Legitimacy is achieved when stakeholders view the process of community participation as fair and competent, and working within existing laws and regulations. Capacity of individuals is improved through developing a shared understanding of the issues and a wider consideration of the challenges associated with each decision (National Research Council 2008; Renn & Schweizer 2009).

5.2 Governance

A fundamental aim of a future health study is to conduct an activity that is viewed as both scientifically robust and meeting community expectations. This project identified the importance of conducting a study that would not only deliver scientifically reliable and valid findings but would also be undertaken in a way that was considered independent and trusted by the community. The purpose of the governance structure in a future study is to support the quality and legitimacy of the research processes and outcomes so that findings can be trusted. Establishing an Oversight Committee, Community Reference Group and Subject Matter Reference group (or equivalents) and ensuring the functioning of each group through appropriate terms of reference will be a major task of the *Scoping and Planning* stage of a future study. Incorporating such steps into the ethics review, including how community, government, industry and technical stakeholders would be identified and engaged, would also provide improved legitimacy to the governance structure of the project. In addition, a Joint Steering Committee (or equivalent) would provide high-level oversight and further support to research governance and translation of the study findings and recommendations into outcomes.

Figure 4 shows an example of how such a project structure could work to support quality and legitimacy in the research. A brief description of the function of each is provided to give an indication of the role of each committee and group, although the precise role, responsibilities and function would depend on the context and funding of the actual study.

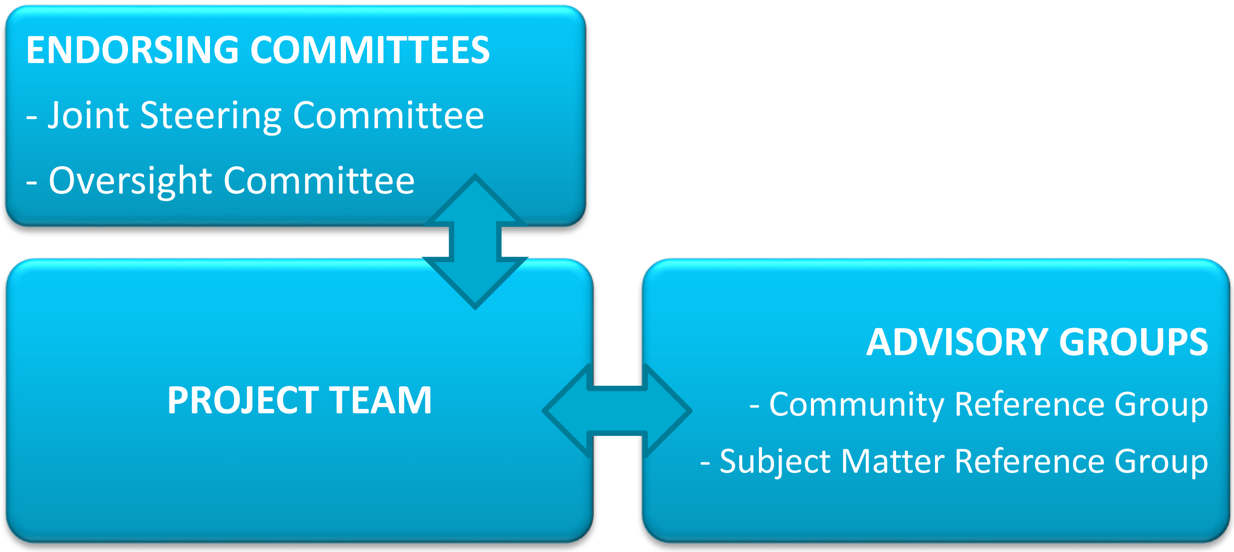


Figure 4 Example of project functional structure

Joint Steering Committee

An overarching Joint Steering Committee or equivalent would function to provide endorsement of major project decisions, particularly at key decision points within the framework, such as decisions to proceed to the next research stage or in relation to funding. The Joint Steering Committee would also endorse project recommendations and act as champions of the project using their influence to leverage recommended changes into policy, industry guidelines and community programs and initiatives as necessary.

Oversight Committee

The Oversight Committee contributes to the legitimacy and quality of the research by safeguarding the integrity of the processes undertaken throughout the research. Adopting a neutral and balanced approach, it performs an oversight role to ensure independence of the project is maintained and research outputs and findings can be trusted. The Oversight Committee would also function to make sure the research is undertaken in a manner that meets ethical and regulatory guidelines. Examples of tasks would be to oversee the development of processes for maintaining transparency and independence, and check processes related to selection of committee members including community and subject matter reference groups.

Community Reference Group

Legitimacy is also fostered through the involvement of community stakeholders who can be described as parties interested in and affected by potential health effects from CSG development at a local level. They include community members, local government, local and regional health service providers and other relevant stakeholders. Through the Community Reference Group these stakeholders will bring valuable insights to the process, which are integral to the success of the research, including community values and perspectives and local knowledge. These aspects will contribute to formulating, identifying and prioritising problems which in turn will shape research questions and the research process. Local knowledge will also assist data collection and help contextualise findings. A commitment to inclusion of community stakeholders and their involvement through the Community Reference Group will also help to build trust in the project's findings among all stakeholders and the wider public.

Subject Matter Reference Group

The Subject Matter Reference Group will provide technical expertise and scientific knowledge. The involvement of experts from a range of fields will also contribute to the legitimacy and quality of the findings. The Subject Matter Reference Group may, in reality, comprise multiple technical reference sub-groups formed to provide advice on a range specific functional area or subject matters. For example, a specific technical reference sub-group may exist in relation to water contaminants, or air monitoring, or public health expertise. In this way, industry and government experts can be incorporated into functionally based technical reference groups, with each group comprising a diversity of backgrounds and employer groups. This would help to balance the potential influence of industry or government which otherwise may operate as a distinct advisory entity.

Sharing information and learning

The two reference groups may also be supported by more distal groups, such as existing community groups or a technical community of practice outside of the governance structure. These distal connections would help to support an extended network for enabling two-way communication and create effective mechanisms for feeding back information and feeding in issues for consideration. In addition, processes to support cross-pollination and sharing of information, ideas and learnings between the Community Reference Group and the Subject Matter Reference Group should be established. This would foster strengthening of capacity in terms of community stakeholders' understanding of scientific information and technical experts' understanding of community values and local knowledge. Depending on the context, these two groups may choose to function as one group or may do so intermittently.

Project team

The project team would be responsible for delivering the project objectives outlined in the commissioning of the project and undertake decision-making with respect to the execution of the research. They would ensure that the research processes and outcomes reflect both stakeholder values and technical expertise such that the project outcomes are viewed as justifiable and reflect robust science. The project team would also undertake an administrative role to ensure that the functions of the project are conducted in a timely and cost-effective manner and meet budgetary, legal and regulatory requirements.

In addition, the project team would undertake an advisory role to the Joint Steering Committee, providing advice on key project decision points that incorporates perspectives from both the Community Stakeholder Reference Group and Subject Matter Reference Group. The project team would seek endorsement from the Joint Steering Committee for major project decisions.

5.2.1 Guiding principles to foster independence and trust

The study design project identified a range of factors that are important for supporting trust in the research process and subsequent findings. The international literature also provides useful insights for ensuring those values important to stakeholders are realised in the research approach (National Research Council 2008; North et al. 2014; Wheeler et al. 2015). In combination, these can be considered as guiding principles and would be relevant for project execution and all committee functioning in a future health study. These guiding principles would be reflected in the respective terms of reference.

Guiding principles for functioning of the project team and associated governing committees and working groups

- Transparency of processes and decision-making
- Collaborative approaches to problem identification and process design
- Genuine two-way dialogue and good-faith communication
- Paying explicit attention to both facts and values
- Promoting explicitness about assumptions and uncertainties
- Using independent and appropriately skilled researchers or others to perform the activities required in the research process
- Allowing for iteration and reconsideration of past decisions and processes on the basis of new information
- Involving community stakeholders in communication plans, products and processes
- Considering context and situation in all decision-making

6 Identification (Stage 2)

A core prerequisite of any study conducted under the proposed framework is to establish a comprehensive understanding of the study region. Critical information for the *Identification* stage for chemical, physical and social stressors includes:

- geographical location of CSG infrastructure and community resources/services (e.g. schools) and residential dwellings
- regional geology, pedology and hydrogeology, atmospheric composition and meteorology
- topography and environmental setting (e.g. natural barriers such as wooded areas)
- CSG industry practices, process/occupational health and safety controls in place and incidences of accidents and other non-compliance issues
- profile of the population (e.g. demographics, population density, age, occupation, landowners with CSG wells)
- health concerns of the local population
- baseline health indicators
- nature, source and exposure routes of chemical, physical and social stressors from CSG activities
- confounding factors in the region (e.g. alternative source of stressors resulting from, for example, non-CSG industries, the regional economy or drought; pre-existing stressors).

This site-specific information enables the identification of stressors relevant to the site and establishes which of these stressors are expected to have a complete human exposure pathway. If an exposure pathway is not complete, then there is no risk to human health (enHealth 2012).

To be complete, all of the following elements should be present (USEPA 1989):

- A source and release **(emission)**
- Movement or a transport medium away from the source **(fate and transport)**
- Contact with humans **(exposure point)**
- Exposure through ingestion, inhalation or dermal contact (chemical stressors), sight or hearing (physical stressors), or awareness (social stressors) **(exposure route)**.

The exposure pathway concept is equally applicable to chemical, physical and social stressors. For social stressors, the stress (e.g. increased traffic, housing impacts or on-farm impacts) may exist but will only potentially impact on the health and wellbeing of an individual who is aware of the stressor and is reactive to the stressor (either to his or her detriment or benefit).

The key output of the *Identification* stage is a conceptual site model (CSM) that attempts to encapsulate all the above information. Presentation of a CSM usually involves a graphical representation and/or a flow chart or table of complete exposure pathways, with accompanying explanatory text.

