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Identification and screening for potential physical hazards to human health from coal seam gas activities at a study site in the Surat Basin, southern Queensland

Synthesis Report

Cameron R Huddleston-Holmes and Erin Dunne

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Key terminology and abbreviations

Key terminology and concepts

Naming conventions

CSG health study framework: The CSG health study framework developed by Keywood et al. (2018).

H.2 project: The CSIRO GISERA project “Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland.” This report is synthesising the results of the research conducted for the H.2 project.

H.2 additives study: The component of research on drilling, hydraulic fracturing and water treatment additives completed by the Queensland Alliance for Environmental Health Sciences at the University of Queensland and reported on in Rigby et al. (2023) for the H.2 project.

H.2 air study: The component of research on air emissions conducted by CSIRO and reported on in Dunne (2021) for the H.2 project.

Technical terms and concepts

There are some terms that are used in specific ways in the field of environmental health studies that may not be familiar to the broader community. Understanding some of the terminology as used within the H.2 project is useful when considering its methods and results. The definitions are primarily taken from enHealth’s Health Impact Assessment Guidelines (enHealth, 2017) and Environmental Health Risk Assessment guidelines (enHealth, 2012) as they provide a standard and accepted language for this field of science.

Environmental health: A subset of public health which focuses on environmental conditions and hazards which affect, or have the potential to affect, human health, either directly or indirectly. It includes the protection of good health, the promotion of aesthetic, social and economic values and amenity, and the prevention of illness and injury by promoting positive environmental conditions and reducing potential hazards – physical, biological, chemical and radiological (enHealth, 2017).

Health impact assessment (HIA): A combination of procedures or methods by which a policy, program or project may be judged as to the effects it may have on the health of a population (WHO European Centre for Health Policy, 1999).

Environmental health risk assessment (EHRA): The process of estimating the potential impact of a chemical, biological, physical or social **factor** on a specified human population system under a specific set of conditions and for a certain time frame (enHealth, 2017). An **EHRA** informs the process.

The H.2 project is not a full **HIA** or **EHRA** as it does not establish risk, risk mitigations and residual risks associated with the factors identified (after stage gate 3 in Figure 1). The assessment and characterisation of risk are outside the scope of the H.2 project.

Factor: The term factor was defined for the H.2 project as an individual component of CSG activities, or an individual component used in CSG operations, that potentially could be released or emitted to the environment. A factor could be a **chemical factor** (any substance that has a defined composition), or it could be a **physical factor** (dust, noise and light)¹.

Additive: A material that is used in drilling, hydraulic fracturing or water treatment. An additive may be a mixture of chemicals or and single chemical. The chemicals that make up an additive are the **chemical factors** considered in the H.2 project.

Hazard: A hazard can be defined as the inherent property of a **factor** having the potential to cause adverse effects when a population may be exposed to it (enHealth, 2017).

Risk: Risk is the probability that, in a certain time frame, an adverse outcome will occur in a population that is exposed to a particular dose or concentration of a hazardous **factor**. Risk depends on both the intrinsic **hazard** potential of a **factor** (the toxicity of a chemical for example) and the level of **exposure** (enHealth, 2012).

Key concept – hazard vs risk

A hazard is something that has the potential to cause harm.

The level of risk posed by a hazard is determined by considering the likelihood and consequences of an impact from the hazard occurring.

Chemical of potential concern (COPC): A **chemical factor** that is potentially associated with the site or exposure medium under consideration and whose data is of sufficient quality to be judged as a **hazard** potentially causing an adverse health effect (enHealth, 2012). In the context of the H.2 project, a COPC is a chemical factor appraised to be a hazard. The level of **risk** posed by a COPC cannot be determined without an **exposure assessment** and **risk characterisation**.

Exposure: The concentration or amount of a particular **chemical factor** that reaches a target organism, system, population or subpopulation in a specific frequency for a defined duration. Exposure is usually quantified as the concentration of the agent in the medium integrated over the time duration of contact (enHealth, 2012). This concept can also be applied to physical factors.

Exposure pathway: The pathway by which a target organism, system, population or subpopulation might be exposed to chemical or physical factors. Each exposure pathway includes a source or release from a source, an exposure point and an exposure route. If the exposure point differs from

¹ This is analogous to the term **agent** defined in enHealth (2012) as a chemical, physical or biological substance or factor (including social factor) being assessed in the context of an environmental health risk assessment. This definition differs from the enHealth (2012) definition of a factor, which includes terms like safety factor and uncertainty factor that used to determine acceptable intake.

the source, a transport/exposure medium (such as air or groundwater) or media (in case of intermedia transfer such as groundwater to soil) is also indicated (enHealth, 2012).

Exposure assessment: A component of an **EHRA** that involves the estimation (qualitative or quantitative) of the magnitude, frequency, duration, **exposure pathway** and extent of **exposure** to health impacts for the general population, for different subgroups of the population, or for individuals. An **exposure assessment** is an important component of assessing risks (enHealth, 2012).

Risk characterisation: The qualitative and, wherever possible, quantitative determination, including attendant uncertainties, of the probability of occurrence of known and potential adverse effects of a **factor** in a given organism, system or (sub) population under defined **exposure** conditions (enHealth, 2012).

Stressor: A chemical or physical **factor**, environmental condition, external stimulus or an event that causes stress to an organism (Keywood et al., 2018).

Abbreviations

| | |
|--------|---|
| AICIS | Australian Industrial Chemicals Introduction Scheme |
| APLNG | Australia Pacific Liquified Natural Gas |
| CAS RN | Chemical Abstract Society Registration Number |
| COPC | Chemical of potential concern |
| CPP | Central processing plant |
| CSG | Coal seam gas |
| CSM | Conceptual site model |
| EHRA | Environmental health risk assessment |
| EIS | Environmental impact statement |
| EPP | Environmental Protection Policy |
| GAB | Great Artesian Basin |
| GHS | Globally Harmonised System of Classification and Labelling of Chemicals |
| GPF | Gas processing facility |
| HIA | Health impact assessment |
| KEDP | Known environmental degradation product |
| LNG | Liquified natural gas |

| | |
|-------------------|---|
| LSRG | Local stakeholder reference group |
| MSDS | Material safety data sheet |
| NICNAS | National Industrial Chemical Notification and Assessment Scheme, now known as the Australian Industrial Chemicals Introduction Scheme |
| NP | Nonylphenol |
| NPI | National Pollutants Inventory |
| NPE | Nonylphenol, ethoxylated |
| OGIA | Office of Groundwater Impact Assessment |
| PAH: | Poly aromatic hydrocarbons |
| PM _{2.5} | Particulate matter with a diameter of 2.5 micrometres or less |
| PM ₁₀ | Particulate matter with a diameter of 10 micrometres or less |
| QGC | Queensland Gas Company (owned and operated by Shell) |
| RCS | Respirable crystalline silica |
| SDS | Safety data sheet |
| THP | Phosphinidynetrimethanol |
| THPO | Tris(hydroxymethyl)phosphine oxide |
| THPS | Tetrakis (hydroxymethyl) phosphonium sulfate |
| TRG | Technical reference group |
| TTPC | Tributyl tetradecyl phosphonium chloride |
| VOC | Volatile organic compound |

Executive summary

This report synthesises the key outcomes of CSIRO GISERA H.2 project *Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland* (the H.2 project). The purpose of H.2 project, was to:

- identify potential hazards to human health from CSG activities at a study site in the Surat Basin, Queensland
- conduct a screening assessment of existing data related to these potential hazards
- determine whether further in-depth assessment of these potential hazards is needed

This project represents the first time the CSG health study framework, an output from the 2017 *Human Health Effects of Coal Seam Gas – Designing a Study Framework* project, has been applied to the study of potential human health impacts of CSG activities. This study was completed over a four-year period and involved close collaboration between CSIRO and The University of Queensland.

There are three individual components conducted for the H.2 project, with reports for each component:

- *Site profile: Collation of background information and data sources for the CSIRO GISERA H.2 project – identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland* (Huddleston-Holmes et al., 2023).
- *Hazard identification of Coal Seam Gas (CSG) drilling and hydraulic fracturing additives with potential for community human health impacts* (Rigby et al., 2023) (H.2 additives study)..
- *Identification and screening of air pollutant emissions from coal seam gas (CSG) activity in the Surat Basin, Queensland* (Dunne, 2021). (H.2 additives study).

This report synthesises the key outcomes of the three individual reports and is an output of this project.

The H.2 project identified factors associated with CSG activities at a study site in the Surat Basin, in the vicinity of Miles and Chinchilla. CSG has been in full production from the study since 2013 as part of two CSG developments (Australia Pacific Liquefied Natural Gas, APLNG and Shell's Queensland Gas Company, QGC). There is a range of gas infrastructure including wells, pipelines, water treatment facilities and gas processing facilities. The factors identified included chemical factors (chemicals used by industry, emitted by industry and naturally occurring chemicals that may be released by industry activities) and physical factors (air emissions, noise, light and dust).

A key component of this project was developing a detailed understanding of the study site and the activities that are conducted within it. This component was significantly more challenging than anticipated due to the scale and complexity of the activities. Researchers conducting similar studies in the future should ensure close engagement with experts in those activities, which in the case of site-specific CSG activities, are the operators.

A methodical approach was applied to appraise the factors identified. Chemical and physical factors were appraised based on their use or presence in the study site and available literature. The appraisal considers aspects such as the factor's potential to impact on human health, whether the factor is emitted to the environment, the potential mobility and persistence of the factor in the environment, and whether there is a possible exposure pathway to humans.

Ninety-seven unique chemical factors were identified as components of additives used in drilling muds of over 2400 wells and in hydraulic fracturing of over 60 wells at the study site. Of these 97 chemical factors, 40 chemical factors were identified to be of inherently low hazard potential to local communities and required no further consideration. Thirty-two chemical factors were appraised through a rigorous and systematic approach to have low hazard potential to local communities.

Twenty-five chemical factors (in eight groups – chemicals with very similar composition and properties were grouped in the appraisal) were identified as warranting further assessment. Four groups (one group of three chemical factors and three individual chemical factors) were appraised to be COPCs. Four groups (one group of 16 chemical factors and three individual chemical factors) were identified as having knowledge gaps that prevented a complete appraisal of their hazard potential but to ensure thoroughness were included in warranting further assessment. These chemical factors are:

- CMIT/MIT (a single chemical factor). A biocide used in drilling additives (5 wells) and hydraulic fracturing fluids (35 wells). Commonly used in Australia as a preservative in cosmetic, cleaning and laundry products and paint. Appraised as a COPC.
- THPS (a single chemical factor). A broad-spectrum biocide and fungicide used in industrial water systems and in drilling and hydraulic fracturing fluids. Appraised as a COPC.
- Nonylphenols. (a single chemical factor and its breakdown products) Surfactants used in a drilling additive (97 wells) and hydraulic fracturing additive (5 wells). These chemicals are also used in industrial cleaning, agriculture, plastics, textiles, paper, phenolic resins, plastics additives, detergents, emulsifiers and pesticides. Appraised as a COPC.
- Crystalline silica (three chemical factors). Crystalline silica is the main component of the earth's crust. Quartz sand is used as a proppant in CSG wells and crystalline silica is present as an impurity in mineral-based drilling additives that are widely used in the study site. The respirable form (particles less than 10 micrometres in diameter) has been appraised as a COPC.
- Fluorobenzoic acid tracers (a broad grouping of 16 chemical factors). This group of chemical factors has been used as tracers in hydraulic fracturing fluids for 10 wells in the study site. Limited information exists on toxicity and environmental fate of this group of chemical factors and further research is warranted.
- TTPC (a single chemical factor). An antimicrobial agent used in hydraulic fracturing fluids for 11 wells in the study site. No data are available on environmental behaviour and fate and further research is warranted.
- Glutaraldehyde (a single chemical factor) is used in drilling and well workovers in the study site. Commonly used in domestic, industrial and hospital applications. It readily degrades under aerobic and anaerobic conditions and is susceptible to biodegradation. Uncertainty

about the persistence of this chemical factor in shale gas resources raised in recent literature means that further research is warranted.

- Polyacrylamide (a single chemical factor and its breakdown product, acrylamide). Used as a viscosity modifier and friction-reducer in drilling and hydraulic fracturing fluids. Polyacrylamide is also commonly used in water treatment, as a soil conditioner and in other industrial processes. It has inherent low toxicity and, along with its breakdown products, is readily photo degraded. A potential breakdown product, acrylamide, has high toxicity. Although considered very low the potential of acrylamide formation warrants further research.

The H.2 project is not a full health impact assessment as it does not establish risk, risk mitigations and residual risks associated with each of these chemicals. Further assessment of these 25 chemical factors is the subject of further research.

The regulatory requirements in Queensland for recording drilling additive use do not require the additives to be uniquely identified or for their ingredients to be listed. This created challenges in identifying chemicals used in the drilling process. Recent changes to Queensland Government reporting requirements for well completion reports will improve this by requiring additives data to be submitted in a standard format. However, there is no requirement to include chemical identification data. This contrasts to Queensland Government reporting requirements for hydraulic fracturing that require the names of any chemical compound contained in the hydraulic fracture fluid to be reported.

A potential pathway for CSG activities to impact the broader community is through inadvertent releases. Based on data provided to the H.2 project by industry and the Queensland Government, such incidents are infrequent and of low consequence within the study site. Conditions on Environmental Authorities for CSG activities in Queensland require operators to report incident data to the regulator. However, these data are not publicly available. Access to these data would further improve assessment of likelihood of potential pathways associated with chemical factors.

Nineteen unique chemical factors were identified from water treatment facilities and one chemical factor was identified for gas processing facilities. Six of these chemical factors from water treatment facilities were also identified in drilling and hydraulic fracturing additives, and two that are known environmental degradation product of chemical factors used in drilling and hydraulic fracturing. All water treatment facility and gas processing facility chemical factors appraised were found to have inherently low hazard potential or were appraised to have little to no evidence of toxicity potential.