6.1 Conceptual site model for a CSG region

Potential human exposure pathways that may be relevant to an Australian CSG production region, and therefore included in the CSM, were identified at the Expert Workshop (Table 2). Exposure pathways are expected to change over the life of a CSG region (from construction to operation and through to decommissioning/well abandonment). Some exposure pathways may be common to two or more development phases.

The following general points should be considered when developing a CSM:

- The construction phase stimulates greatest change for a region, especially for those living in towns, and is associated with a high flux of fly-in-fly-out (FIFO) workers. Social stressors dominate this phase. Significant change and associated stressors may also be experienced during the pre-construction, impact assessment process.
- During the operational/production phase, chemical emissions can be associated with accidents or faults in the CSG operations. The likelihood of a complete exposure pathway being present therefore depends on the frequency of operational 'failures'. Physical stressors are, by contrast, often associated with normal operational practices (e.g. flare light, drilling noise).
- Controls and other strategies to mitigate and alleviate stressors already in place should be accounted for in the CSM. The residual risk, after relevant controls and mitigations are considered, is risk of the exposure pathway that is assessed.
- Some exposures may continue after the well decommissioning phase is complete. The longevity of potential exposure pathways highlights the needs for long-term monitoring of decommissioned sites.
- While the term 'stressor' is generally associated with impacts that may adversely affect human health, the exposure pathways associated with health benefits for individuals and the community (particularly from a social perspective) should also be included in the CSM.
- The likelihood of these hazards occurring is considered as part of the risk assessment activity conducted in the *Further Assessment* stage.

Table 2 Example of a hypothetical conceptual site model for the operational phase of CSG development. Letters correspond with a potential exposure pathway inFigure 5.

	HAZARD	SOURCE	MEDIA	EXPOSURE ROUTE
CHEMICAL STRESSORS				
A	VOCs, nitrogen oxides	• Truck/other vehicle exhaust • Generators	Air	Inhalation
A	Dust, particulates	• Well construction/drilling • Unpaved roads – traffic, heavy equipment • Diesel trucks and other engines • Rehabilitation post decommissioning	Air/ Water/ Soil	Inhalation, ingestion
B	Drilling muds and additives	• Well drilling • Produced or flowback water	Water/ Ground water/ Air (if volatile)	Ingestion, inhalation (if volatile)
C	Hydraulic fracturing fluids	• Mixing 'place' (offsite or onsite) • Accident or spillage during transport • Leaking storage containers • Fractured well casing, hoses, etc. • Flowback water	Soil/ Water/ Ground water/ Air (if volatile)	Ingestion, dermal, inhalation (if volatile)
D	Gases (may include hydrogen sulphide, VOCs, carbon dioxide, nitrogen oxides, radon)	• Well construction/drilling • Produced or flowback water • Fugitive emissions from wells – e.g. uncapped and/or abandoned wells • Fugitive emissions from pipes • High point vents off the gathering lines • Low point valves off the gas lines • Well engines causing unprocessed gas to be emitted • Fugitive emissions via geological faults (due to disturbed coal seam beds) • Leaks in casings greater than 50 years old, vertical movement along abandoned well • Natural emission from soil	Air	Inhalation
E	Salts, heavy metals, petroleum hydrocarbons (non-volatile), naturally occurring (geogenic) radioactive materials	• Naturally present in groundwater • Well construction/drilling • Produced water spills and leakages • Water treatment facility discharge • Waste disposal methods – e.g. spray produced water on roads to control dust • Vertical movement along abandoned well	Water/ Ground water/ Soil	Ingestion, dermal

F	Combustion products, metals from rooftops to collect rainwater	• Flaring • Gas-fired gas processing facilities (compressors, generators) • Gas-fired water treatment facilities	Air/ Roof rainwater	Ingestion, inhalation
E	Radioactive tracers	• Injected to well (to measure how far fracturing has gone)	Water/ Ground water	Ingestion, dermal
PHYSICAL STRESSORS				
A **C** **F**	Noise, low frequency noise	• Trucks and increased traffic • Pumps • Diesel engines, generators • Drilling • Hydraulic fracturing • Venting/flaring	Air	Hearing
A	Vibration	• Heavy equipment • Drilling • Hydraulic fracturing	Air, ground	Touch
A **F**	Light	• Flaring • Traffic at night • CSG activity lighting	Air	Sight
A **D**	Odour	• Trucks • Fugitive and combustion emissions	Air	Smell
A	Methane	• As listed above for gases	Air	Explosion (methane is not considered an inhalation hazard except in a confined space)
SOCIAL STRESSORS				
A	Traffic accidents	• Increased traffic • Large trucks, heavy equipment • Speeding drivers on unfamiliar roads • Young drivers	Individuals and community can be ‘exposed’ to social stressors through, for example: • Personal experience, contact or involvement • Experiences of neighbours and friends • Media reports • Social media • Community meetings	How an individual responds to a social stressor will determine the potential health impacts. This may include, for example: • Worry • Fear • Anger • Frustration • Injury • Despondency • Mistrust • Apathy
	Demographic change	• Changed employment opportunities • Changed property market		
	Change in character of the region Poor aesthetics Wellbeing decline	• Infrastructure • Increased traffic • Damaged roads • Land clearing		

		• Loss of habitat for native fauna; injury to native fauna and stock animals	• Government reports and information	• Sadness • Disappointment The focus in this table is primarily on negative impacts. It is important to note that there are also perceived and real benefits from CSG activities. Social changes leading to health improvements for both individuals and the community should be included in the social stressor assessment (for examples, see final line in table).
G	Water resource impacts	• Loss of/competition for ground water		
	Degradation of environment Ecosystem impacts	• Land clearing • Contamination of ground water • Seismic activity		
	Unemployment	• Post-CSG reduction in job opportunities • Local businesses fail		
	Environmental health impacts: - Human health - Ecosystem health - Global warming	• Chemical and physical stressors		
	Credibility of regulator Community confidence if a leak occurs	• Any post-decommissioning problems with plug and abandon (P&A) wells		
	Loss of community cohesion	• Winners and losers • Blame if you 'let it in'		
	Helplessness/ Hopelessness Social disruption/ dislocation	• Land use conflict • Loss of identity		
	Rent stress and displacement	• Influx of people – rent prices increase • Market dynamics change		
	Decreased property values	• Population movement out of region • Oversupply rental properties post-CSG		
	Work stress and overwork	• Skills in community are lost to the industry • Salary differences		
	Sexually transmitted infections (STIs) and unplanned pregnancies	• Influx of FIFO workforce		
	Alcohol & drug abuse	• Increase in alcohol consumption		

		• Drug dealers move into area
	Disease outbreaks	• Construction camps • Social contact
H	On-farm concerns	• Impact on daily operations • Loss of privacy • Impact on farm profitability • Dealing with CSG operator
	Disappointment with government	• Seen to support industry and not community
I	**Benefits**	• Improved safety culture at work that extends to the wider community and local businesses • Improved health and social services through corporate support of community programs and local services that support health related initiatives • Reduced financial stress from economic benefits to local enterprises – both farm businesses and local town businesses.

Some of the stressors in Table 2 are illustrated in an example (hypothetical) graphical representation of a CSM in Figure 5. The graphic shows some of the main stressors associated with the operational phase of a CSG region but does not include stressors specific to well construction or decommissioning. Examples of graphical representations for these two additional phases can be found in the Expert Workshop Summary (Keywood et al. 2017).

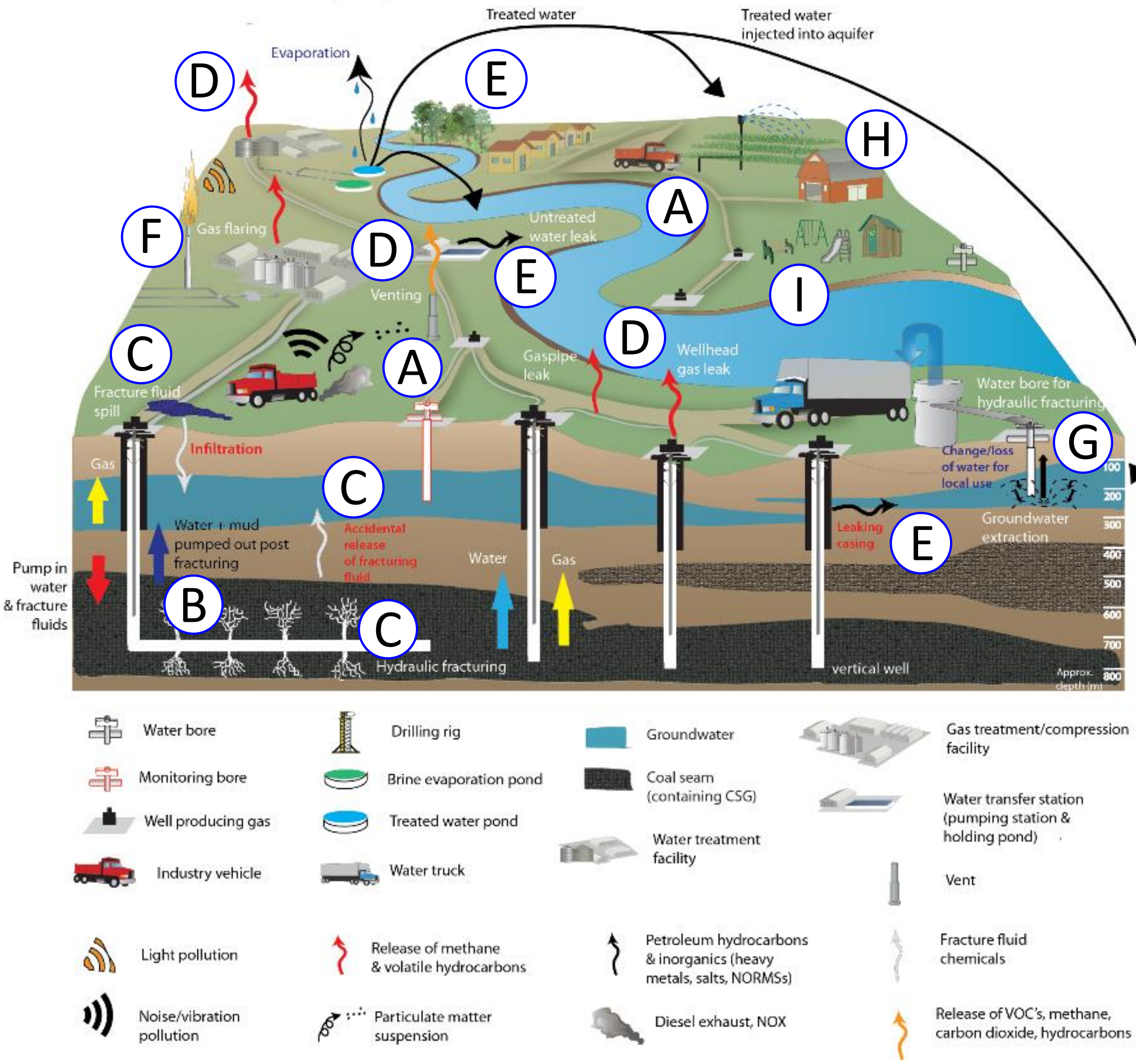


Figure 5 Example of a hypothetical conceptual site model for the operational phase of CSG development. Letters correspond with a potential exposure pathway in Table 2. Graphic developed by Rachel Mackie (QAEHS)

7 Sources of existing data – Screening (Stage 3)

In this section, we highlight some of the sources of data and information that could be accessed for a health study. While not exhaustive, this section provides a starting point for discovering data. A significant activity of the *Screening* stage of the health study will involve identifying relevant data sources before accessing them.

The section is divided into sub-sections on air quality, water and soil quality, social stressors and health data sources. Government and industry information are discussed for the air quality and water/soil quality data sources. A sub-section listing research data and information sources completes this section.

Environmental impact statements (EIS) are a significant source of information. An EIS is required as part of the application process for mining projects in Queensland and New South Wales. The EIS is a tool to assess the current environment in the area of the project, the potential environmental, economic and social impacts of the project, and proposed mitigation processes to reduce or offset the potential impacts. The EISs with information that may be relevant to a health study are listed in Table 3.

Table 3 Environmental impact statements for Queensland and New South Wales gas field developments

Company and Location	EIS website
Santos Bowen and Surat Basins, Qld	http://www.statedevelopment.qld.gov.au/assessments-and-approvals/santos-glng-environmental-impact-statements.html
Santos Narrabri, NSW	http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6456/
APLNG Surat and Bowen Basin, Qld	https://www.aplng.com.au/content/origin-aplng/en/index/about-us/compliance/eis.html
Arrow Bowen Basin, Qld	https://www.arrowenergy.com.au/projects/project-assessment-eis/bowen-gas-project-eis
Arrow Surat Basin, Qld	https://www.arrowenergy.com.au/projects/project-assessment-eis/surat-gas-project-eis
QGC-BGI Group Surat Basin, Qld	https://www.statedevelopment.qld.gov.au/assessments-and-approvals/queensland-curtis-liquefied-natural-gas-project.html
AGL Camden, NSW	https://www.agl.com.au/about-agl/how-we-source-energy/natural-gas/natural-gas-projects/camden-gas-project/camden-gas-project?yearFilter=&categoryFilter=Environmental%20Assessments%20CGP&sortOrder=DESC&pg=1

7.1 Air quality information

Air monitoring data are collected by regulatory authorities (New South Wales Office of Environment and Heritage, Queensland Department of Environment and Heritage), by industry and during research activities by universities and other research organisations including CSIRO.

The data collected by regulatory authorities and industry are prescribed as part of reporting for health-based standards. These include:

- **National Environment Protection (Ambient Air Quality) Measure – 2015.** The pollutants to which this NEPM (2015) measure applies are nitrogen dioxide, carbon monoxide, ozone, sulphur dioxide, particulate matter (PM) with diameters less than 10 µm (PM10) and 2.5 µm (PM2.5) and lead.
- **National Environment Protection (Air Toxics) Measure – 2011.** The pollutants to which this NEPM (2011) measure applies are BTEX compounds (benzene, toluene, xylenes, ethylbenzene) as well as formaldehyde and polycyclic aromatic hydrocarbons (PAHs) as benzo(a)pyrene.
- **Queensland Environmental Protection (Air) Policy (EPP) – 2008.** The EPP (2008) includes all air toxics prescribed in the Air Toxics NEPM (above) along with 18 other organic and inorganic pollutants.

7.1.1 Regulatory authorities

New South Wales

In New South Wales these data are collected by NSW Office of Environment and Heritage (http://www.environment.nsw.gov.au/topics/air), which operates a network of air quality stations across five regions. The Rural NSW region of the network includes an air quality station at Tamworth (170 km south-east of Narrabri). Variables measured include meteorology, PM10 and PM2.5. The station was commissioned in 2000 but does not comply with the Australian Standard AS/NZS 3580.1.1:2007 – Methods for sampling and analysis of ambient air – Guide to siting air monitoring equipment, as the clear sky angle is <120° due to trees within 20 metres to the north-east and east of the monitoring site. Another station, located at Bathurst (500 km south of Narrabri) was commissioned in 2000 and includes the measurement of meteorology, ozone, PM10 and PM2.5.

An air quality station situated at the Camden aerodrome in New South Wales has been collecting data on meteorology, oxides of nitrogen, carbon monoxide, visibility, PM10 and PM2.5 since 2012. Between 1994 and 2004 ozone and oxides of nitrogen were also monitored at this station.

The NSW Environment Protection Authority commissioned CSIRO to carry out an investigation of methane and VOC emissions in New South Wales (Day et al. 2016). The report includes VOC concentrations measured at well pads and well heads at the Camden Gas Project and well pads and a compression plant at the Narrabri Gas Project during winter and spring of 2015. In addition, VOC concentrations measured at 10 sites around Camden during winter and spring 2014 and summer and autumn 2015 are reported.

NSW Office of Environment and Heritage has been operating the DustWatch program since 2002. This is a citizen-science program that gathers data about dust storms to primarily monitor wind erosion. The network includes close to 40 monitoring stations in New South Wales where community volunteers help maintain the stations and report dust activity in their area. While a DustWatch station does not exist at Narrabri, the map shown in Figure 6 shows DustWatch stations at Moree (100 km north of Narrabri), Walgett (185 km to the west of Narrabri), Gunnedah (94 km south-west of Narrabri) and Dubbo (280 km south-west of Narrabri).

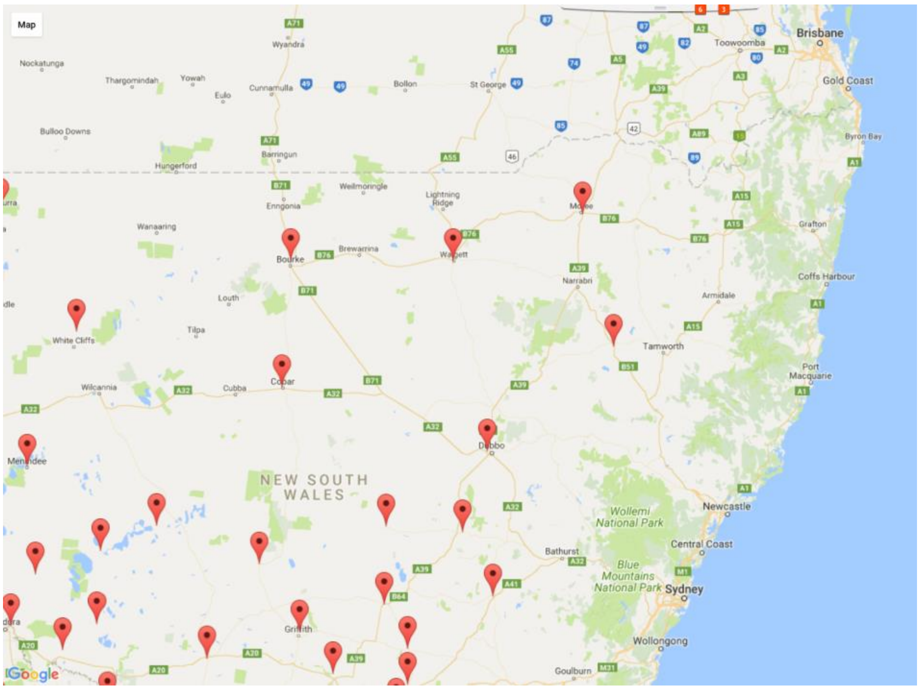


Figure 6 Dustwatch Network (Source: http://www.environment.nsw.gov.au/topics/land-and-soil/soil-degradation/wind-erosion/community-dustwatch)

Queensland

In Queensland air quality monitoring data are collected by the Department of Environment and Heritage Protection which operates a network of air quality stations across seven regions. Air quality monitoring in south-west Queensland was established within the Western Downs region by CSIRO's GISERA as part of the Surat Basin Air Quality study (Lawson et al. 2017). These stations were located to specifically assess air quality in an area of intensive CSG production. Air quality monitoring stations are located at Hopelands, Miles Airport, Condamine, Burncluith and Tara Region. Three of these monitoring stations (Hopeland, Miles Airport and Condamine) are situated on properties near CSG infrastructure such as gas processing facilities and active gas wells while two of these stations (Tara Region and Burncluith) are 10–20 km from major CSG infrastructure. Environmental consultants operate the monitoring network on behalf of CSIRO/GISERA. Method and data validation for the network is overseen by CSIRO. These stations have been operating since 2015 and include measurements of meteorology, oxides of nitrogen, ozone, carbon monoxide, total suspended particles (TSP), PM10 and PM2.5, methane and total VOCs (see https://www.ehp.qld.gov.au/air/data/search.php). In addition, VOC monitoring using passive samplers was conducted at 10 locations around the Surat Basin Ambient Air Quality Study (Miles) region from 2014 to 2016 (Lawson et al. 2017) and five sites around Roma as part of the GISERA Hydraulic Fracturing study in 2016-2017 (Dunne et al. 2017).