The CSG industry is a source of potentially hazardous emissions to air of known pollutants. Available data from a number of sources indicates the levels of these chemical factors in air at the study site are within air quality objectives and are unlikely to pose a hazard to human health. These chemical factors are nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM₁₀ and PM_{2.5}), volatile and semivolatile organic compounds (VOC), ozone (O₃) – secondary production from emissions of NO_x and VOCs and inorganic gases - including hydrogen sulfide, radon and mercury.

The CSG produced at the study site is predominantly composed of methane with small amounts (~1 -4%) of nitrogen, carbon dioxide (CO₂), and hydrocarbons with trace amounts of other organic

and inorganic substances. This study concluded that these components of CSG are unlikely to pose a hazard to human health at the study site.

Particulate matter, or dust, is also considered as a physical factor in the H.2 project. Occasional exceedances of PM_{2.5} air quality objectives were observed in monitoring data from the study site. Modelling indicated that during these peak events, CSG-related emissions contributed at most between 4 - 37 % to the 24-hour observed PM_{2.5} concentrations. Analysis of satellite data and other trace species in the monitoring studies showed that high PM_{2.5} events were typically associated with smoke from local and regional fires.

Noise and light emissions from CSG activities were appraised to not pose a hazard to physical health to the community in the study site. This appraisal is primarily based on the intensity and duration of community exposure to these physical factors. The nuisance value or impacts on social stress of noise and light emissions were out of scope in this study.

Part I Background and Project design



1 About this report

There are three individual components conducted for the CSIRO GISERA H.2 project *Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland*. There are individual reports for each of these components:

- *Site profile - Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland* (Huddleston-Holmes et al., 2023)
- *Hazard identification of Coal Seam Gas (CSG) drilling and hydraulic fracturing additives with potential for community human health impacts* (Rigby et al., 2023)
- *Identification and screening of air pollutant emissions from coal seam gas (CSG) activity in the Surat Basin, Queensland* (Dunne, 2021).

This report synthesises the key outcomes of the three individual reports and is an output of this project.

2 Background

Potential human health risks from CSG activities are consistently raised as an issue of concern to the community and the wider public (OCSE, 2014). In response to these concerns, GISERA has an ongoing portfolio of health-related projects, that has involved collaborations with the Queensland Alliance for Environmental Health Sciences, Sustainable Minerals Institute and Centre for Coal Seam Gas at the University of Queensland, Summit Toxicology LLP and Hunter Research Foundation Centre at the University of Newcastle.

Most available scientific knowledge and data regarding health outcomes and unconventional gas activity relates to international studies on shale gas, which does not translate to the Australian context of CSG regulation, geological conditions and gas extraction methods.

2.1 CSG health study framework

In response to these community concerns about potential human health risks from CSG activities, CSIRO's GISERA conducted the GISERA H.1 project—[Human Health effects of Coal Seam Gas—Designing a Study Framework](#) (Keywood et al., 2018) to develop a robust approach to conducting research into possible health effects associated with CSG activities.

An output of [Human Health effects of Coal Seam Gas—Designing a Study Framework](#) project was the **CSG health study framework** outlined in Figure 1. This framework is based on the Health Impact Assessment (HIA) methodology (enHealth, 2017), an existing approach used widely in Australia to identify potential health impacts on a population from a proposed development. The CSG health study framework allows research to be broken into individual projects that cover the different stages of the framework, different types of hazards or stressors, and for prioritisation of the research to specific locations and CSG activities. This allows the diversity of CSG activities in Australia, their scale and locations to be addressed efficiently.

A series of staged steps with consultation and decision points at each step, are the essence of the CSG health study framework shown in Figure 1. The stage gates shown are logical points to evaluate the resources required for the next step in the process and to receive feedback from stakeholders. Stage gate 3, after the screening assessment step, is a logical boundary that allows for the scoping of in-depth assessment of any hazards or stressors that have been identified as requiring further evaluation. It is also a point where many potential stressors may be ruled out.

CSG health study framework

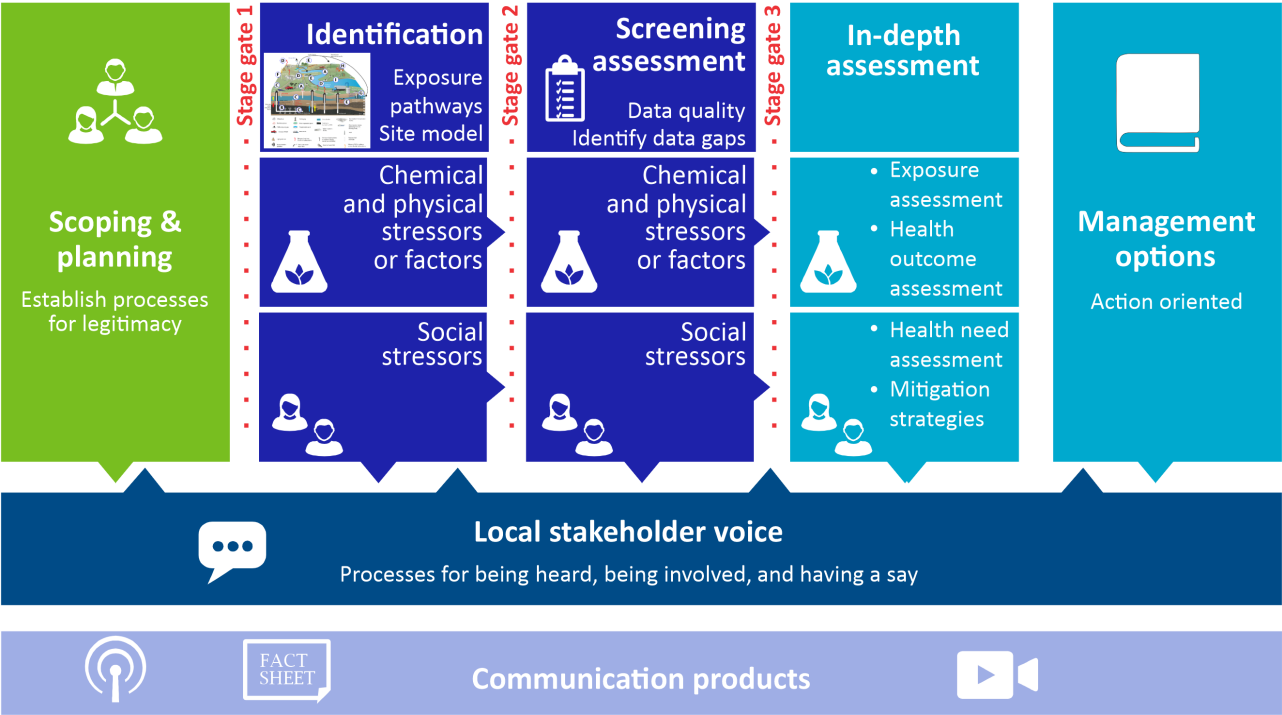


Figure 1: Overview of the CSG health study framework.

3 Project design

3.1 Project scope

The H.2 project is the first study of the potential human health impacts of CSG activities to implement the CSG health study framework (Figure 1) developed in the GISERA H.1 project—[Human Health effects of Coal Seam Gas—Designing a Study Framework](#) (Keywood et al., 2018).

The purpose of the H.2 project was to :

- identify potential hazards to human health from CSG activities at a study site in the Surat Basin, Queensland
- conduct a screening assessment of existing data related to these potential hazards
- determine whether further in-depth assessment of these potential hazards is required

Specifically, the project's scope included:

- selecting a study site and defining the scope of CSG activities to be assessed, (up to stage gate 1 in Figure 1)
- profile the study site and activities (population characteristics, environmental conditions, other land uses, CSG activities)
- conduct the identification and screening assessment steps of the CSG health study framework (up to stage gate 3 in Figure 1) to identify potential hazards that have complete potential exposure pathways to humans (see the Key terminology and abbreviations section for definitions of hazard and exposure pathways)
- develop a conceptual site model for the study site
- scope further work for in-depth assessments of potential hazards identified in this project

The H.2 project is not a full **HIA** or **EHRA** as it does not establish risk, risk mitigations and residual risks associated with the factors identified (after stage gate 3 in Figure 1). The assessment and characterisation of risk are outside the scope of the H.2 project.

3.2 Study site

As part of the scoping and planning step of the CSG health study framework, the study site for the H.2 project needed to meet the following criteria:

- extensive CSG infrastructure in the operational phase
- a minimum of two operating companies
- hydraulic fracturing in a proportion of the wells
- diverse land use (irrigated agriculture, dryland agriculture, grazing, state forest, towns)

3.3 CSG activities and receptors

The H.2 project scope **includes** the following activities and receptors located within the study site:

- the local community as receptors of interest
- operational phase activities
- CSG well construction and workover activities
- hydraulic fracturing activities
- water treatment facilities, gas processing facilities, water and effluent ponds, gas and water gathering pipelines on site, well integrity information, high point vents, flares, spills, environmental emissions and impacts associated with access roads, noise, dust, lights

The project scope **excludes** the following activities and receptors:

- CSG worker, contractor, or visitor hazard assessments.
- Power lines, electrical substations, communication towers, office buildings, power stations, personnel camps, chemicals used in fully closed-loops (e.g. engine oils within vehicles), household chemicals directly used for cleaning office/communal areas.
- Most construction phase (construction of infrastructure such as water treatment plants and pipelines) and decommissioning phase activities

3.4 Project method overview

The main component of the H.2 project, once the scope was defined, was the identification and screening assessment steps of the CSG health study framework. The identification stage established the potential sources of chemical and physical factors and appraises whether they are of potential concern to human health.

3.4.1 Identification of factors

The H.2 project identified factors associated with CSG activities in the study site. These included chemical factors (chemicals used by industry, emitted by industry and naturally occurring chemicals that may be released by industry activities) and physical factors (air emissions, noise, light and dust).

The H.2 project identified CSG factors in five categories:

- chemical factors – additives: chemicals in additives used in drilling, hydraulic fracturing, and water treatment
- chemical factors – geogenic: naturally occurring chemicals in produced or treated water and drill cuttings
- chemical factors – air emissions: chemicals in air emissions such as CSG, combustion products
- physical factors – noise and light

- physical factors – dust

Chemical factors - geogenic were not appraised in this project and will be the subject of future research.

3.4.2 Appraisal of factors

A methodical approach was applied to appraise the factors identified, as shown in Figure 2. Chemical and physical factors were appraised and screened, based on their use or presence in the study site and available literature. The appraisal considers aspects such as:

- the toxicity of the factor and its potential to impact on human health (under realistic conditions)
- whether the chemical/physical factor is emitted to the environment
- mobility of the factor in the environment
- persistence of the factor in the environment
- whether there is a possible exposure pathway to humans
- occurrence of the factor (spatial and temporal).

For physical factors such as noise and light, the degree to which a factor can harm humans was appraised in place of toxicity. This process identifies factors that are potential hazards that warrant in-depth assessment.

Factors that do not constitute a potential concern are also documented along with the evidence that leads to that conclusion. These factors are not considered to present a significant potential hazard in the context of the study site.

In the screening assessment step, available data on factors identified in the identification stage were collated and assessed. The screening assessment allows for the scoping of additional research required for the in-depth assessment step. Section 5, 6 and 7 describe the methods used in the H.2 additives study, H.2 air study and the appraisal of physical factors respectively.

As a result of this appraisal, each of the identified factors were characterised as:

- inherently low hazard² to human health at the study site
- low hazard potential to human health at the study site, or
- warranting further assessment for hazard potential to human health at the study site

Some factors are already known to pose a potential hazard to human health, and are subject to regulation. For example, the [National Pollutants Inventory](#) lists a suite of air emissions that must be reported and/or monitored. For these factors, the screening process considered whether they posed a hazard for human health based on available data for the study site. These factors, were characterised as:

² Deemed to be inherently low hazard to the community in the context of their use identified in this study. Some of these chemicals are hazardous in a concentrated form, or in occupational settings.

- known hazard that poses a low hazard potential to human health at the study site, or
- known hazard that requires further assessment for hazard potential to human health at the study site.

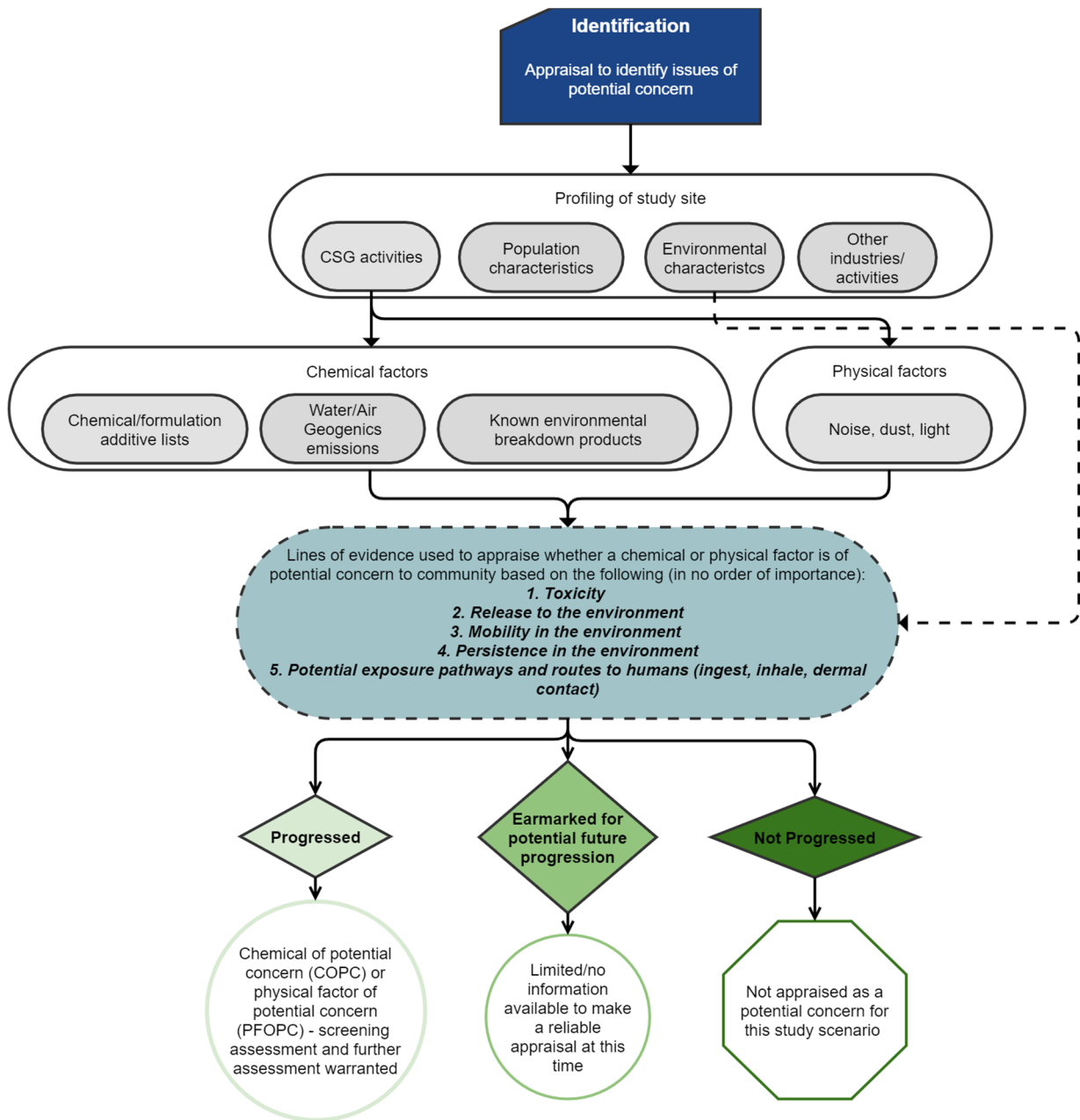


Figure 2: Workflow for appraising chemical and physical factors of potential concern) used in the identification stage in the CSG health study framework (Rigby et al., 2023).