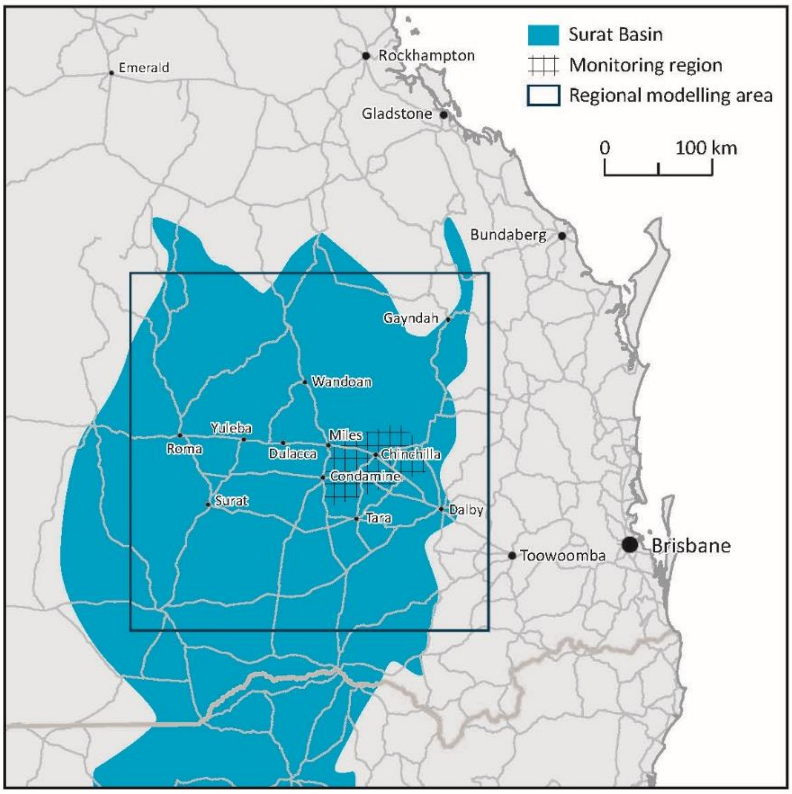


Figure 7 Map showing the Surat Basin (shaded in blue), the areas covered by the current Surat Basin Ambient Air Quality Study air monitoring network, and regional monitoring area (Source: Lawson et al. 2017).

The Toowoomba air quality station operated between 2003 and 2010 by the Queensland Department of Environment and Heritage Protection included measurements of meteorology, oxides of nitrogen, ozone, sulphur dioxide, carbon monoxide, PM10 and PM2.5.

Concentrations of VOCs measured at the Wieambilla Estate in July 2012 and at Hopelands and Chinchilla in March 2015 are reported in DSITIA (2012) and DSITIA (2015) respectively.

7.1.2 Industry

The data collected by industry are generally for compliance purposes (e.g. as part of the EIS). However, data collected by industry could also make a significant contribution to a health study. While some data may be discoverable in reports produced for compliance purposes, other unpublished data sets will require negotiation with industry to access. Some information is available in the EISs listed in Table 3, which generally include an air quality assessment chapter. Most air quality information in the EISs is based on scenario modelling.

While not exhaustive, following are a few examples of ambient air observational programs operated by industry:

- The Origin Combabula Development Area (CDA) Air Monitoring Program comprised an air quality monitoring station (AQMS) located at Combabula, 80 km north-east of Roma. Air pollutants measured as part of the CDA program included carbon monoxide, oxides of nitrogen (NO, NO_2, NO_x) and ozone for the period July–November 2015.
- Santos GLNG installed two ambient air quality stations (Roma and Fairview) to collect representative ambient air quality data upstream of gas extraction and processing activities

in 2014. The air quality impact assessment report that makes up part of the Santos GLNG EIS (SLR 2014) states that the stations would operate for at least six months and would include the measurement of NO_2, CO, wind speed and wind direction and monthly average VOCs by passive sampling.

- An example of industry monitoring emissions sources is demonstrated at Camden where AGL are required to monitor air emissions at specified points on the licensed premises on a quarterly and continuous basis. The focus of the monitoring is on the Rosalind Park Gas Plant which is reported quarterly (https://www.agl.com.au/about-agl/how-we-source-energy/monitoring-data).

7.2 Water and soil quality information

As with air monitoring, water monitoring data are collected by various regulatory agencies, by industry to meet extraction licencing requirements and during research activities. Soil monitoring can also be undertaken, although this is not prescribed and is usually in conjunction with trials related to beneficial re-use of CSG water or research assessing potential exposure to communities.

Water quality monitoring data is generally compared with the ANZECC and ARMCANZ (2000) water quality guidelines, which relate to both human and ecological health values. Also, National Environmental Protection (Assessment of Site Contamination) Measure 1999 (NEPM 1999) has guidelines for health and ecological investigation levels relating to contaminated soil and groundwater. These guidelines take into account the existing state of the environment, aesthetics, the cultural and social values of the water body and the intended end use of the water.

Both of these standards cover a range of contaminants potentially associated with CSG activities, including PAHs, BTEX, total recoverable hydrocarbons (TRH), metals and phenols.

7.2.1 Regulatory authorities

The Federal *Environmental Protection and Biodiversity Conservation Act 2013* can be applied as a 'water trigger' where proposed CSG developments that represent a significant impact on a water resource can trigger a comprehensive assessment by an independent body. This relates to both water quality and quantity. There are also specific state-based authorities in Queensland and New South Wales.

New South Wales

A number of different legislative instruments apply to CSG in New South Wales, including the *Petroleum Onshore Act 1991*, *Protection of the Environment Operations Act 1997*, *Environmental Planning and Assessment Act 1979* and *Water Management Act 2000*.

In New South Wales water quality data is collected by NSW Office of Water, which includes real-time monitoring of 2000 surface water sites and more than 9000 groundwater sites (http://realtimedata.water.nsw.gov.au/water.stm?ppbm=STATE_OVERVIEW&so&3&sobkm_url). This real-time data generally relates to water quantity and measures flow and depth in surface water and depth below surface at ground water sites. Limited information on water quality, including data on salinity, temperature and turbidity, can also be found at a number of these locations.

Queensland

The two main pieces of legislation that apply to CSG extraction in Queensland are the *Petroleum and Gas (Production and Safety) Act 2004* and the *Environmental Protection Act 1994*. The Environmental Protection Act takes into account potential impacts on water quality and quantity for downstream water users due to extraction activity.

Monitoring of ground water and surface waters includes parameters such as pH (acidity), EC (electrical conductivity), turbidity, TDS (total dissolved salt), temperature, %DO (percentage dissolved oxygen), alkalinity, cations, silica, metals, phosphorous , N(NO_x + NH_4) i.e. nitrogen comprised of oxides of nitrogen and ammonium, TRH (total recoverable hydrocarbons), PAHs, BTEX and radionuclides, in line with ANZECC & ARMCANZ (2000) guidelines.

As discussed in the introduction, an EIS is required prior to undertaking exploration and extraction activities which can be a source of data. Also, the *Queensland Water Act 2000* requires the baseline monitoring of bores prior to work commencing.

The Queensland Government also monitors real-time water quantity data, relating to surface water flows and groundwater levels (https://water-monitoring.information.qld.gov.au/).

The Office of Groundwater Assessment (https://www.business.qld.gov.au/industries/mining-energy-water/resources/land-environment/ogia) has recently completed an assessment of underground water impacts in the Surat Basin that includes an underground water monitoring plan (https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0007/345616/uwir-surat-basin-2016.pdf).

The Queensland GasFields Commission website includes links to some data and research sources. One report from the Commission collates water-related science and research activities in the Queensland coal seam gas sector (http://www.gasfieldscommissionqld.org.au/resources/documents/collating-csg-water-related-research-projects-report%20(1).pdf)

7.2.2 Industry data

The CSG industry is required to undertake ongoing monitoring of water quality and quantity and a large amount of data is likely to be available, although this data is generally unavailable to the public. However, Santos maintains a water quality portal that measures real-time data relating to surface water quality and groundwater quantity (http://waterportal.santos.com/). Also, APLNG releases six-monthly reports relating to the environment, which flag non-compliance with water quality in its operations (https://www.aplng.com.au/about-us/compliance/reports.html).

An example of industry monitoring emissions sources is demonstrated at Camden where AGL are required to monitor water emissions at specified points on the licensed premises ongoing on a quarterly basis The focus of the monitoring is on the Rosalind Park Gas Plant Flare Pits which is reported quarterly (https://www.agl.com.au/about-agl/how-we-source-energy/monitoring-data).

7.3 Social stressors information

There is a range of data available to assess the extent and location of social stress in a community near existing or proposed CSG development. Data can be broadly categorised as:

- precursors of social stress (including factors that may put a community under stress whether or not CSG activity was occurring or is proposed)
- other data which suggest levels of concern related to CSG activities expressed by residents and landholders and potentially also levels of individual and community resilience
- data that indicate when and where medical or mental health assistance is being sought.

There are direct ways to 'measure' stress, for example, via surveys or by counting the number of people with stress contributing to their medical or mental health concerns. There are also indirect ways to assess the level of stress being experienced in a community, for example, by identifying social and economic precursors or by monitoring complaints registers. The key sources of this information are given in Table 4.

Table 4 Sources of information related to social stressors in a CSG community

Information	Description	Source
Social stressor precursors	Social and economic data on a community, that can indicate, for example, social stress related to housing costs when rents are rising due to a demand for short-term housing for CSG workers and others lured by an increase in economic activity Data would need to be augmented by information on incomes in a community, particularly information on what fraction of a community is in the lowest income quintile and the level of income that represents Overall patterns of community change that instil or exacerbate social stress can be identified	The University of Queensland's Boomtown Toolkit (https://boomtown-toolkit.org), which includes links to: • Australian Bureau of Statistics • Real estate information • Crime information (e.g. provided by the police in each state) See also The University of Queensland's Annual Report on Queensland's Gasfields Regions (https://boomtown-indicators.org)
		Queensland Government Statistician's Office (QGSO) periodically issues brief reports containing economic and employment data on local government areas (LGA) with CSG development
		Australian Petroleum Production and Exploration Association – e.g. the number of industry employees in the LGA (note: this data may not cover all subcontractors or those who arrived in the area not to work in the resource industry directly but in some other sector with job opportunities stimulated by CSG development, such as accommodation or food services)
Concerns related to CSG activity	Data are generally garnered from surveys and complaints registers.	Complaints registers are kept by each company as part of their project's operating conditions provided by the State Coordinator-General's office
		CSG Compliance Unit of the Queensland Department of Natural Resources and Mines (DNRM)
		CSG company quarterly surveys of residents
		CSIRO and academic researchers survey results on community perceptions in CSG areas (e.g. Leonard et al. 2016; McCrea et al. 2016; Walton et al. 2017; Morgan et al. 2016)
		Ethnographic studies – employing interviews of residents and observations of meetings – from academic researchers,

		e.g. through Queensland's Darling Downs (note: North American research in this domain is available through members of the Energy Impacts research network (https://www.energyimpacts.org))
'Help-seeking behaviours'	Data on medical visits and prescribed drugs, or access to other support services, for stress-related concerns or ailments	The cause for every visit to a general practitioner (GP) or medical specialist or a hospital emergency room in Australia is coded for Medicare. There are privacy restrictions around this data, but there are also ways to conduct assessments at aggregate levels.
		Data on drugs prescribed during GP visits are available in Medicare
		The number of calls to help lines, such as Lifeline, or number of visits to GPs or mental health services (note: these statistics may not accurately measure the entire proportion of the population dealing with social stress, but should indicate general trends)
'Self-medicating' behaviours	Includes, for example, the level of smoking, consumption of alcohol, and use of illicit drugs	Cigarette sales, alcohol sales and information from police on the number of drug arrests or estimated volume of drug traffic
		Crime related to excessive use of alcohol or drugs, ranging from domestic violence to theft

With all these sources, it is important to be aware of potential confounding and complicating factors. As discussed in Section 3.2, there may be pre-existing social stressors in an area. Such pre-existing stresses underlie the notion that the level of social stress experienced by an individual is cumulative, and when social stress is experienced by many individuals in one community, community resources may be taxed. These pre-existing conditions may also be effective modifiers of associations between CSG activities and health outcomes. Other complicating factors include a stigma that is attached to mental health issues, patterns of help-seeking or help-avoidance behaviours in regional and rural areas, and the positive impacts of community resilience structures. The availability and accessibility of appropriate mental health services for these rural and remote communities is also important in identifying social stress.

7.4 Health information

As presented in the Expert Workshop Summary Report (Keywood et al. 2017), numerous information sources of health data were proposed (Table 5). These data allow the identification of existing health issues and comparison with other rural and regional areas, which can inform the scope of the health assessment, as well as providing sources of monitoring data for epidemiological and other studies.

The data sources listed in Table 5 included information at the individual level (e.g. hospital admissions) and at the community scale (e.g. waste water epidemiology). Several considerations when gathering health data should be considered, including privacy issues when managing health data for individuals and the specificity of available data to a community or region.

Table 5 Information sources to determine health and wellbeing of community and individuals identified in the Expert Workshop (Keywood et al. 2017)

Information source	Comments
Hospital admissions	Small numbers in the GP data
Pharmaceuticals Benefits Scheme (PBS)	Privacy issues
Waste water epidemiology	Geographic scale and boundaries
Chief Health Officer's Report – Qld GP software – clinical audit tools Data from the Emergency Department	Standardisation and validation of data
Lifeline Australia statistics of calls	
School absenteeism	
Registry data (births, deaths, cancer)	
Reportable conditions (e.g. STIs).	STIs are reported based on where you live and therefore misses the numbers reported in FIFO workers
Cancer atlas – Qld	
Syndromic surveillance	Requires big data mining.
Health direct	
Health contact centre data – 13 HEALTH	
Previous research studies	
Cluster randomisation study Compare flu tracking – 80% participation rate.	
Biomonitoring	

7.4.1 Biomonitoring information

Human biomonitoring studies measure levels of chemicals or biomarkers of exposure (e.g. biomarkers of stress) in human tissues such as blood or urine. These 'internal' levels reflect the total exposure of an individual to chemicals or other stressors from all exposure pathways and sources. Biomonitoring is therefore an effective approach to establish that individuals are being exposed and at what levels, and can complement measurements of 'external' exposures through analysis of water, air and soil. Biomonitoring has become the 'gold standard' worldwide for assessing human population exposure, understanding exposure-response relationships and detecting emerging chemical exposures (Sexton et al. 2004).

Australia currently lacks a national human biomonitoring program. Most data on human biomonitoring are collected by research organisations and reside in peer-reviewed publications and reports (e.g. Toms et al. 2012; Aylward et al. 2014; Toms et al. 2014; Drage et al. 2017; Heffernan et al. 2015; Heffernan et al. 2016). Data and trends on background levels in the general Australian population for a range of chemicals have been established, including for pesticides, phthalates, flame retardants, perfluorinated chemicals, dioxins, polychlorinated biphenyls and polycyclic aromatic hydrocarbons. These data result from analyses of ~18,000 blood samples

(2002–2015), 4800 urine samples (2012–2015) and ~300 breast milk samples (Heffernan et al., 2016; Toms et al., 2012; Toms et al., 2014).

Biomonitoring data from specific CSG regions in Australia are currently not available. However, the utility of this approach for use within the proposed framework is exemplified by studies investigating human exposures in the vicinity of other industries (Hearn et al. 2013), occupational cohorts (Rotander et al. 2015) and specific sub-populations (Toms et al. 2015).

7.4.2 Toxicity information

A variety of toxicity criteria are available for use in assessing measured concentrations of contaminants in environmental media. The Australian National Health and Medical Research Council publishes comprehensive water quality guidance, including drinking water guidelines and fact sheets for a wide variety of chemical contaminants (NHMRC 2011). The World Health Organization also publishes guidance for drinking water quality (WHO 2011). Similarly, air quality guidance values are available for selected hazardous air pollutants both domestically (Australian Department of the Environment and Energy, http://www.environment.gov.au/protection/publications/factsheet-national-standards-criteria-air-pollutants-australia) and internationally (http://www.who.int/mediacentre/factsheets/fs313/en/). These criteria generally pertain to broad categories of air pollutants, but there are also available standards in some jurisdictions for a broader suite of hazardous air pollutants (see, for example, https://www.epa.gov/haps).

Toxicity criteria are based predominantly on assessments carried out on individual substances. However, it is likely that simultaneous exposure to multiple chemicals occurs throughout a lifetime. There are a number of possible combinations of chemicals related to CSG activities. To quantify the combined toxicity of a mixture of chemicals requires detailed knowledge of the mode of action (i.e. how a chemical affects a target cell, etc.) for each chemical. Predictive models are available to estimate mixture toxicity but there remains considerable uncertainty regarding combined effects. Acknowledging these uncertainties, the European Commission (2011) developed a decision tree to evaluate the risk of chemical mixtures, which while providing a starting point, does not completely address the fundamental issue of lack of data on chemical mixtures.

Often, chemical-specific air or water quality standards are not available. However, in many cases quantitative toxicity criteria are available for specific chemicals. In combination with estimated exposure rates, these criteria can be used to assess the potential health risks of exposure to the chemical. An overview of available toxicity criteria derived by a variety of international agencies for many compounds can be found in the International Toxicity Estimates for Risk database (ITER; https://toxnet.nlm.nih.gov/newtoxnet/iter.htm).

7.5 Research information

The data collected by research institutions are generally for health outcome research or to understand a process or mechanism. Some research centres and organisations that collect or collate information relevant to a health study include:

- University of Queensland Centre for Social Responsibility in Mining (SMI-CSRM) – conducts social science research about resource development https://smi.uq.edu.au/csrm/
- University of Queensland of Centre for Coal Seam Gas Research – the CCSG website includes a comprehensive research directory that lists the research and outputs of all coal seam gas research activities in Australia http://research.ccsg.uq.edu.au/
- CSIRO's Gas Industry Social and Environmental Research Alliance – provides quality-assured, independent scientific research and information to communities living in gas development regions, focusing on social and environmental topics including: groundwater and surface water, biodiversity, land management, the marine environment, human health impacts and socio-economic impacts https://gisera.csiro.au/
- Queensland University of Technology Groundwater Systems Research https://www.qut.edu.au/research-all/research-projects/groundwater-systems-research
- The Queensland GasFields Commission includes links to some data and research sources http://www.gasfieldscommissionqld.org.au/communities/environment/

In addition, databases such as Google Scholar, Web of Knowledge and Scopus provide access to peer-reviewed literature. A list of available databases can be found at https://en.wikipedia.org/wiki/List_of_academic_databases_and_search_engines.

7.6 Assessing data quality

A key component of the *Screening* stage is assessing the quality of available data and thus determining if the data are suitable for use in the health study. Key to determining the quality of data is a technical understanding of the source and the data gathering processes. In addition, a systematic approach to assessing data quality is required (e.g. Henson 2016; Nousak and Phelps 2002; Eurostat 2007; EPA 2009). A review of data quality assessment methods used in 49 studies focused on public health data sets showed that completeness and accuracy were the two of the most common attributes of data quality used (Chen et al. 2014).

Some important attributes of data quality to be considered for a health study are listed and described in Table 6. While it will be the role of the project team to design the data quality assessment approach to be used in the *Screening* stage, Table 6 provides some examples.

Table 6 Some attributes to consider during assessment of data quality. Modified from Nousak and Phelps (2002), Eurostat (2007) and EPA (2009).