3.5 Reference groups

3.5.1 Ethics approval

The project design and procedure was reviewed by CSIRO's independent Social and Interdisciplinary Science Human Research Ethics Committee to ensure it adhered to the National Statement on Ethical Conduct in Human Research. Ethics approval was granted in August 2018.

3.5.2 Local stakeholder reference Group (LSRG)

In the first few months of the project, and once Ethics approval was granted, a LSRG was established for the project. The main purpose of the group was to bring community perspectives, values and local knowledge into the research process. The research team recognised the importance of having community and local stakeholder involvement throughout the project so that local stakeholder perspectives could be integrated into the project design, planning and decision-making.

The LSRG members comprised local stakeholders interested in health in relation to CSG development at the local level. There were 11 members including landowners, representatives from local business groups, members of a local indigenous group, health sector workers from the region, and representatives from the local regional council. LSRG members were all residents from the local government region and each had demonstrated involvement in local community groups and activities. Through their organisations or community involvement they had an awareness and understanding of the issues of concern to local communities regarding health and CSG activity. One member lived in an adjacent regional council area but was specifically involved to provide insights from the perspective of a resident from a gas field further afield than the local study site.

The LSRG held its first meeting in September 2018 and met 11 times over the life of the project at approximately 3-4 monthly intervals.

The main functions of the LSRG included providing feedback on project planning, posing questions to the project team that would be representative of queries from the wider community, and highlighting difficult to understand concepts for the project team to clarify in subsequent reports and communications. For example, this included feedback and questions related to site selection, proposed methodologies, scope of the H.2 project, data quality and data sourcing matters.

Over the life of the project, the LSRG provided the project team with valuable insights and perspectives about the H.2 project. These views were used to help project decision-making and planning. For example, the LSRG provided useful feedback about the proposed study site and contributed to the final site selection. The LSRG's feedback also assisted the project team to develop explanations about the technical aspects of the H.2 project so that the methodologies and approaches used in the research would be easier to understand by a nontechnical person. The project team has been very appreciative of the time and effort that the LSRG members have provided to the project.

3.5.3 Technical reference group

A technical reference group was established to provide guidance on technical aspects of the project. This group comprised:

- a representative from each of the operators to provide advice on operations and infrastructure in the study site and the availability of data
- representatives from Queensland Health, Queensland Department of Environment and Science, Queensland Department of Natural Resources, Mines and Energy (now Department of Resources), Office of Groundwater Impact Assessment to provide advice on Queensland Government held data and regulations
- research experts in areas relevant to the H.2 project including ecotoxicology, air quality, occupational health, public health, environmental health assessment and agriculture

The role of the technical reference group was advisory. They provided technical and scientific input that the research team incorporated into decisions about the conduct of the research. The group met twice during the first half of the project and did not have any direct input into the conduct of the research or its results.

Part II The study site



4 Study site profile

4.1 Overview

The study site selected for the project (Figure 3) takes in the area where CSG was first developed in the Surat Basin and covers an area of 2150 square kilometres. The regional town of Miles is within the study site and Chinchilla and Condamine are immediately adjacent to it. The study site extends from just north of the Warrego Highway, between Chinchilla and Miles, extending south towards Tara.

The study site contains significant CSG infrastructure that includes over 2400 wells. The CSG activities in the area have been undertaken by two operators, Australia Pacific LNG (APLNG) and Shell's Queensland Gas Company (QGC). Upstream operations are conducted by Origin Energy for APLNG and Shell for QGC. There is An Arrow Energy held Petroleum Lease in the north of the study site that has had limited activity and is excluded for the H.2 project. To date, a small proportion of wells in the study site have been hydraulic fractured.

The study site is located in a rural area that includes a number of small townships, agriculture and other industries.

4.2 Site profile

The study site profile report *Site profile - Identification and screening for potential human health effects of coal seam gas (CSG) activity in the southern Surat Basin, Queensland* (Huddleston-Holmes et al., 2023) describes the study site in more detail, with a description of population characteristics, economic indicators, land use, geology, groundwater and CSG infrastructure. The report provides background information on CSG activities and their regulation. Sources of data used for this project are also provided in the study site profile report.

The following sections provide a summary of the study site profile report.

4.2.1 People

According to the 2016 Census of Population and Housing (Australian Bureau of Statistics, 2017), the population of the study site is approximately 3500 people, of which approximately 1100 reside in the township of Miles. Chinchilla lies just outside the study site and has a population of around 6600.

4.2.2 Land use and industry

Within the study site, "agriculture, forestry and fishing" is the dominant industry sector, followed by "construction," then "education and training" (Australian Bureau of Statistics, 2017). The primary land use in the study site is "production from relatively natural environments" totalling

1656 km², followed by “conservation and natural environments” (192 km²), closely followed by “production from dryland agriculture and plantations” (185 km²).

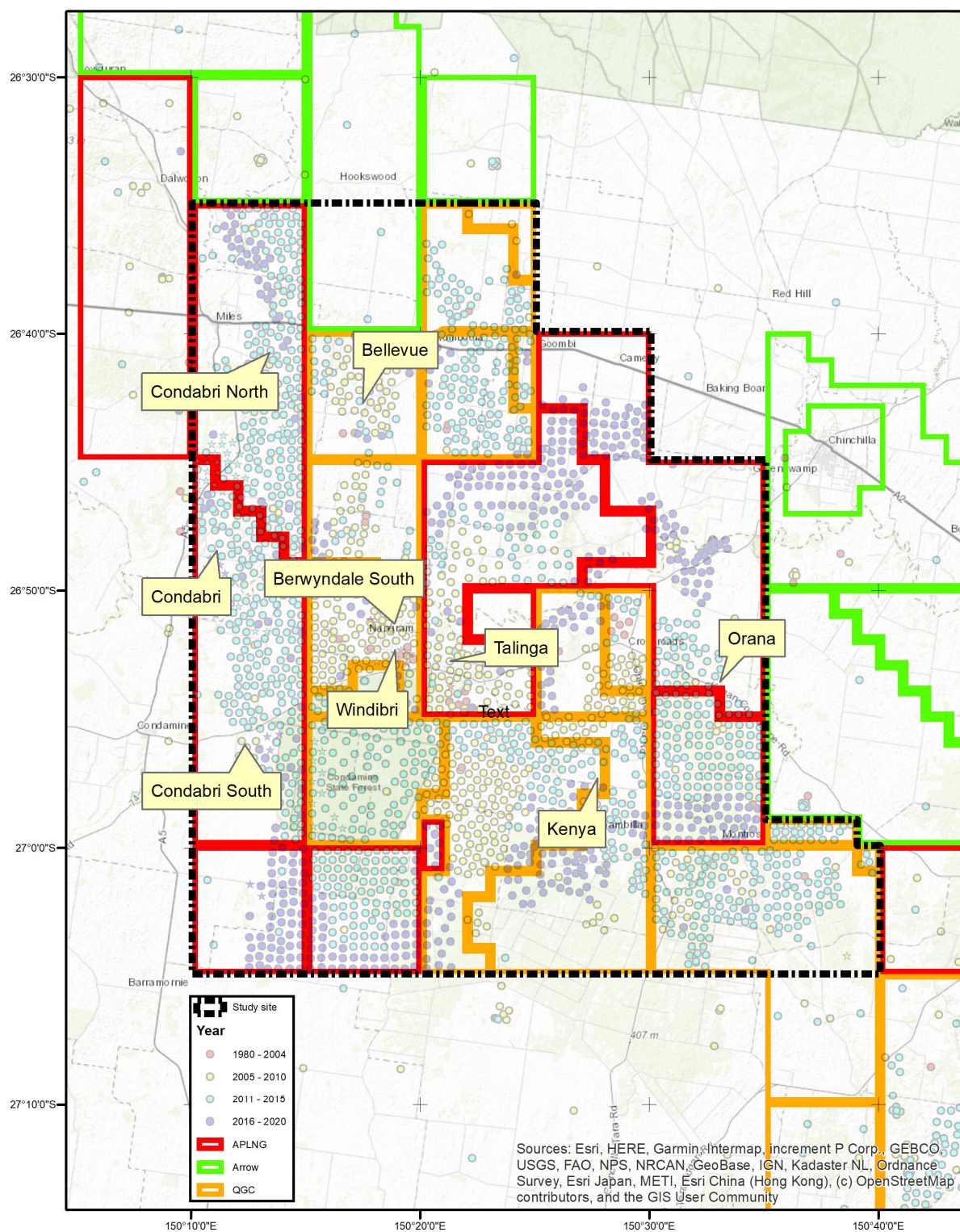


Figure 3: Location of the study site showing Petroleum Leases, well locations and the locations of major CSG infrastructure.

4.2.3 Geology

The study site incorporates the northern edge of the Surat Basin, and western margin of the underlying Bowen Basin. These basins have been well studied for their extensive coal, gas and oil resources.

The Surat Basin covers an area of approximately 300 000 km² in southern Queensland and northern New South Wales. It is the third largest of the contiguous series of shallow intracontinental sag basins that formed during the Triassic to Cretaceous periods across inland Queensland, South Australia and the Northern Territory, and forms the eastern extent of the Great Artesian Basin (GAB). Within the study site, CSG developments access the Walloon Fairway, which is a highly prospective CSG area within the Surat Basin. The Walloon Fairway extends along the northern and north-eastern basin margin down dip of the Walloon subcrop, between Roma and Dalby.

At the study site, the sedimentary strata of the Bowen Basin are overlain by the younger strata of the Surat Basin. CSG activities at the study site are entirely within the Surat Basin.

4.2.4 Groundwater

Key groundwater resources within the study site include the aquifers of the GAB, and a small section of the Upper Condamine alluvium. The Surat Basin contains several important GAB aquifers and aquitards. Groundwater is extracted from the Central Condamine Alluvium aquifer for irrigation, industrial, stock and domestic use.

The Office of Groundwater Impact Assessment (OGIA) estimate that there are approximately 8000 water bores in an area of interest centred around CSG production areas in the Surat Cumulative Management Area, with around 4000 of these accessing aquifers in the GAB (OGIA, 2021). Non-CSG groundwater extraction from these bores is around 59 000 ML/year, of which 20 000 ML/year is from the GAB. Groundwater extracted from GAB aquifers is utilised primarily for grazing, feedlot and domestic supply. Water extraction from CSG activities was estimated to be 54 000 ML/year.

4.2.5 CSG activities and infrastructure in the study site

The CSG activities in the study site have been conducted since the early 2000s as part of two larger CSG developments in the Surat and Bowen Basins belonging to APLNG and QGC. These activities can only be conducted when the project proponent holds the appropriate resource authority. For exploration this is usually an Authority to Prospect and for production, it is a Production Licence. The project proponent must also obtain an Environmental Authority for their activities. An Environmental Authority defines the environmental conditions and risk management requirements that must be complied with for a specific activity and development.

During the exploration stage of a resource development, activities are typically limited to drilling of a small number of wells to characterise the resource. Small volumes of water and gas may also be produced, with the gas flared if there is no readily accessible way of using it (for example a pipeline to existing infrastructure). Once a resource has been discovered, the production phase can commence, which starts with construction of the well field and surface infrastructure (gathering lines, water storage and treatment facilities, gas processing facilities, pipelines and

supporting infrastructure). Production of gas usually commences during the construction phase. This gas produced during the construction phase may be delivered into the gas market if infrastructure is available; however, some gas may need to be flared. During the production life of a CSG development, additional wells will be drilled and surface infrastructure may be added to allow gas production to be maintained.

The key components and activities involved in a CSG development are shown in Figure 4.

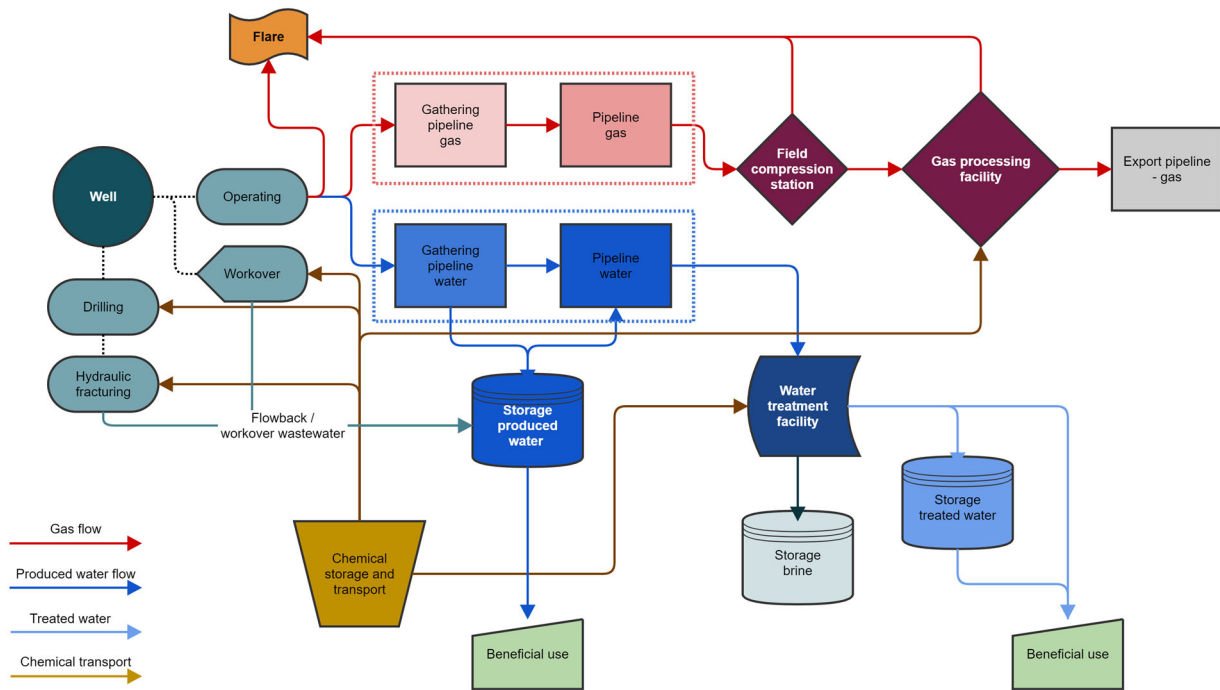


Figure 4 : Key components of a typical CSG development in Queensland (note that less than 3% of wells in the study site have been hydraulically fractured).

For CSG resources, the development of the well field involves drilling production wells that are initially used to remove water for the reservoir so that gas can flow. In the study site, all the production wells are vertical and between 400 m to 1000 m deep. The productive coal seams in the Walloon Fairway dip (get deeper) towards the southwest in the study site, so the shallower wells are in the northeast of the area and the deeper wells are in the southwest. As of February 2020, 2424 CSG wells had been drilled in the study site (Figure 5 and Table 1). Of these, 67 wells had been hydraulically fractured (Table 1). Hydraulic fracturing is only used when needed to increase gas or water production to a economically desirable level. The characteristics of the CSG resource in the study site are such that the majority of wells are highly productive without hydraulic fracturing.

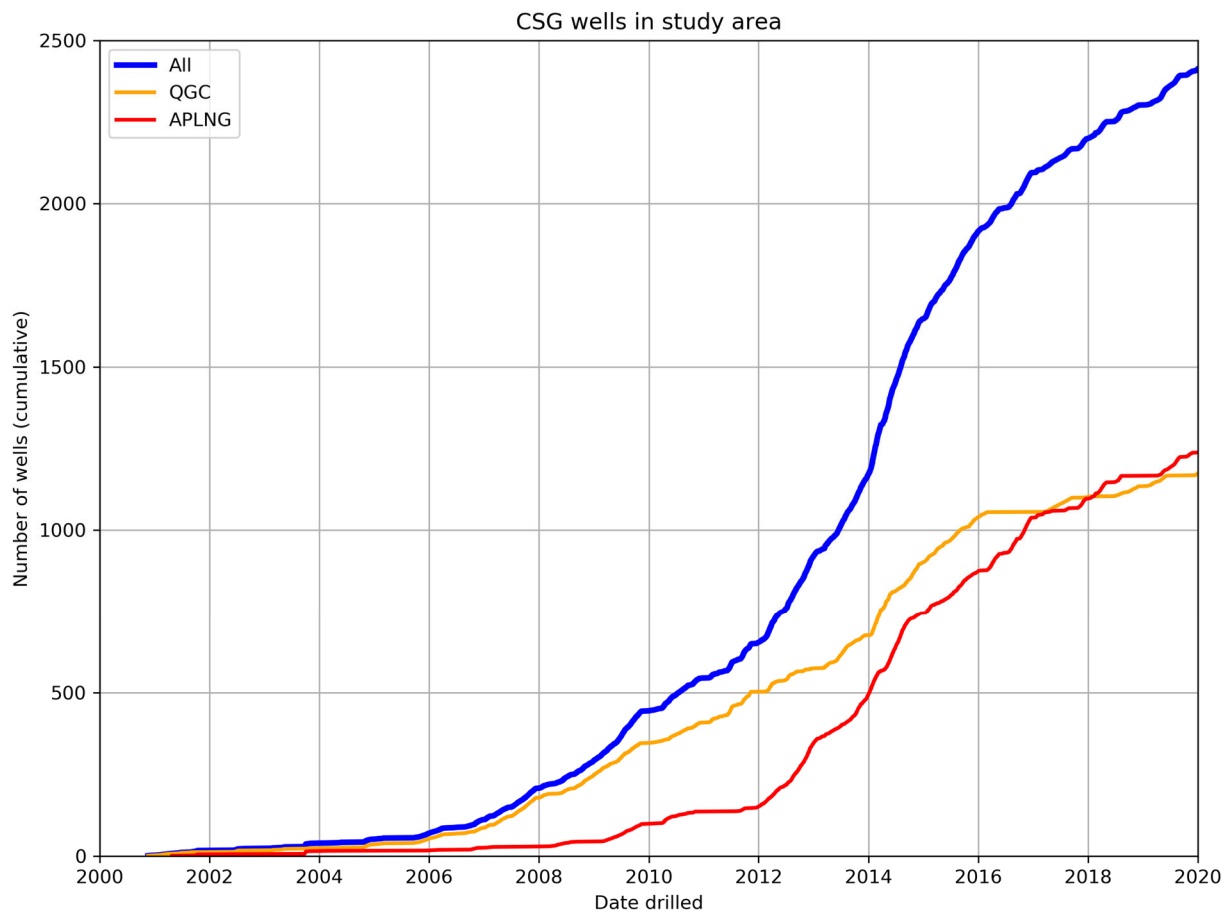


Figure 5: Cumulative count of wells drilled in the study site up to February 2020.

The first production licences in the study site were issued in 2004. Significant levels of production commenced after 2013 (Figure 6). The majority of gas is exported to market with a small volume used, flared or vented within the gas field (Figure 6, Figure 7). While flaring or venting appears to have been more frequently used between 2013 and 2017 (as gas production ramped up), the volume of flared or vented CSG has significantly reduced in recent years.

Table 1: Major CSG infrastructure components in the study site.

| Category | APLNG | QGC |
|-------------------------------------|---------------------------|----------------------------|
| CSG Wells | 1240 | 1184 |
| Wells hydraulically fractured | 43 | 24 |
| Gathering pipelines (water and gas) | 2286.7 km | 2313.5 km |
| High point vents/Low point drains | 1386/823 | 199/323 |
| Water ponds | 47 (2.4 km ²) | 24 (6.01 km ²) |
| Water treatment facilities | 2 | 2 |
| Field compression stations | 3 | 12 |
| Gas processing facilities | 5 | 3 |
| Flares | 11 | 24 |

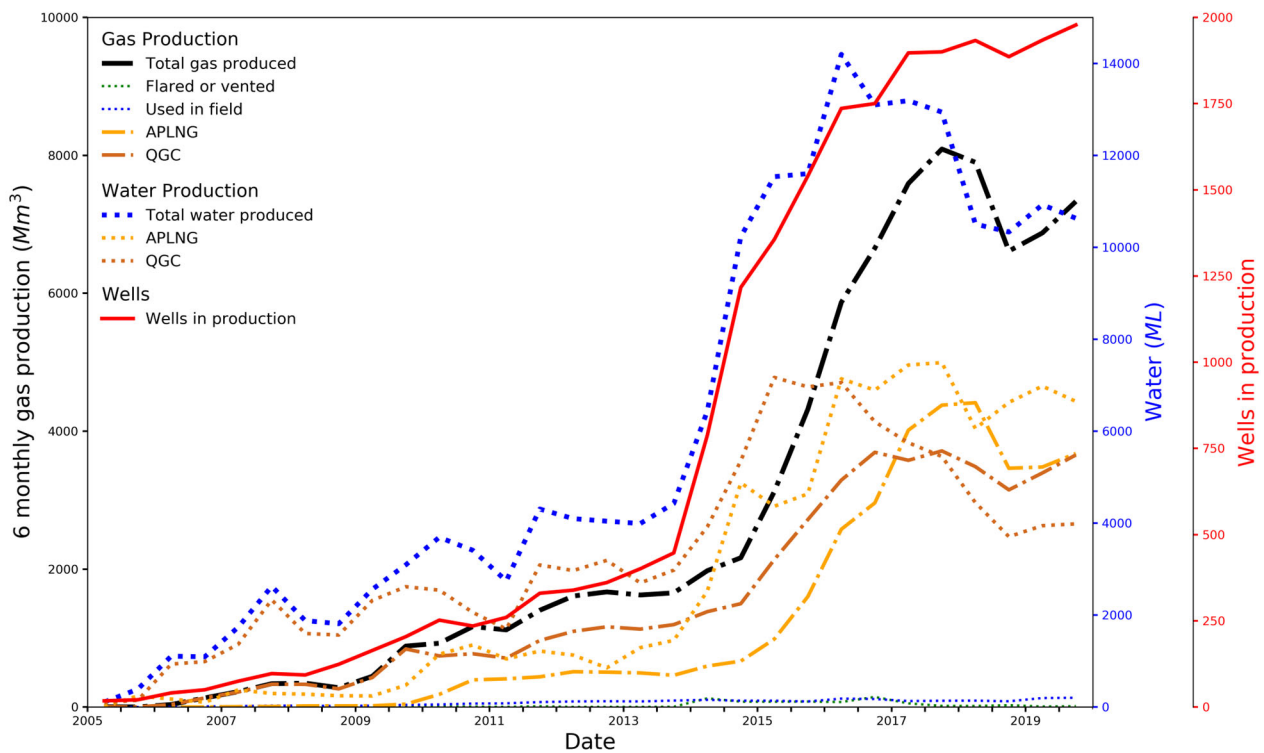


Figure 6: Cumulative water and gas production in the study site up to June 2019 (Queensland Government, 2022a).

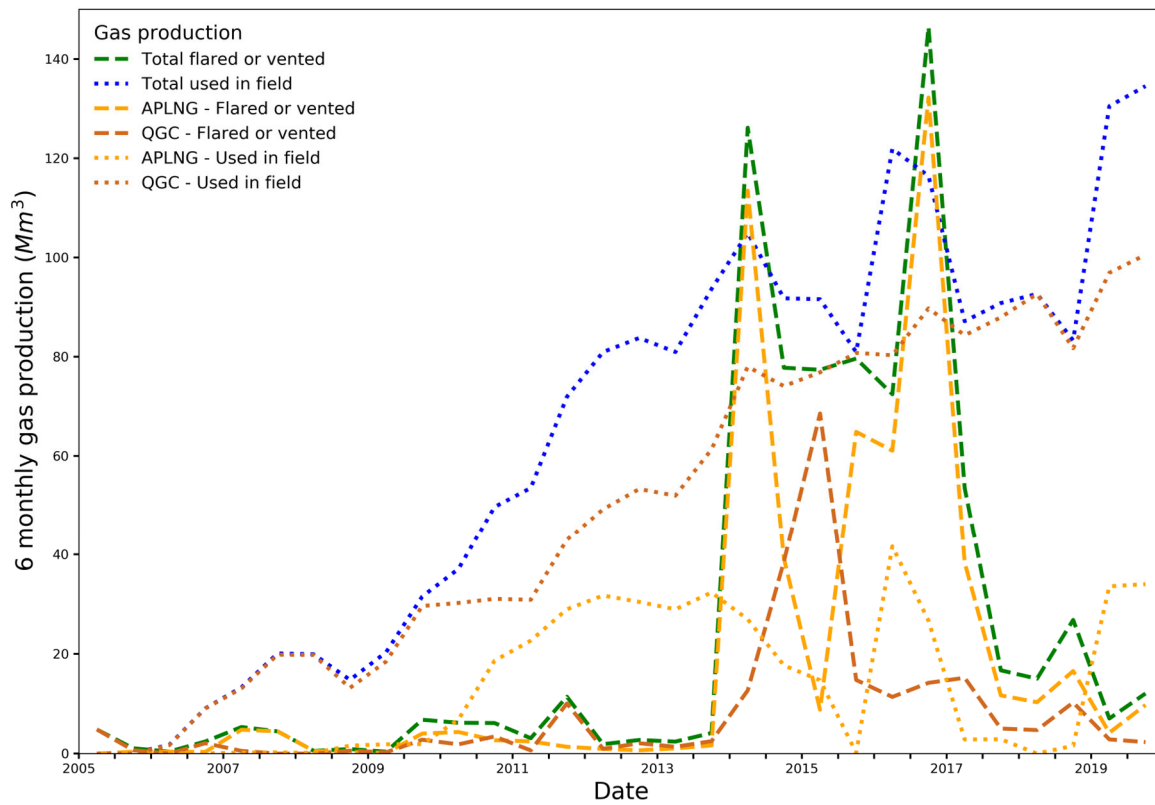


Figure 7: Gas use within the gas field in the study site up to June 2019 (Queensland Government, 2022a).

Part III Identification and screening assessments



5 Chemical factors – additives

Chemicals, chemical risk and humans

The general population are exposed to many chemicals on a day-to-day basis from both natural and anthropogenic (human derived) sources, and adverse health effects are not often observed. Certain chemicals are necessary for life (e.g. water, oxygen), indeed we are made up of chemicals as is all water, soils and rocks, foods, air etc. The human body has protective systems such as metabolism and excretion to assist with processing many chemicals. Exposure to chemicals occurs through various routes including inhalation (air), ingestion (food, water), or direct contact (water, soil).