Attribute	Description	Example
Validity	Data element passes all edits for acceptability	Validity flags established and passed, e.g. sample volume greater than threshold value; span and calibration check within certain threshold values
Completeness	Missing data elements are minimal, i.e. below a threshold percentage	Hourly averages only calculated from minute data with > 80% coverage in the hour
Consistency	Data element is free from variation and contradiction based on the condition of another data element	PM2.5 should be less than or equal to PM10

		Time stamps on different instruments should be consistent
Uniqueness	Data element is unique—there are no duplicate values	Sample identifiers only occur once (i.e. are not duplicated)
Representativeness	Degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition	Percentage of population or time period sampled above a threshold value that is statistically determined
Accuracy	Data elements represent true values	Methods can be traced back to a primary standard Standard methods are used
Precision	Data elements are reproducible	Duplicate measurements are carried out and agree to within 10%
Comparability	Data elements from one data set or method can be compared to another	Difference in concentration of a compound measured by two independent methods less than a threshold amount

8 In-depth exposure assessment methods (Stage 4)

8.1 Air, water and soil monitoring

It is beyond the scope of this report to produce a comprehensive list of all methods that could be used to monitor air, water and soil quality during the in-depth exposure assessment of Stage 4. Instead the general principles to be considered during selection of a method are considered.

A three-tier hierarchy of air, water and soil monitoring methods can be established. If a method is not available from the first tier, a subsequent tier can be used. The tiers are:

- ***Tier 1* –** Standard methods that are traceable to a primary standard
- ***Tier 2* –** Appropriate internationally recognised methods or standard techniques that have been published in the peer review literature
- ***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/or Tier 2).

Consideration of measurement cost and practicalities (e.g. security, power supply, site access, human intervention frequency) will also influence the choice of measurement method.

Finally, the objective of the measurement program will govern method selection. For example, comparison of environmental concentrations between two different locations may require reproducible but less accurate methods while comparison to health-based standard will require accurate and reproducible methods.

8.2 Biomonitoring

Human biomonitoring can be conducted at either an individual or population level using a range of biological tissues such as blood, urine, faeces, hair and breast milk. Compounds of interest to a biomonitoring study in a CSG region include:

- **Chemicals associated with CSG activities:** levels of chemicals released from the CSG site can be measured in the local population. This option is best suited to chemicals that are persistent in the human body (i.e. are not rapidly metabolised to another chemical).
- **Metabolites of CSG chemicals:** for chemicals that are metabolised in humans, the metabolite, in addition to or instead of the parent compound, can be measured. If the ratio between the parent compound and the metabolite is known, the exposure to the parent compound can be estimated from metabolite levels.
- **Biomarkers of exposure and effect:** exposure to some chemicals and other stressors (including social stressors) can result in an induced variation in cellular or biochemical functions in the body. These variations or 'biomarkers' of exposure can be measured to understand the combined exposure to all chemicals associated with CSG activities with a similar mode of action.
- **Medications for specific health outcomes**: biomonitoring can also be used to understand levels and trends in health outcomes in a CSG region using excreted pharmaceuticals (or

their metabolites), such as anti-anxiety medication, as surrogates for adverse health effects.

8.2.1 Biomonitoring – individual level

Individual biomonitoring approaches (i.e. collecting biological samples from targeted or randomly selected individuals) preserves the ability to relate individual health outcomes to individual exposures. This approach is considered important in many traditional epidemiological methodologies. Individual sampling can, however, be resource intensive and requires an often-lengthy participant recruitment process. Ethical issues must be carefully considered, and approval sought to ensure appropriate interaction with and privacy of participants and ethical reporting of individuals' results.

An alternative biomonitoring approach has been developed and applied in Australia which involves the pooling of samples from individuals of the same age and gender within a region (Heffernan et al. 2013). A pool may comprise, for example, an equal sample volume of blood serum from six individuals of the same age and gender. An average exposure or pharmaceutical usage level is determined and reported for each pool of individuals. The advantages of a pooled approach are:

- pooled samples can be obtained from de-identified, surplus pathology samples
- sample collection and analysis are cost-effective
- time and resources are reduced as there is no lengthy recruitment process of individuals
- ethics approval is required but complexities with reporting individual results are avoided
- data are stratified by gender and age allowing analysis by sub-groups within the population
- where health outcomes are observed in a population, samples can be pooled by disease or health parameter and screened for a suite of chemicals to identify statistical correlations between exposures and health parameters.

The drawbacks of using a pooled approach include:

- limited data are available on the variability of exposures within a population (i.e. this approach may not capture exposed individuals)
- sufficient pathology samples may not be available for a specified CSG region
- surplus pathology samples may be skewed towards individuals presenting with a health issue and therefore results cannot be extrapolated to the entire population
- individual information is lost, such as, for example, residential proximity to a CSG well, which may limit interpretation of the pooled results.

Both individual and pooled monitoring approaches have been used in Australia and standard methodologies are reported in the peer-reviewed literature (e.g. Toms et al. 2014; Drage et al. 2017; Heffernan et al. 2015; Toms et al. 2012; Heffernan et al. 2016).

8.2.2 Biomonitoring – population level

Population-scale exposure to chemicals or consumption of pharmaceuticals can be measured using wastewater analysis, or wastewater-based epidemiology (WBE). The method underlying WBE in a given population, such as a CSG community, is based on the principle that any given compound to which we are exposed (irrespective of whether it is ingested, inhaled or dermally transmitted) will subsequently be excreted (either in the chemical form it is consumed and/or in a chemically modified form that is referred to as a metabolite). Collectively, waste products in the sewer system arrive at a wastewater treatment plant where wastewater samples are collected over a defined sampling period. Measuring the amount of target compound in the wastewater stream allows for a back-calculation factor to be applied to determine the amount of chemical exposure or pharmaceutical use over the collection period. The method is non-invasive and is done on a population-scale level, so individuals are not targeted, and privacy is respected.

WBE has been applied in Australia to understand, for example, population-level drug use (Lai et al. 2016) and exposure to other chemicals (Thai et al. 2016; O'Brien et al. 2015). The methods underlying WBE are well established in Australia and worldwide and are available in the peer reviewed literature (e.g. Zuccato et al. 2008; Lai et al. 2011).

Overall, WBE is a cost-effective, non-intrusive approach to understand population-level exposures or consumptions. There are some potential limitations of the approach that need to be considered to assess its applicability to a CSG region, namely:

- Chemicals must be at detectable levels in the wastewater.
- Chemicals must be persistent in the sewer system.
- For compounds that are also released environmentally, metabolites must be used to distinguish human exposure from environmental levels.
- Data are generally less accurate for small populations (uncertainties are higher), although trend analyses can be robust.
- This approach would need to be reconsidered in the context of septic systems, which are commonly used in rural areas for managing wastewater.

The uncertainties related to the estimation of exposures using WBE involve:

- the estimation of the population contributing to the levels measured in wastewater
- the excretion rates of chemicals from humans
- degradation rates of chemicals in the sewer system
- flow rates of water into the wastewater treatment plant
- sampling and measurement uncertainties.

For more information, see Lai et al. (2011).

8.3 Approaches for exposure and risk assessment

Exposure assessment can be a powerful tool for addressing community concerns about potential chemical exposures. Qualitative or quantitative evaluation and characterisation of potential exposure to chemicals associated with CSG or UNG activity plays a central role in a variety of study designs. Exposure assessment can be the primary focus of a study designed to detect and quantify specific chemical exposures via air, water or other media. Such quantitative exposure assessments can in turn be used in combination with toxicity information to conduct a risk assessment, once exposure pathways have been established. Finally, each of the potential epidemiological study types require some sort of exposure characterisation, classification or ranking of study participants or cases in order to evaluate potential associations between exposure and the health outcome(s) under study.

An initial and important basis for designing an exposure characterisation approach is a conceptual site model. As discussed in Section 6, such models include identification of the potential chemical and non-chemical stressors likely to be relevant to the site as well as potential pathways between the source and the population(s) that may be exposed. These models provide the basis for designing an appropriate exposure characterisation approach.

Exposure characterisation and assessment can be conducted using a number of approaches or combinations of those approaches. Broadly, these approaches fall into three categories:

- qualitative or semi-quantitative approaches based on geographic categorisation
- exposure monitoring employing measurement of chemical or non-chemical stressors
- exposure modelling.

These categories are discussed further below.

8.4 Geographic categorisation

These approaches rely on characterising the proximity of populations or individuals to the activity of interest – in this case, CSG wells. The approach can be very high level, for example, residence in a county, parish or district with CSG activity vs. residence in one without. At the other extreme, exposure by geographic categorisation can involve construction of a detailed proximity index that accounts for number of wells and distance from a residence for each individual in a study, in some cases with a weighted activity metric that accounts for temporal changes in well activities (see, for example, exposure indices used in McKenzie et al. (2014) or Rasmussen et al. (2016)). In general, exposure characterisations using approaches of this type are most relevant for epidemiological studies. Limitations of such approaches include lack of measurement or data on specific chemical exposures. This limits the understanding of what agent(s) might be responsible for observed associations between the exposure and outcomes and limits the ability to address or mitigate relevant exposures. However, such approaches, when well-executed, do provide an integrated marker for the activity of interest (in this case, CSG activity). Adverse effects may occur because of complex interactions of a mixture of chemicals or a mixture of chemical and physical or other non-chemical stressors. In such cases, integrated indices may be of more value than analytical measurements of selected contaminants, which may not provide information on the full suite of relevant factors.

8.5 Exposure monitoring

Previous studies of potential chemical exposures in the vicinity of UNG development have often included measurements of chemical concentrations in environmental media (e.g. McKenzie et al. 2012; Bunch et al. 2014; Queensland Health 2013). The medium that has been most often sampled is air, followed by water and soils.

Exposure monitoring can also be employed to measure noise and light pollution. In their evaluation of health complaints in Tara, Queensland Health examined data on low frequency noise levels collected by the Department of Environment and Heritage Protection on the Wieambilla Estate (Queensland Health 2013). They identified possible elevations in low frequency noise levels that were potentially associated with the nearby gas processing facility. Standard methods for monitoring noise are available and can be employed where noise is a potential stressor of concern or interest (e.g. DEHP 2013; NSW EPA 2017). Interpretation of the results of such monitoring in terms of potential for annoyance or even health outcomes is possible, but impacts may be somewhat subjective, depending on the magnitude of noise levels and frequencies observed. Methods for monitoring for light pollution are less standardised, and interpretation of the measurements in terms of potential for annoyance or health disturbance is more difficult (Garvey 2005).

Biomonitoring described in Section 8.2 can be a powerful tool for assessing exposure. The utility of biomonitoring depends on the specific chemicals of interest, how they metabolise in the body, and the analytical sensitivity of the methods used (Aylward et al. 2012). In the case of CSG, key exposure candidates for biomonitoring would be VOCs. While VOCs are often difficult to measure in biomonitoring studies due to their high volatility (which requires special sample collection procedures), VOC metabolites and/or biomarkers of VOC exposure in humans may be suitable alternative markers to measure. The following points should be considered when using biomonitoring to assess CSG VOC exposure:

- VOCs of major interest with respect to petroleum-associated natural gas contaminants, including benzene, are also present from many other sources in the environment, including cigarette smoke (Aylward et al. 2013; 2014)
- VOCs are highly transient in blood, so that the timing of biomonitoring sample collection relevant to when exposures occur is a major factor in the interpretation of the resulting measurements (Aylward et al. 2012).

8.6 Exposure modelling

Modelling can provide estimates of exposure for individuals or geographic areas based on physical models of processes that account for sources, fate and transport of contaminants as well as information on the location and activities of the receptor population(s). The conceptual site model provides the basis for identifying both the potential contaminants of interest and the potential exposure pathways that can be considered in exposure modelling. Often modelling also relies in part on monitoring data to provide inputs, to help structure the model, and as part of the process of verification of the model outputs. Modelling can be used to extend the interpretation of monitored data to a wider area, particularly with respect to air concentrations. The reliability of exposure modelling depends on the information available to develop the exposure models, and limitations and uncertainties must be clearly identified.

8.7 Risk assessment

Quantitative risk assessment involves comparison of measured environmental monitoring data or estimated exposure levels for particular chemical or non-chemical stressors to tolerable or 'safe' exposure levels. Thus, risk assessment is a natural follow-on to quantitative exposure assessment, providing a health risk context for the exposure assessment. This approach allows identification of contaminants present at levels that might pose a health risk. This, in turn, provides one basis for identifying possible approaches to mitigating risks. Criteria for assessing tolerable exposure levels are an integral part of risk assessment. Such criteria are available for many chemicals based on air or water concentrations. Criteria for non-chemical stressors such as noise are less commonly available and in some cases must be extrapolated from occupational standards, which may not be appropriate for a residential and environmental setting. However, if no toxicity criterion or other basis for evaluating the measured exposure levels for a chemical or other stressor is available, the stressor cannot be included in a quantitative risk assessment. Other limitations of risk assessment should be clearly identified and stated. For example, risk assessment methods cannot directly address possible synergistic effects that could arise from exposure to multiple stressors. Nor does risk assessment typically address the combination of chemical and non-chemical stressors. However, the process of conducting a risk assessment can identify where and when such combinations of exposures are occurring and provide a basis for further evaluation or investigation.

8.7.1 Exposure estimation based on contact rates (inhalation, drinking water, etc.)

Potential exposures to chemicals can be estimated based on environmental monitoring data or models. Measured or estimated concentrations in air, water, soil or locally raised agricultural products can be combined with estimated contact rates for these media. Such contact rates include daily breathing rates, drinking water consumption rates, estimated incidental ingestion of soil, and intake rates for local foods. The estimated doses from individual exposure pathways can be summed to estimate total potential daily doses of trace chemicals in the environment.

8.7.2 Approaches for cumulative risk assessment

When multiple chemical stressors are present, a variety of approaches can be used to estimate cumulative risks. For non-carcinogenic chemicals, chemical-specific hazard quotients, which are the ratio of estimated exposure to tolerable exposure levels, can be estimated for each chemical. If exposures do not exceed the tolerable exposure level, the hazard quotient will be below 1. When multiple chemicals that have the same toxic effect are present, the chemical-specific hazard quotients can be summed to calculate a hazard index. The target for this hazard index is to remain below a level, which would indicate that, relative to tolerable exposure levels, the estimated exposures across chemicals are not exceeding the risk-based targets. For carcinogenic compounds, chemical-specific carcinogenic risks can be summed.

As discussed above, these approaches rely on the availability of quantitative assessments of toxicity and estimated exposures for each of the chemicals; lack of such data makes this type of quantitative risk assessment infeasible.

A variety of other semi-quantitative or qualitative approaches have been proposed, including approaches that address non-chemical stressors in combination with chemical stressors. Adgate et al. (2014) present a modified version of the source-to-exposure-to-outcome framework that underlies most chemical risk assessments that incorporates acknowledgment of an extensive range of non-chemical stressors. In addition, they explicitly discuss modifying factors that can either intensify or buffer adverse effects, both on a community basis and on an individual basis. For example, on a community basis, a lack of affordable housing in a community prior to or during CSG development will exacerbate the economic and social stresses associated with an influx of workers when UNG development occurs. In contrast, a well-developed system of parks and green space in a community may ameliorate stresses associated with changes in the natural landscape occurring due to UNG development. On an individual level, pre-existing health conditions, such as asthma, may render an individual more susceptible to adverse effects from air pollution.

Boyle et al. (2016) present a somewhat different approach, employing what they call a “hazard ranking” methodology including ranking of eight categories of potential hazards based on seven elements:

1. Presence of vulnerable populations (e.g. children under the age of 5, individuals over the age of 65, land owners)
2. Duration of exposure
3. Frequency of exposure
4. Likelihood of health effects
5. Magnitude/severity of health effects
6. Geographic extent
7. Effectiveness of buffer zones.

The categories of hazards evaluated were:

1. Air quality
2. Water quality (including water quality, soil quality, and naturally occurring radiological materials)
3. Noise
4. Earthquakes
5. Social determinants of health (e.g. crime, injuries, mental health, STIs and substance abuse) and lifestyle factors
6. Occupational health
7. Healthcare infrastructure
8. Cumulative exposures and risk.

The authors suggest that this sort of structured ranking can help to inform communities and decision-makers as evaluations of potential UNG development projects are made.

8.8 Approaches for health outcome assessment

As summarised in Table 7, a variety of health assessment designs are available for studying different health outcomes. Broadly, these range from high-level ecological studies, which look at differences in statistics for various outcomes by geographical area (county or parish, census tract, etc.) to detailed analytical epidemiological studies that seek to evaluate associations between measured or estimated exposures in a specific cohort and health outcomes. Ecological studies can demonstrate that rates of a condition or outcome (for example, hospitalisation rates for a given disease) differ between geographic areas, but they cannot establish the cause(s) of such differences. Analytical epidemiological study designs can provide a more detailed look at the relationship between an index or measurement of exposure and a health outcome, although caution must still be exercised in interpreting the results of such studies due to their inherent bias related to their observational design.

As discussed, the community acceptance of a study will be strongly influenced by how directly it addresses the concerns expressed in the community. Thus, the potential health endpoints of interest for a study will be strongly influenced by specific community concerns and observations. However, a number of endpoints can be identified as potentially being of *a priori* interest based on the literature review and other experiences in Australia:

- Headaches, eye irritations, nosebleeds and skin rashes; other general unwell complaints (Queensland Health 2013)
- Hospitalisations for “All Causes” (Werner et al. 2017)
- Hospitalisations for “Blood/Immune” conditions (Werner et al., 2017; 2016)
- Hospitalisations for “Neoplasms” (Werner et al. 2016).

There are other endpoints identified in oil and shale gas studies in the United States that should be considered for their applicability in the Australian CSG context:

- Asthma, chronic obstructive pulmonary disease (COPD) and other respiratory complaints (Rasmussen et al. 2016)
- Specific birth defects: neural tube defects and congenital heart defects (McKenzie et al. 2014)
- Childhood acute lymphocytic leukemia (McKenzie et al. 2017).

The different outcomes range from very broad indicators (hospitalisation rates for all causes) to extremely specific and rare outcomes (e.g. neural tube birth defects). In addition, the list of *a priori* endpoints includes both well-defined endpoints with specific diagnostic criteria (e.g. childhood ALL) and endpoints that are harder to assess (e.g. subjective symptom complaints such as headaches or fatigue). Different epidemiological study designs are more appropriate for addressing endpoints with different characteristics.

The framework recommends that these types of studies be conducted after completion of a hazard identification and screening stage so that relevant exposure pathways can be established, and screening exposure assessments conducted accordingly. Using an exposure assessment approach in tandem with follow-up health outcome assessments helps overcome the issues of conducting these types of studies in small populations and in the presence of confounding variables.