Any chemical can become a contaminant when it is found somewhere unusual or at concentrations above normal background levels. Many chemicals that are naturally occurring and even many chemicals produced industrially are not found to present risk to the environment and humans. However, there are human-made and naturally occurring chemicals that can pose a potential hazard to humans (and the environment/wildlife) if present at high enough concentrations.

Dose-response is an important concept when considering whether a chemical may be hazardous (Tsatsakis et al., 2018). Some chemicals may be defined as ‘hazardous’ if humans are directly exposed to high concentrations (i.e. occupational exposure on a regular basis) but at lower concentrations the same chemicals do not pose a risk to human health. It may be that a chemical substance is not readily taken into the body (therefore reducing exposure) or that the body is able to break the chemicals down easily via metabolism. Alternatively, certain chemicals can be hazardous from low dose, long term exposures due to a continual source, high chemical persistence and/or tendency for the chemical to accumulate in the body. Sensitivity of an animal or human to a substance also varies between species and within a population of the same species.

Additives are used in CSG specific activities such as well drilling, hydraulic fracturing, water treatment and gas processing.

For the H.2 project, the chemicals in additives that are used in CSG specific activities were considered as one set of chemical factors. The CSG specific additives used in the study site and are:

- Additives used in drilling fluids during the drilling of CSG wells
- Additives used during hydraulic fracturing operations in CSG wells
- Additives used in wastewater treatment plants
- Additives used in gas processing facilities

Additives or chemicals used in aspects of CSG activities which are also commonly undertaken by other industries were not considered in the H.2 project. These include fuels and oils used in vehicles or machinery, products used in administration facilities or camps, or chemicals used during earthworks or rehabilitation. These additives or chemicals are widely used in other

applications within the study site. Additives used during the cementing of casing in CSG wells were also not considered.

5.1 Identifying chemical factors in additives

Data on the chemical additives used by the CSG industry is held by the industry with some data reported to government. These data are collected for a variety of purposes, and not necessarily for an environmental health study. Regulatory requirements by government for data reporting have also changed through time. Complete lists of additives and chemicals identified in the H.2 project are provided in the accompanying study site profile report (Huddleston-Holmes et al., 2023).

5.1.1 Drilling additives

The drilling additives used in CSG wells are typically recorded for each well. This information is reported through well completion reports that industry must submit to the regulator within 12 months of completing a well. Well completion reports are kept confidential for a period of five years from completion of production wells. Operators are required to list the additives used, however, they are not required to list the ingredients of these additives.

CSG operators will also typically maintain their own database on drilling operations and chemical use. For this project, additive use information was sourced from publicly available well completion reports, extracts of operator databases and well completion reports provided by operators for wells that are still within the confidentiality period. The quality of these data are variable, with data not recorded for some wells or generic terminology used. The quality of the data recorded by CSG operators has been observed to have improved over time.

The H.2 project looked the 2424 CSG wells that had been drilled up to February 2020 (the first well was drilled in November 2000). The wells were identified from the Queensland Government's CSG well dataset (Geological Survey of Queensland, n.d.). From these 2424 wells:

- 121 wells had no record of whether drilling additives were used
- 185 wells had records that explicitly stated that no drilling additives were used (the drilling fluid was water without any additives)
- three wells had records that were incomplete (partial list of the drilling additives that were used)
- 2111 with records of the drilling additives used

Based on these records

- 106 unique drilling additives were identified. Of these:
 - 82 had a uniquely identifiable name for an additive product (such as AMC Biocide G)
 - 24 were a generic name for a material used as an additive (such as KCl or bentonite)
- five additional additive descriptors used on some well completion reports that were a generic name for a type of additive (such as biocide or loss control measure).

5.1.2 Hydraulic fracturing additives

The hydraulic fracturing chemical additives used in CSG are recorded for each well. This information is reported through hydraulic fracturing activities completion reports that industry must submit to the regulator within six months of the hydraulic fracturing activity. These reports are kept confidential for a period of five years from the completion of hydraulic fracturing activities. Operators are required to list the additives used. Since regulatory changes in 2011, operators must also provide a hydraulic fracturing fluid statement that lists the additives used, their quantities, concentrations and the name of all chemical compounds contained in the hydraulic fracture fluid.

For this project, additive use information was sourced from publicly available hydraulic fracturing reports and hydraulic fracturing reports provided by operators for wells that are still within the confidentiality period. 67 wells have been hydraulically fractured or stimulated within the study site. Additive data was available for all of these wells. From this, 59 unique hydraulic fracturing additives were identified. One of these additives is common to drilling and hydraulic fracturing.

5.1.3 Chemical factors in drilling and hydraulic fracturing additives

The chemical factors in additives used in hydraulic fracturing were primarily sourced from composition data in Safety Data Sheets (SDS, previously known as a material safety data sheet). The majority of these SDS are available on the operator's websites. Additional SDS were provided directly by the operators, accessed through chemical management databases (ChemWatch and ChemAlert), manufacturer websites or as included in other studies or assessments. The data sources are provided in the accompanying study site profile report (Huddleston-Holmes et al., 2023).

Chemical Abstracts Service Registration Number (CAS RN)

For the purposes of the H.2 project only chemicals with a Chemical Abstracts Service Registration Number (CAS RN) were appraised. The CAS RN provides certainty about the identity of the chemical.

The requirements for which products or chemicals require an SDS is regulated under state-based workplace health and safety legislation (these laws are part of nationally harmonised work health and safety laws). In Queensland, SDS requirements are contained within the *Work Health and Safety Regulation 2011*.

The regulations require an SDS is when a manufacturer determines that a product or its ingredients are hazardous according to relevant criteria. This is currently the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), 3rd revised edition (United Nations, 2009), although this is being transitioned to the 7th edition (United Nations, 2017). The regulations also set requirements for whether ingredients need to be named with a unique chemical identity, and whether the exact concentration is required or a range of concentrations (for commercial in confidence products). Chemical manufacturers are not required to have their SDS approved, but

the regulator may review SDS information to determine whether they are compliant with relevant regulations.

According to these regulations, SDS do not need to list those ingredients that are determined to be nonhazardous, or provide chemical identifiers in certain circumstances. As a result, SDS do not always contain a complete list of the ingredients of a product. This regulation applies to the majority of industrial chemicals in Australia, not just those used in the CSG sector.

For the 105 drilling additives, 58 hydraulic fracturing additives and the one additive used in both drilling and hydraulic fracturing, an SDS or ingredient list could be found for all additives except six of the drilling additives. The hydraulic fracturing fluid statements required since 2011 must list the name of any chemical compound contained in the hydraulic fracture fluid. In most cases this is provided as a separate list to the list of additives.

Based on these data sources, 144 uniquely identifiable chemical factors with a CAS RN were identified. Some of the additives contained a single chemical factor, while others contained a mixture. Some chemical factors were found in multiple drilling and/or hydraulic fracturing additives.

The SDS or ingredients lists also contained entries that did not have a CAS RN. These ingredients are discussed further in section 5.3.2.

5.1.4 Water treatment and gas processing chemical factors

Data on the use of chemicals used in water treatment facilities was derived from company reports on the operation of these facilities (Rigby et al., 2023). A total of 19 unique chemical factors with a CAS RN were identified for water treatment plants. Six of these chemicals were also identified as chemical factors used in drilling and hydraulic fracturing additives, two are known environmental degradation products of chemical factors used in drilling and hydraulic fracturing.

Only one unique chemical factor with a CAS RN within the project's scope was identified for gas processing facilities (Rigby et al., 2023). Gas processing facilities are primarily used to compress gas for pipeline transmission. Processing of the gas is limited to dehydration using triethylene glycol. There are other chemicals used, such as lubricants in gear boxes on compressors, which are outside of this project's scope.

5.2 Chemical factor appraisal

The H.2 additives study was completed by the Queensland Alliance for Environmental Health Sciences at the University of Queensland, and is available in the report *Hazard identification of Coal Seam Gas (CSG) drilling and hydraulic fracturing additives with potential for community human health impacts* (Rigby et al., 2023). Section 5.2 is drawn from that report.

A site-specific human health hazard identification and appraisal of chemical factors was completed specifically to assess "is there a potential hazard to the local community in the study site from site-specific CSG chemicals used in drilling muds or hydraulic fracturing?" Scientific knowledge regarding the environmental fate and toxicity of the chemicals identified as being used within the study site were gathered and realistic routes of potential exposure conceptualised from site-

specific CSG emission sources to the local community. An independent hazard appraisal of each chemical factor was completed primarily considering surface water and groundwater as the media for pathways to local communities.

The appraisals did not include an assessment of whether notable concentrations of these chemical factors were likely to reach community members (an exposure assessment). The appraisal determined whether any of the chemical factors were chemicals of potential concern (COPCs) that warrant further consideration and assessment for their human health hazard potential.

Similarly, no complete exposure pathway/s to local community were examined or identified therefore no risk to human health has been suggested, rather, the chemical factors which warrant further assessment or have information gaps were identified.

5.2.1 Hazard identification method

Potential hazards posed by CSG chemical factors and known environmental degradation products of those chemicals were assessed according to the workflow shown in Figure 2. The hazard appraisal methodology was adapted and expanded from the enHealth EHRA guidelines (enHealth, 2012). The approach was modified to incorporate all available information, involving an in-depth literature review. This project aimed to gather detailed site-specific information on actual usage of chemical factors, including the location of use, frequency of use and purpose of use.

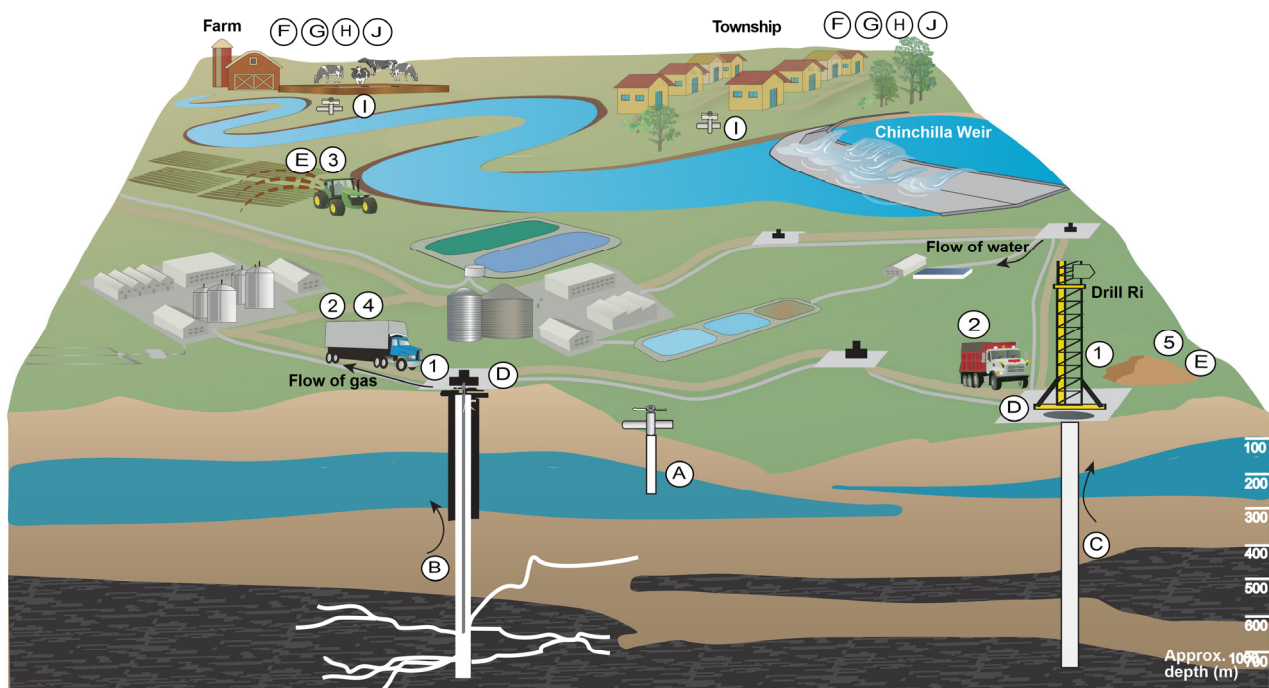
The hazard identification appraisal included an assessment of:

- the physiochemical and fate properties of a substance, that is molecular weight, monomer units, water solubility dissociation, partitioning, surfactant activity, degradation process and half-life
- identification of relevant environmental compartments and potential exposure pathways using information on the site-specific application of the substance (usage)
- toxicity in relevant species and relevant potential end point exposure routes, bioavailability, metabolism and global hazard classifications

Frequency and concentration of chemical factor use was broadly considered but no specific exposure estimates or monitoring were undertaken. The quality of the data used to inform the appraisals was assessed. A reliability assessment was conducted on literature data and audits of the datasets received from companies, where possible. Reliability of company provided chemical lists was “not assessable” given there is no independent verification of datasets available.

Data collection and assessment included considerations of both modelled and experimental data. The precautionary approach was applied to degradation and toxicity data where the most conservative value was considered and presented.

The potential exposure pathways of chemical factors used in the CSG industry relate to how the chemical factor may theoretically move from its industrial source to the community living within or near the study site. Figure 8 is a conceptual model showing the hypothesised pathways considered for this appraisal. Pathways A to E are potential pathways from CSG activities to environmental compartments and pathways F to J are potential pathways from these compartments to humans.



- | Drilling and Fracturing Processes | Possible Shallow and Deep Groundwater Pathways | Possible Exposure Pathways to Humans |
|---|--|--|
| ① Mixing and pumping of drilling and fracturing uids | Ⓐ Fracture growth or aquifer connectivity | Ⓕ Recreational activities (bathing) in surface waters |
| ② Transportation of chemicals | Ⓑ Well casing rupture during injection or well integrity issue | Ⓖ Incidental ingestion of soil and dust particles |
| ③ Land spraying of drilling uids and cuttings | Ⓒ Migration of drilling uids via uncased bore | Ⓖ Inhalation of vapours, soil and dust particles |
| ④ Flowback trucked o-site for specialised treatment | | Ⓖ Bore water for domestic use, stock watering and irrigation |
| ⑤ Disposal of drilling cuttings and uids via mix, bury, cover | | Ⓖ Human consumption of crops and/or stock |
| | Possible Shallow Soil and Surface Water Pathways | |
| | Ⓓ Spill of drilling and fracturing uids | |
| | Ⓔ Land disposal of drilling muds | |

Figure 8: Possible exposure pathways from drilling and hydraulic fracturing CSG processes to local communities (Rigby et al., 2023).

Appraisal workflow

Each chemical factor was appraised through a consistent workflow, as shown in Figure 9. The first step considered whether the chemical posed inherently low hazard to human health using the criteria described in the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) manual for the risk assessment for chemicals associated with coal seam (Department of the Environment Energy, 2017). Chemicals that were deemed to have low hazard potential to the community in the H.2 additives study context were not progressed from detailed appraisal tasks. This is equivalent to section 3.4.2's *inherently low hazard to human health at the study site*. The toxicity, physical and chemical properties and environmental fate of chemicals that confer low adverse health effects were identified. In general, the identification of chemicals of low hazard involves examining the capacity of a chemical factor to cause adverse health effects in humans and / or animals.

For all other chemical factors not deemed inherently low hazard for the H.2 additives study context, their assessment was progressed for detailed hazard identification (Figure 9). The appraisal methodologies for organic and inorganic chemicals were tailored based on the availability of information. The current hazard appraisal is designed to consider, where possible,

source, transport, management, mitigation into the assessment of hazard potential. It does not however, measure or estimate exposure. The lines of evidence were used to appraise each chemical are:

- physicochemical properties (including soil/water/air partitioning, mobility, persistence, bioaccumulation potential)
- toxicity profile
- hypothesised exposure pathways to humans and routes of exposure.

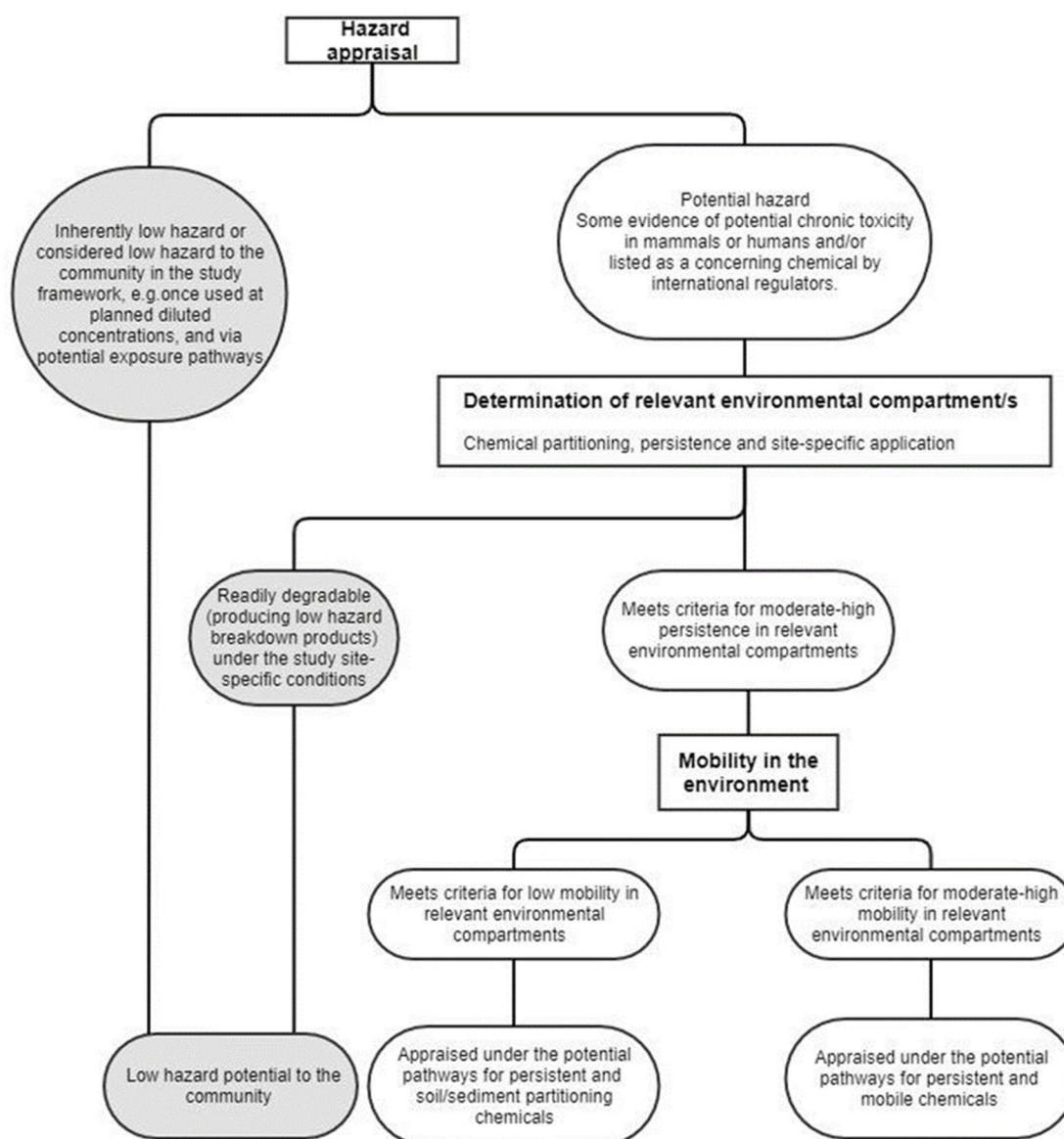


Figure 9: Hazard appraisal decision tree for chemicals (Rigby et al., 2023).

The specific appraisal and scientific justification for the conclusions reached for each chemical are presented in a series of factsheets (Rigby et al., 2023). Since decisions were made throughout the appraisal process using the data gathered from across the scientific literature, it is crucial to communicate a measure of the expert opinion regarding the strength of the evidence available. A method for determining a measure of the expert opinion of the data reliability was included. Key

information gaps in the scientific research, if any, are therefore readily identifiable in each chemical factsheet.

The final hazard appraisal decision considered the toxicological profile, the chemical persistence, bioaccumulation, pseudopersistence, environmental behaviour and fate. This, together with knowledge of the chemical use patterns by industry (once, rarely, sporadically, regularly), and verified management controls and mitigation strategies were used to define each chemical as either demonstrating:

- evidence of toxicity potential to humans/mammals via H.2 additives study specific potential exposure pathways, (equivalent to section 3.4.2's *warranting further assessment for hazard potential to human health at the study site*) OR
- little to no evidence of toxicity potential to humans/mammals via H.2 additives study specific potential exposure pathways (equivalent to section 3.4.2's *low hazard potential to human health at the study site*).

5.2.2 Results – drilling and hydraulic fracturing chemical factors

The list of drilling and hydraulic fracturing additives and the chemical factors used for the appraisal detailed in Rigby et al. (2023) was based on the data collated before mid-2020. This is a subset of the additives and chemical factors described in section 5.1. See section 5.3.4 for further detail.

In total, 97 unique chemical factors were identified from a total number of 140 additives reportedly used in well drilling, hydraulic fracturing and well workover operations.

Low hazard chemicals

40 chemical factors were identified as having inherently low hazard potential to human health in the study site. These factors include:

- simple inorganic salts, such as potassium chloride and sodium chloride
- organic salts, such as potassium acetate
- acids, such as hydrochloric acid and acetic acid
- bases, such as sodium hydroxide (caustic soda)
- naturally occurring minerals, such as barite, calcite and limestone
- cellulose, cellulase and their derivatives
- sugar and polymers of sugars, such as sucrose, starch, xanthan gum and guar gum
- sulfates and sulfites, such as potassium sulfate and sodium sulfite
- polypropylene
- chemicals used in food, such as coffee extract, gelatine and glycerol

Many of these chemicals are in high volume use and in general, have undergone extensive regulatory assessment, and are considered of low concern. Sufficient evidence is presented to

make robust conclusions in terms of the low hazard potential. Additionally, this project assumed that bulk spills of undiluted additives was not a highly likely pathway to local community in terms of acute exposures, since no bulk spills have been reported in the study site. These chemicals identified and the criteria used to support this appraisal are presented in the *Low Hazard Appendix* of Rigby et al. (2023).

Appraised chemicals

This detailed chemical appraisals for the remaining 57 chemical factors considered in the H.2 additives study are presented in individual chemical specific factsheets in the *Chemical Factsheets Appendix* of Rigby et al. (2023). 32 chemical factors were appraised to have little to no evidence of toxicity potential to humans/mammals via H.2 additives study specific potential exposure pathways³.

The remaining chemical factors have been appraised as either having evidence of toxicity potential to humans/mammals via H.2 additives study specific potential exposure pathways, or having knowledge gaps that prevent a complete appraisal⁴ (equivalent to section 3.4.2's *warranting further assessment for hazard potential to human health at the study site*).

A summary of the appraisal of these chemical factors is provided here.

³ Equivalent to section 3.4.2Error! Reference source not found.'s *low hazard potential to human health at the study site*.

⁴ equivalent to section 3.4.2Error! Reference source not found.'s *warranting further assessment for hazard potential to human health at the study site*.

Respirable crystalline silica

| Chemical name | CAS RN |
|--------------------------------------|------------|
| Silica crystalline quartz (c-silica) | 14808-60-7 |
| Cristobalite (c-silica) | 14464-46-1 |
| Silica amorphous (a-silica) | 7631-86-9 |

Silica (SiO₂), also known as silicon dioxide, is the main component of the earth's crust, and is therefore naturally abundant in the environment. Silica comes in natural and synthetic forms, and crystalline (c-silica) and amorphous (a-silica) polymorphs. Quartz is the most common mineral form of c-silica. Silica is used in a wide variety of industrial and consumer uses. Finely ground c-silica is used in household products including food additives, pet litter, art glazes, soaps, toothpaste, skin care and pharmaceuticals.

In the CSG industry, quartz sand is used in hydraulic fracturing as a proppant (solid particles in the fracturing fluids that remain in the fractures to prevent them from closing after the fracture fluid is allowed to flow back to the surface). Many of the additives used in drilling are sourced by quarrying (clays, barite) and these products can contain small amounts of c-silica as an impurity. Naturally occurring (geogenic), silica may also be a small component of produced water from CSG activities. This silica may accumulate in settling or brine ponds that are part of water treatment operations.

Exposures to c-silica dust of respirable size (less than 10 micrometres in diameter) can produce lung diseases (silicosis or silico-tuberculosis) and increases the risk of tuberculosis, nonmalignant renal disease and autoimmune diseases. C-silica is a carcinogen classified by the International Agency for Research on Cancer. Negative health consequences related to respirable c-silicas have been predominantly associated with occupational exposures. Although the general population are also exposed to respirable c-silica through dust, adverse effects of inhaled silica have not been linked to exposure to the low levels of c-silica in typical urban or rural environments or to exposure to c-silica particles above respirable size.

The hypothesised exposure route for respirable c-silica from CSG operations identified in the H.2 additives study is through potential for inhalation of dust (pathway H in Figure 8). CSG activities may change the amount of respirable c-silica in dust in the environment through resuspension and concentrating of c-silica containing materials that have been released during transport, mixing, handling or use or from sediments containing respirable c-silica that have accumulated at water treatment infrastructure (assuming that these sediments are exposed). The immediate risk of this exposure route occurring can be mitigated through occupational health and safety practices and regulations.

Nonoccupational exposure to respirable silica dust may occur in populations living near silica-based industries or operations. Agricultural activities including ploughing, harvesting, machinery, burning of agricultural waste and possessing agricultural products have also been associated with dust generation from soil sources containing a small proportion of silica.

Case study – silica concentrations attributed to soil dust emissions

In a study at a CSG development site in the Surat Basin (Dunne et al., 2019), 94 samples of 12-hour PM₁₀ dust were collected during drilling and hydraulic fracturing and were analysed for chemical composition. A 12-hour PM₁₀ sample is where a continuous sample of air is drawn through a filter over a period of 12 hours to catch all airborne particulates below 10 micrometres in size. The case study findings were:

- silica was the dominant element measured in the analysis of the PM₁₀ samples
- assuming all silica was present as SiO₂, an average concentration of 2.86 µg/m³ of SiO₂ was determined over all the samples collected during drilling and hydraulic fracturing at the study site
- the maximum 24-hour concentration at the study site was measured to be 22.03 µg/m³
- concentrations of SiO₂ were highly correlated with known soil markers aluminium and titanium oxides, and their ratios to silica were typical of soil dust (Lide & Frederikse, 1997)

It can be concluded that while SiO₂ was detected in the 12-hour PM₁₀ samples taken during drilling and hydraulic fracturing, the observed concentrations were primarily attributable to soil dust emissions.