Table 7 Assessment types: Exposure and health assessments

Assessment Type	Inputs/Data Required	Applications	Strengths	Limitations
Exposure Assessment	Physical stressors (noise, vibration, light, trucks), Social & chemical Stressors (Air, Water, Soil)	Is there a likelihood of exposure from CSG? Qualitative & quantitative Yes – No	Proof of exposure (not necessarily cause) High demand Could decrease worry Source attribution Can inform mitigation The community are likely to understand Potentially lower uncertainty	Trustworthiness Can't assess everything Can't assess cumulative effects Could create fear Community 'doesn't buy' it – acceptable level Identified exposure pathway isn't the only exposure pathway Broader view of 'damage' beyond humans – cows, aquatic life
Human Health Risk Assessment (Hazard & Exposure)	Requires toxicity assessment & requires an exposure assessment	Prioritising and screening	Prioritisation tool to tell us if exposures are well below, close to, or well above levels that may be associated with health outcomes	Unknown / lack of toxicity data Over-estimation of toxicity for known chemicals Gives answer that doesn't predict health outcome or a particular risk Uncertainty is high risk for people, a challenge for

Assessment Type	Inputs/Data Required	Applications	Strengths	Limitations
				communities to understand / abstract More subjective & open for dispute (assumptions) Lack of information on toxicity at low levels and in early life as a limitation.
Cluster Investigation	Other non-CSG studies as inputs Common (shared) community complaints (People or GPs? Public health?) Health data sets Need a reference or a control population Geographically identified Community	Common community concern Perception or occurrence	Community is responsive Can be carried out on small populations Community reassurance	Clusters can occur randomly – not causal Could require a labour-intensive process to confirm cases Could be politically contentious No choice – when it presents, you must respond
Longitudinal Studies (Cohort)	Time Identify baseline data Agreeable, participatory community	If there are known / expected changes to a community and their environment	'Gold standard' in environmental epidemiology Better for common outcomes	population loss to follow-up Resource intensive Ongoing commitment of resources and loss of staff

Assessment Type	Inputs/Data Required	Applications	Strengths	Limitations
	Informed consent Hypothesis Registry data doesn't require informed consent	If we suspect delayed effect – lateness Can look at lots of different health outcomes Monitoring & surveillance Relatively common outcomes	Powerful study design – can watch population over time As close as environmental health gets to cause & effect Can measure many outcomes Can control for other exposures and individual characteristics that may act as potential confounders, effect modifiers or effect the health outcome independently Can do nested cross-sectional and case-control studies	Requires special set or circumstances Not applicable to rare outcomes
Cross-Sectional Study	Range of exposures (e.g. proximity to wells) Willing population supported by register data if required	Quick result Quick comparison method Can be hypothesis generating Exploratory	Demonstrates responsiveness to community Looking at individuals Can control for other exposures / factors	Resistance to environment? Single time point – doesn't prove causation or capture changes over time

Assessment Type	Inputs/Data Required	Applications	Strengths	Limitations
Case Control Studies	Compares levels of exposures between people with (cases) and people without (controls) disease/ health outcome retrospectively Hypothesis that guides investigation (e.g. suicide) Informed consent Registry data doesn't require informed consent	If a rare outcome presents Range of exposures	Can be powerful for hypothesis building for cohort studies; identifying outbreaks; investigating risk factors for a rare outcome. Can be high profile	Need a rare outcome to present / be noticed Can be bias towards a false positive Can't quite claim causality Can be high profile

9 Resourcing future health studies

The framework described in this report will require a transdisciplinary project team. Expertise required includes:

- Air quality science
- Water quality science
- Soil quality science
- Exposure science
- Epidemiology/public health science
- CSG process science
- Social science
- Ethics
- Project management
- Communication and knowledge brokering.

The staged approach described in the framework includes several decision points. This makes it very difficult to estimate the timeframe required to carry out an entire health study. For example, proceeding to a Stage 4 *In depth assessment* that requires significant new air quality and water quality observations will require more time than if further measurements are not required. For this reason, we estimate timeframes up to and including Stage 3 *Screening* as:

- Stage 1 – Planning and scoping – 6 months
- Stage 2 – Identification – 6 months
- Stage 3 – Screening – approximately 12 months

10 Conclusions

A 2014 report by the NSW Chief Scientist on managing environmental and human health risks from CSG activities identified potential risks to the environment (air, soil, water) and risks and uncertainties around human health from emissions arising from CSG activities (OCSE 2014). The report concluded that the risks can be managed through regulation and monitoring. Despite this finding, concerns about possible health effects continue to be voiced in communities with CSG development and more widely. Acknowledging the concern over the potential health impacts of CSG activity, GISERA and QAEHS have funded a study design project that would investigate the influence of CSG activity in Australia on human health.

This study design project focuses on a review of the state of knowledge about health impacts of CSG activity, identification of gaps in the knowledge base, and development of a framework that can be used to design a study to address identified gaps. The framework produced in the study design project will be used to develop proposals for one or more future studies across Australia's CSG regions.

The literature review conducted as part of the project highlighted a lack of robust studies around the stressors and health impacts associated with Australian CSG activities. Most available scientific knowledge and data relates to shale gas regions in the United States, and does not necessarily translate to the Australian context, where CSG industry regulation, geological conditions and gas extraction methods differ. In particular, current Australian CSG activity has a lower prevalence and intensity of hydraulic fracturing activities. The CSG resource is found closer to the surface than shale gas and does not contain liquefied petroleum material that is often associated with shale gas. With only a few limited studies being carried out in the area of health impacts of CSG activities, the literature review found that there is currently insufficient evidence to conclude whether there are health impacts associated with CSG activities. However, the literature review has revealed methods and approaches that are applicable to Australian CSG regions.

Understanding community concerns about CSG development and health is fundamental to the design of a potential health study. Community perspectives were collected in Queensland and New South Wales to inform the project. The main factors raised by community stakeholders as warranting investigation and inclusion in a future health study were concerns related to direct chemical and physical hazards, concerns related to social stressors and mental health effects, and benefits related to improved health outcomes for the region.

The project was informed by an Expert Workshop in May 2017. The workshop involved technical experts from government, academia, industry, as well as community-based health professionals. The discussions in the workshop were divided into three topics: stakeholders; information needed for a health study; and potential health study approaches. The importance of community involvement in any future health study was a recurring and fundamental theme that was expressed by participants across all three days of the workshop. Community involvement was seen as critical to the success of work in this area and trust, transparency and independence were criteria considered vital for the success of a future health study (factors that were also raised during the community perspectives research). The workshop participants agreed that a study should address both chemical/physical stressors and social stressors, with research into social stressors focusing on strategies to alleviate the sources of stress and add to the community's resilience.

There was general consensus amongst workshop participants, that the Health Impact Assessment (HIA) framework is an effective and useful framework to evaluate health impacts related to CSG activities.

The study framework proposed here uses the core tenets of the HIA to identify potential health impacts on a population from a proposed development. HIAs generally apply existing knowledge and evidence about health impacts to develop evidence-based recommendations. The framework proposed here is aimed toward generating new, foundational evidence on the possible exposures on residents living in the vicinity of CSG activities in Australia and any associated health impacts.

The framework being offered here has two parallel streams of research:

1. Conducting exposure and health impact assessments for chemical and physical stressors.
2. Identifying CSG activities contributing to social stress and defining effective intervention and mitigation strategies to reduce exposure to these stressors, while maximising benefits will enhance overall community resilience.

A series of staged steps are the essence of the framework, with consultation and decision points at each step:

- A *Scoping and Planning* stage defines the overall structure for a study in a given location, including strategies for involving stakeholders, communicating findings and meeting research ethics requirements. This stage establishes processes to support the quality and legitimacy of the research. Details of the governance principles are included in Section 5 of this report.

- The *Identification* and *Screening* stages establish the potential sources of chemical and physical hazards (air, water, soil, noise and light) and other stressors, such as social stressors and define how community members near CSG activities might be exposed. These stages compile existing data, assess the data for quality and validity, and establish a data archive. Through these processes, gaps in knowledge are identified. Details of a conceptual model approach that can be used to identify hazards (Stage 2) and sources of data (Stage 3) are included in Section 6 and Section 7 of this report, respectively.
- The *Further Assessment* stage involves in-depth assessments of exposures and risks as well as health outcome assessments. This stage addresses gaps in data in relation to relevant chemical and physical stressors. This stage also identifies social stress status as well as needs and mitigation opportunities to minimise social stress impact. Details of exposure assessment and health outcome assessment methods are presented in Section 8.
- The *Recommendations* stage is the final stage in the framework and integrates findings, draws conclusions, and makes recommendations, including identifying needs for ongoing monitoring.

The framework is designed around three key principles identified in the Expert Workshop and through discussions with community stakeholders:

1. All aspects of the study should be open and transparent, and outcomes must be publicly available, working within ethical approval guidelines.
2. The study should seek community and stakeholder involvement throughout the process, from scoping to recommendations.
3. The study should result in recommendations to mitigate negative health impacts and promote positive impacts (benefits to the community and individual health).

It is widely recognised that in any Australian CSG region there may be confounding factors to be considered when conducting an investigation using the proposed framework. Confounding factors are extraneous factors that are associated with the exposure to a stressor and independently affect the risk of developing a health outcome. Their presence can make defining single associations between an exposure and an outcome challenging. These confounding factors include the presence of other industries in a region that may be an alternative source of chemical, physical and social stressors. They can also include pre-existing sources of chemical contamination before CSG development commenced. Further, they may also include other, non-CSG related, social stressors such as how drought can affect agricultural businesses and farmers. These factors may also act as effect modifiers by interacting with CSG development stressors. Ensuring that confounding factors are identified, documented and accounted for in the study design are part of the *Identification* stage of the framework.

Some chemical stressors may be specific to a particular industry, such as pesticides and agriculture. For other stressors, which may come from both CSG activities and other industries, such as dust, the study approach may involve designing monitoring strategies to isolate industry-specific sources. Where that is not possible, the total exposure of the community to all sources could be determined and appropriately communicated.

The nature of confounding factors underlies the framework's approach to social stressors. It is not designed to quantify stressors and benefits associated specifically with CSG (or other singular) activities. Rather, it is to identify those aspects of CSG activity that contribute to the overall stress experienced by individuals or communities and to develop mitigation and amelioration strategies to reduce exposure to these stressors and to support increasing resilience for the region as a whole regardless of the source of the stress. In relation to confounding factors, strategies for interpretation and communication of results will be an important aspect of the communication and community involvement strategies defined in the *Scoping* stage.

The staged approach described in the framework includes several decision points. These multiple stages, and participatory decision-making about progression, make it very difficult to estimate the exact timeframe required to carry out an entire health study. However, up to and including Stage 3 *Screening*, one can expect at least 24 months to be required.

The framework described here will require a transdisciplinary project team with expertise ranging from physical and chemical sciences to social science and ethics. A core capability will be communication and knowledge brokering. In addition, while the examples and context given in this report have been developed around current CSG extraction activities in Australia, the framework is equally applicable for all UNG activities.

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