Table 2: Summary of silica appraisal, from Rigby et al. (2023).

| Summary of appraisal - Silica |
|--|
| <ul style="list-style-type: none"> • Silica is an additive in drilling and fracturing fluids. Silica in the form of quartz sand is one of the highest volume additives use on site. • The source water from the Walloons coal seam contains natural silica with high portions of quartz and there is evidence of silica aggregating in waste streams and in brine ponds. • Some specific forms of silica are highly toxic and persistent in the environment. • The main exposure route of concern for silica compounds is through inhalation of airborne respirable crystalline silica. Two potential pathways to community have been identified at the CSG site that may generate and transport dust containing c-silica. Firstly, the generation of airborne particles during the moving and mixing of silica products in drilling and fracturing fluids. Secondly, produced water and brine water ponds containing c-silica particles could potentially become airborne generating dust under various climatic conditions. • There is insufficient information about the source proportion of respirable crystalline silicas and particle size from all CSG activity sources. • There are limited monitoring data available to assist in understanding management controls adequacy for nonoccupational exposures. • There are limited risk assessments and monitoring activities undertaken of ambient air quality associated with potential for respirable c-silica pathways from drilling additives and/or potential for respirable c-silica pathways from brine storages undergoing evaporation. • There are no background data on ambient levels of respirable crystalline silica available for the study site. Queensland has no current ambient particulate matter air quality standards for c-silica standards that are protective of the community. PM_{2.5} and PM₁₀ standards may not be protective of silica exposure without knowing the respirable crystalline fraction of the particulate matter. • Recent studies in Queensland and the US have indicated that worker exposure to respirable silica during hydraulic fracturing activities may exceed safe work levels (Esswein et al., 2013; Resources Safety and Health Queensland, 2019). Transferring using compressed air and pumping activities generated dust plumes containing high portions of respirable quartz (Resources Safety and Health Queensland, 2019). These findings highlight that while the portion of respirable particles in 20/40 and 40/70 sand is relatively small, it still has the potential to generate hazardous levels with high quartz content. Exposure to respirable dust is dependent on proximity to point source and environmental conditions such as rainfall and wind direction. Sand spillage and deposition was also identified. • Given the complexity and uncertainty around toxicity potential, there is insufficient information on silica age, particle size distribution and crystalline content for additives, proppant and source water. |
| <p>CONCLUSION: Silica and silica containing minerals are progressed for further assessment, on the basis of potential exposure pathways to the environment of respirable c-silica which may be present in these drilling and hydraulic fracturing additives.</p> <p>Respirable sized c-silica is a known human health hazard.</p> |

CMIT/MIT

| Chemical name | CAS RN |
|--|------------|
| CMIT/MIT in a 3:1 ratio | 55965-84-9 |
| CMIT (5-Chloro-2-methyl-3(2H)-isothiazolone) | 26172-55-4 |
| MIT (2-Methyl-3(2H)-isothiazolone) | 2682-20-4 |

CMIT/MIT (3:1) is an antimicrobial surfactant that contains the chemical 5-Chloro-2-methyl-3(2H)-isothiazolone (CMIT) and 2-Methyl-3(2H)-isothiazolone (MIT) in a 3 to 1 ratio. Outside of CSG activities, it is used in pesticides, paints, adhesives, detergents and other industrial products. CMIT/MIT is also used as a preservative in food packaging and in cosmetics, perfumes and other personal care products (sunscreen, moisturisers, shampoo etc.). CMIT/MIT is also widely used in Australia as a preservative in cosmetic, personal care (including baby products), cleaning and laundry products and as a preservative in paint.

In CSG activities in the study site, CMIT/MIT was a component of the biocide M275 (comprising 5-10% of the formulation of this additive) reportedly used during hydraulic fracturing of 35 wells. CMIT/MIT (3:1) is also a trace component (< 0.0015 weight %) of the drilling additive Defoam NS that was used in five wells in the study site.

The hypothesised route of exposure to CMIT/MIT from CSG operations identified in the H.2 additives study is through groundwater (pathway I in Figure 8). These pathways would require CMIT/MIT to be released to the groundwater resource that is used by the community for this route of exposure to represent a risk.

Table 3: Summary of CMIT/MIT appraisal, from Rigby et al. (2023).

| Summary of appraisal – CMIT/MIT |
|--|
| <ul style="list-style-type: none"> • CMIT/MIT (3:1) is a biocidal surfactant that is used during hydraulic fracturing. • CMIT/MIT may interact with both water and soils/sediments due to its surface-active properties. • Due to high toxicity, US EPA considers this chemical important to be replaced as a preservative as part of safer chemistry innovation, where and when feasible. • CMIT/MIT is observed to rapidly break down in water when exposed to sunlight or if sufficiently diluted in water. Therefore, no potential pathway to the community via surface water has been identified. • Recent research suggests that under low light conditions CMIT/MIT has the potential to persist in groundwater. • Unintentional release of CMIT/MIT to the environment may be via accidental spills at the surface or leaks into subsurface groundwater systems. • Site-specific usage data received, to date, does not suggest the use of CMIT/MIT would pose significant potential hazard to the local community human health, given that persistence in surface water is anticipated to be low. • If CMIT/MIT entered aquifers, microbial communities may be impacted which may subsequently influence other aspects of water quality in those aquifers. • The persistent detection of CMIT/MIT in produced water (for up to 2 months) highlights the importance of verification of chemical behaviour in environmentally and industrially relevant scenarios, and the complexity of groundwater systems when appraising chemical persistence. |
| <p>Conclusion: CMIT/MIT is progressed as a COPC. It is highly mobile in soils, and toxic particularly in occupational settings. The potential for expanded use in future hydraulic fracturing activities both within the study site and/or across future Australian unconventional gas developments means that the occurrence of CMIT/MIT may increase in future.</p> |

Nonylphenols

| Chemical name | CAS RN |
|-----------------------------------|------------|
| Nonylphenol, ethoxylated (NPE) | 9016-45-9 |
| Nonylphenol (NP) | 25154-52-3 |
| 4-Nonylphenol, branched (4-NP) | 84852-15-3 |
| Ethoxylated 4-nonylphenol (4-NPE) | 26027-38-3 |

Nonylphenol ethoxylates belong to the group of chemicals known as alkylphenol ethoxylates (APEs). APEs have been widely used as part of phenolic resins, plastics additives, detergents, emulsifiers, pesticides and in other industrial chemicals. The most prevalent APE are Nonylphenol ethoxylates (NPEs), representing approximately 80% of production, of which 60% is estimated to be released to the environment, suggesting that background contamination may be ubiquitous. Nonylphenols (NPs) are the ultimate breakdown products of APEs and are also used in the manufacturing of NPEs. Although NPE use in household cleaners has diminished substantially over recent times, industrial cleaning and certain uses in agriculture, plastics, textiles and paper continue. NPEs in textiles and clothing are easily washed out mainly during the first few washes, and subsequently degrade readily to NP in the environment.

Given that NP is not typically considered naturally occurring, any detection can potentially be related to multiple anthropogenic influences. NPEs and NPs may occur in the study site environment from other human uses such as agriculture, other industries, in effluent from wastewater treatment facilities, and from domestic use. Hence, there is the potential for confounding factors and additional sources when studying these chemicals.

NPE is a surfactant and is a component of the drilling fluid additive IDP-404 (1-5%), which is a wetting agent. IDP-404 was reportedly used in 97 wells during 2014. 4-NPE is a component of the CI-25 hydraulic fracturing additive (5-10%) used in five wells in 2010.

Two hypothesised routes of exposure to NPE from CSG operations were identified in the H.2 additives study. The first is through spills or release of drilling fluids to soil and then through crops or stock (pathway J in Figure 8). This pathway requires NPEs to be present in drilling fluids released to the environment through landspray while drilling or accidental releases. The second is through groundwater (pathway I in Figure 8). This pathway requires NPEs to be released to groundwater that is used by the community.

Table 4: Summary of Nonylphenol appraisal, from Rigby et al. (2023).

| Summary of appraisal – Nonylphenols |
|---|
| <ul style="list-style-type: none"> • NPEs are a complex mixture of surfactants used in drilling fluid additives. • NPEs are known to rapidly degrade (KEDP) in the environment resulting in more toxic and persistent short chain forms of NPEs and NPs. • Relatively low usage of NPE has been reported at study site with no reported uses since 2014 (based on available occurrence data). Sporadic detection of NP in produced water indicates potential other sources, either its ubiquitous presence in the environment from confounding anthropogenic origins and/or potential presence in other CSG additives. • NPEs and NP are considered Substances of Very High Concern (SVHC) due to endocrine disruption potential, and reproductive and developmental toxicity (European Chemicals Agency, 2016). • Internationally, NPEs are regulated and highly restricted due to persistence and toxicity of KEDP (NPs). • NPEs are highly water soluble and will remain almost exclusively in the water phase. NP tend to sorb to soil and has low mobility in the environment. • NPE/ NPs may be associated with drilling fluids/muds that are applied to land. • Potential pathways of NP to the community from authorised uses include via Soils to crop/stock to human and for NPE/NP via groundwater. • Unintentional release of NPE/NP to the environment would be via accidental spills at the surface or leaking into groundwater systems via uncased well bore well during drilling could be a pathway for NPE/NP to the environment. |
| <p>Conclusion: NPEs and NPs should be progressed for further evaluation as possible COPCs. The recorded occurrence does not appear extensive; however, global classifications and regulatory bodies deem this group of chemicals of high concern due to the persistence, toxicity and bioaccumulation potential of NPs.</p> |

Tetrakis (hydroxymethyl) phosphonium sulfate (THPS)

| Chemical name | CAS RN |
|--|------------|
| Tetrakis (hydroxymethyl) phosphonium sulfate (THPS) | 55566-30-8 |
| Hydrolyses to Phosphinidynetrimethanol (THP) | 2767-80-8 |
| Other names: Bis[tetrakis(hydroxymethyl)phosphonium] sulfate | |

Tetrakis (hydroxymethyl) phosphonium sulfate (THPS) is an organic salt that is used as a broad-spectrum biocide and fungicide for industrial water systems. When added to water it forms the active biocide ingredient phosphinidynetrimethanol (THP). THP targets a wide range of bacteria but is especially effective against sulfate-reducing bacteria. THP minimises microbial influenced corrosion in infrastructure (e.g. pipelines) and reduces the production of hydrogen sulfide (rotten egg gas), a hazardous, corrosive and flammable gas that is regularly encountered during oil and gas mining operations. In Australia, domestic uses of THPS include as flame retardants for textiles and corrosion inhibitors. It is also an ingredient in agricultural and nonagricultural pesticides and preservatives. The by-product tris(hydroxymethyl)phosphine oxide (THPO) is also used as a flame retardant additive in paints, textiles and plastics.

In CSG activities in the study site, THPS is an ingredient in the following additives:

- M575 Magnacide (>60%)
- AQUCAR THPS 75 (76.5%)
- AMC Biocide G (<25%)
- Idcide-20 (18-25%)
- Wildcat 555 (30-60%)

These products are biocides and have been used during the drilling of 320 wells and the hydraulic fracturing of six wells in the study site. These biocides are also used in well workover activities.

The hypothesised route of exposure to THPS from CSG operations identified in the H.2 additives study is through groundwater (pathway I in Figure 8). These pathways would require the THPS enter groundwater that is used by the community.

Table 5: Summary of THPS appraisal, from Rigby et al. (2023).

| Summary of appraisal – THPS |
|---|
| <ul style="list-style-type: none"> • THPS is used during drilling of wells, well completions and hydraulic fracturing - it degrades rapidly in situ to the biocide THP. • Moderate and ongoing usage of THPS has been reported at the study site. • THPS and its known environmental degradation product (KEDP) THP are water soluble, highly mobile and will remain almost exclusively in water. Oxidation KEDP THPO anticipated in aerobic, neutral conditions, hence surface water exposure pathways to communities appraised as less likely. • Hydrolysis and oxidation rates of THPS to THP (and THPO) are expected to be significantly slower under anerobic and/or acidic conditions. Elimination by biodegradation is also significantly slowed when THPS is present at biocidal concentrations. • Persistence and environmental fate of THPS/THP during drilling and fracturing processes and potential emissions to groundwater is complex and difficult to appraise using available literature. There is evidence that THPS/THP may display high persistence and is dependent upon the concentrations used. • Potential pathways to community from authorised uses primarily relate to groundwater aquifers, in particular when THPS is used in drilling where bores are uncased at deeper groundwater zones (>10-100ms deep) or via drilling mud land disposal. Groundwater consumption via stock and domestic bores may undergo limited/no treatment; however, it is acknowledged that this water may be of poor quality for the purpose of human drinking. • While THPS was developed to replace other more hazardous and persistent biocides, and was awarded the Presidential Green Chemistry Challenge in 1997 (USEPA, 1997), chronic health associations have since been identified (reproductive health in test animals). • Unintentional releases of THPS to the environment may be via accidental spills at the surface or leaking into subsurface groundwater systems. |
| <p>Conclusion: There is potential concern regarding THPS (THP) on the basis of observed toxicity, mobility in water, potential persistence in groundwater systems and possibility of emissions to groundwater. Therefore, THPS (THP) has progressed as a COPC.</p> |

Fluorobenzoic acid tracers – chemical group

| Chemical | CAS | Other names |
|---------------------------------|-------------|-------------------|
| 2-fluorobenzoic acid | 445-29-4 | 2-FBA |
| 3-fluorobenzoic acid | 455-38-9 | 3-FBA |
| 4-fluorobenzoic acid | 456-22-4 | 4-FBA |
| 2,6-Difluorobenzoic acid | 385-00-2 | 2,6-DFBA |
| 3,5-Difluorobenzoic acid | 455-40-3 | 3,5-DFBA |
| 3,4-Difluorobenzoic acid | 455-86-7 | 3,4-DFBA |
| 2,5-Difluorobenzoic acid | 2991-28-8 | 2,5-DFBA |
| 2,4-Difluorobenzoic acid | 1583-58-0 | 2,4-DFBA |
| 2,3-Difluorobenzoic acid | 4519-39-5 | 2,3-DFBA |
| 4-(trifluoromethyl)benzoic acid | 455-24-3 | 4- TFMBA |
| 3-(Trifluoromethyl)benzoic acid | 454-92-2 | 3- TFMBA |
| 2-(Trifluoromethyl)benzoic acid | 433-97-6 | 2-TFMBA |
| 2,3,4-Trifluorobenzoic acid | 61079-72-9 | 2,3,4-TFBA |
| 2,4,5-Trifluorobenzoic acid | 446-17-3 | 2,4,5-TFBA |
| 3,4,5-Trifluorobenzoic acid | 121602-93-5 | 3,4,5-TFBA |
| 2,3,4,5-Tetrafluorobenzoic acid | 1201-31-6 | 2,3,4,5-Tetra-FBA |

Fluorobenzoic acid tracers (FBAs) are a group of chemicals used in CSG operations as tracers in water systems. FBAs are synthetic chemicals and are not naturally occurring in the environment. Fluorinated aromatic compounds are also used in agriculture, medicine and industry. Difluorobenzenes are commonly utilised as chemical intermediates in the production of pharmaceuticals and insecticides.

FBAs are used during hydraulic fracturing to understand the extent and location of the created fracture network and subsequent flowback efficiencies of fracturing fluids. Several tracers may be used simultaneously due to their nearly identical environmental transport properties and analytical capabilities to separate and measure fluid movement. Different tracers are used in the different hydraulic fracture fluid injection stages to assess fluid recovery and make changes to the treatment or fluid design.

In CSG activities in the study site, FBAs were used during hydraulic fracturing of 10 wells.

There is limited relevant information available on the toxicity of FBAs on chemical databases and no data exists on the human health effects for FBAs. Very little information exists on the fate of these compounds in humans.

Table 6: Summary of fluorobenzoic acid tracers appraisal, from Rigby et al. (2023).

| Summary of appraisal – Fluorobenzoic acid tracers |
|--|
| <ul style="list-style-type: none">• FBAs are used as chemical tracers in fluids during hydraulic fracturing.• Data on the environmental behaviour of FBAs is highly variable and dependent on environmental conditions.• FBAs may be highly mobile and very persistent in the environment, potentially leading to accumulation in the environment.• Monitoring data suggests that higher concentrations have been applied on site (up to 5 mg/L measured in flowback) than the concentrations which were appraised in the current company risk assessments.• The data supporting this appraisal has low reliability.• Toxicity data of FBAs is lacking and no chronic studies exist.• There is insufficient monitoring of FBAs to inform on the environmental fate.• Based on the data provided, application of FBAs has been sporadic. Due to combination with aggregated produced water, dilution and dispersion of FBAs is assumed. However, given that the company risk assessments to date are based on lower concentrations than have been measured on site, more information on the realistic concentrations and associated risk is necessary. |
| <p>Conclusion: FBAs are earmarked for potential future progression for the current study site. There is limited information available on the toxicity and environmental fate profiles to make a reliable appraisal at this time.</p> |

Glutaraldehyde

| Chemical name | CAS RN |
|------------------------------------|----------|
| Glutaraldehyde | 111-30-8 |
| Other names: Glutaral, Pentanedial | |

Glutaraldehyde is an antimicrobial agent commonly used as a disinfectant in hospitals, agriculture/aquaculture, food handling and water treatment plants. It is used as a preservative in the manufacture of consumer products including cosmetics, cleaners, adhesives, paper, textiles, paints inks and dyes. Glutaraldehyde is also used as a tissue fixative in laboratories, embalming fluid, as well as photographic and X-ray development fluids. General population exposure can occur via inhalation and skin contact with consumer products containing glutaraldehyde.

Predominantly, it is workers in hospitals, janitorial services, nursing homes, veterinary hospitals, and commercial and industrial businesses who are most likely to be exposed to glutaraldehyde by breathing vapours or by direct skin contact with the liquid formulation.

In CSG activities in the study site, glutaraldehyde is an ingredient in the following drilling additives:

- Aldacide G (10-30%), and
- AMC Glute (50%).

These products are biocides and have been used during the drilling of 289 wells. Glutaraldehyde is also used during well workover activities.

Glutaraldehyde degrades rapidly under both aerobic and anaerobic conditions in water and under aerobic conditions in soil. Because of the low persistence; it is not expected to undergo transport in the environment. Some recent experimental studies that have investigated the fate of chemicals in simulated hydraulic fracturing and downhole conditions have found that in certain conditions glutaraldehyde undergoes autopolymerisation (Kahrilas et al., 2016). The resulting oligomers are suggested to sorb to shale underground (Kahrilas et al., 2016; Rogers et al., 2017). The biocidal properties and environmental behaviour of these oligomers is not well understood. This research has also found that once glutaraldehyde reaches 50-100 mg/L biodegradation decreases due to inhibited biotic activity and the persistence increases substantially (Rogers et al., 2017).

Table 7: Summary of glutaraldehyde appraisal, from Rigby et al. (2023).

| Summary of appraisal – Glutaraldehyde |
|---|
| <ul style="list-style-type: none">• Glutaraldehyde has very high usage at the CSG study site. It is the active ingredient in biocide additives used in drilling fluids and reportedly regularly used by one company for routine well maintenance.• Glutaraldehyde degrades readily under aerobic and anaerobic conditions, though this process is inhibited at high concentrations.• Absent data on the concentrations applied in drilling and well maintenance, it is uncertain whether it will readily biodegradable under the realistic usage concentration onsite.• Where dilution above or below the surface occurs, glutaraldehyde is expected to undergo biodegradation.• Recent research suggests there is a possibility that glutaraldehyde autopolymerises in underground systems, thereby becoming less bioavailable by sorbing to the coal seam/soils with the potential to increase persistence and for slow release back into produced water over time (Kahrilas et al., 2016; Rogers et al., 2017).• Toxicity information for glutaraldehyde is well established.• Little is known about toxicity profile or environmental behaviour of autopolymerisation product, this is highlighted as an information gap. |
| <p>Conclusion: Glutaraldehyde has been classified as “insufficient information to complete appraisal” given the lack of information available about the recently identified autopolymerisation process in unconventional gas operations and its high use on the study site.</p> |

Polyacrylamide and its breakdown product, acrylamide

| Chemical name | CAS RN |
|--|------------|
| Polyacrylamide | 9003-05-8 |
| Sodium acrylate/acrylamide polymer | 25085-02-3 |
| Other names: 2-Propenamide, propeneamide | |
| Breakdown products: Acrylamide | 79-06-1 |

Polyacrylamide is commonly used internationally in water treatment for industrial use, sewage treatment and drinking water treatment as a coagulant/flocculant. It is also used as a soil conditioner, viscosity modifier and friction-reducer in enhanced oil recovery and hydraulic fracturing. Acrylamide is a potential breakdown product that may be formed via a number of mechanisms, including mechanical breakdown (potentially during drilling) and photodegradation. These mechanisms are not well understood and the prevalence of acrylamide as a breakdown product of polyacrylamides used in CSG activities is uncertain. Acrylamides may present in polyacrylamide formulations as a residual of the polymerisation process, although this is at typically very low concentrations (0.1 % w/w).

Based on its high molecular weight, polyacrylamide is expected to have low bioavailability and toxicity because it is too large to cross biological membranes. Polyacrylamide meets the criteria for low hazard potential to human health under as a polymer of low concern (NICNAS, 2017). However, this methodology does not consider potential KEDP products. Acrylamide is very mobile in the environment and is known to cause neurotoxicity (Agency for Toxic Substances and Disease Registry, 2011), reproductive toxicity and is a probable human carcinogen (European Chemicals Agency, 2016). Hence, the factsheet appraisal focus is on acrylamide.

In drilling, polyacrylamide is used as a flocculent in fluids to flocculate drill cuttings and bentonite, and in doing so drive the drilling cuttings out of the well. At the study site, polyacrylamide was an ingredient in two drilling fluid additives. Polyacrylamides without a CAS RN are also listed as ingredients in several additives:

- AMC Aus-Gel (CAS RN 9003-05-8, <0.5% of additive), drilling additive used in 117 wells
- PHPA (partially hydrolyzed polyacrylamide, CAS RN 25085-02-3, >60% of additive; acrylamide, no CAS RN, <0.1%), drilling additive used in 14 wells
- CRP (anionic polyacrylamide, no CAS RN, >60% of additive), drilling additive used in nine wells
- FR-28LC (Acrylamide copolymer, no CAS RN, 30-60% of additive) hydraulic fracturing additive, used in one well

While the exact chemical cannot be known without a CAS RN, those ingredients that state that they are an acrylamide or acrylamide polymer will have the potential to produce acrylamide as a breakdown product.

Acrylamides can also be formed when cooking (frying, roasting/baking or toasting) foods high in carbohydrate, principally in the Maillard reaction (Mottram et al., 2002) although these sources are expected to be negligible. Cigarette smoke may also be an exposure pathway of acrylamide.

Table 8: Summary of polyacrylamide appraisal, from Rigby et al. (2023).

| Summary of appraisal – Polyacrylamide |
|---|
| <ul style="list-style-type: none"> • Polyacrylamide is an ingredient in various drilling additives used at the study site. • Polyacrylamide has relatively low-level toxicity, however, depending on the environmental conditions can either KEDP to relatively innocuous products or higher hazard degradation product acrylamide. • Acrylamide has been identified as a potential KEDP product formed under mechanical forces (potentially drilling) and photodegradation. Acrylamide may also be present as an impurity of the additives (typically only 0.1%). • Acrylamide, if formed, is very mobile in the environment and is known to cause neurotoxicity, reproductive toxicity and is a probable human carcinogen. • Acrylamide degrades in aerobic conditions, though degradation is expected to be slower under anerobic conditions and where there is low microbial activity and alkaline conditions (typical of deeper groundwater onsite). • Acrylamide is generally considered a drinking water hazard from the use of polyacrylamide as a coagulant/flocculant additive in drinking water treatment facilities. No evidence found that it has been used CSG water treatment facilities or treated water outflows. • The potential pathway for acrylamide (if any) exposure to the local community may be releases to groundwater during well activities. This is not considered likely, however, additional monitoring may be required to characterise whether acrylamide is being formed during on site drilling use. • Disposal of drilling muds containing polyacrylamide and/or acrylamide to land may lead to possible pathway via Shallow groundwater, however, may also KEDP to innocuous products. • Unintentional release of polyacrylamide to the environment via accidental spills at the surface are unlikely to lead to mechanical degradation or sufficient time to form acrylamide by photolysis (no spills reported of this product from data searches). • Previous CSG risk assessments did not consider potential KEDP product acrylamide. |
| <p>Conclusion: Polyacrylamide has been classified as “insufficient information to complete appraisal” given the lack of information available about the presence and persistence of KEDP product acrylamide in unconventional gas operations (Tepe & Çebi, 2017). Acrylamide has toxic potential, however, a clear pathway to local community is not known (and potentially unlikely) and limited screening data available to assist in the appraisal of groundwater pathways. Surface water monitoring data from water treatment facility does not suggest pathway from the water treatment facility output.</p> |

Tributyl tetradecyl phosphonium chloride (TTPC)

| Chemical name | CAS RN |
|--|------------|
| Tributyl tetradecyl phosphonium chloride | 81741-28-8 |
| Other names: Tri-n-butyl tetradecyl phosphonium chloride | |

TTPC is used as an antimicrobial agent in a range of industrial settings including blocked pipes, corrosion inhibition, scrubbing systems and cooling towers. It is also used in brewery plasticisers and can warmers, nonfood contact paper processing and oil recovery.

TTPC is a cationic surfactant used in industry for its antimicrobial properties. TTPC is the active ingredient in BE-9 Bactericide additive (5-10%) used during hydraulic fracturing of 11 wells in 2019/2020.

Table 9: Summary of Tributyl tetradecyl phosphonium chloride appraisal, from Rigby et al. (2023).

| Summary of appraisal – Tributyl tetradecyl phosphonium chloride |
|--|
| <ul style="list-style-type: none">• TTPC is used in hydraulic fracturing fluids at the study site.• No experimental data is available on the environmental behaviour and fate of TTPC in the environment.• Based on physiochemical properties TTPC is expected to sorb strongly to organic matter, that is soil/sediments/coal seam with limited migration to water compartments.• Based on modelled data, along with strong sorption potential and biocidal properties, TTPC will likely persist in the environment for a long period.• Some evidence of reproductive and neurotoxicity of TTPC in animals, though toxicity information is limited.• TTPC is under registration review by the US EPA.• Unintentional release of TTPC into the environment may occur via spills during transport and mixing, and/or well casing rupture/integrity issues during hydraulic fracturing operations.• The hypothesised route of exposure to the community would be via Soils to crop/stock to humans.• Due to lack of repeated toxicity studies and information on environmental fate, the data for TTPC appraisal is considered to be of low reliability. |
| Conclusion: TTPC has been classified as “insufficient information to complete appraisal” given the lack of information available on the persistence, toxicity and bioaccumulation potential. |

5.2.3 Results – water treatment and gas processing chemical factors

20 unique chemical factors were identified from water treatment facilities and one chemical factor was identified for gas processing facilities. Where these chemical factors are also identified in drilling and hydraulic fracturing additives (eight chemical factors) or are a known environmental breakdown product of drilling and hydraulic fracturing chemical factors (one chemical factor) their appraisal was combined. All water treatment facility and gas processing facility chemicals appraised were found to have inherently low hazard potential or were appraised to have little to no evidence of toxicity potential⁵.

⁵ Equivalent to section 3.4.2Error! Reference source not found.'s low hazard potential to human health at the study site.

5.3 Caveats and limitations on chemical factor – additive appraisals

5.3.1 Additive usage

As noted in section 5.1 there are a number of sources of uncertainty about the additives that were used during drilling. These include:

- Wells where there is no record of what, if any, drilling additives were used (121 of 2424 wells)
- Wells where the record includes a generic additive type (such as biocide or loss control measure) (211 of 2424 wells)

In addition, the project team had limited access to data on the additives that are used during well workovers or the frequency of these activities.

5.3.2 Chemicals with no CAS RN

As noted in section 5.1.3, the ingredients list for many of the additives included an ingredient with no CAS RN, or the listed ingredients did not total to 100% (indicating the remaining ingredients are considered nonhazardous). Around 65 of the additives identified as being used in the study site had at least one ingredient with no CAS RN. In total 47 ingredients were identified which did not have a CAS RN, they can broadly be grouped as follows:

- statement that the manufacturer's assessment is that the ingredient is nonhazardous - *one ingredient*
- generic component (carrier, emulsifier, neutraliser, additives) *six ingredients*
- not disclosed (not available, proprietary) *three ingredients*
- unprocessed plant based materials (nut shells, wood fibre) *four ingredients*
- chemicals with a nonunique name, *33 ingredients*

It was not possible to appraise the hazard potential of these ingredients. See the site profile for the full list of these ingredients (Huddleston-Holmes et al., 2021). The National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia (NICNAS, 2017) considered naturally occurring substances (unprocessed chemicals occurring in the natural environment for which there are no known toxicological effects, such as nut hulls or wood) to be chemicals of low concern for human health.

Three of the chemicals were polyacrylamides or acrylamide and can be considered with the polyacrylamide chemical factor (CAS RN 9003-05-8). The mineral plagioclase is a silicate that is part of the feldspar group (CAS RN 68476-25-5). While plagioclase does not have a CAS RN, the feldspar group does and were appraised along with other silicates.

5.3.3 Generically named additives

Some additives used have generic names that may be one of a number of products. For example, bentonite clay is a commonly used additive that is often recorded as simply "bentonite" or "gel."

There are several additives made by various manufacturers that contain bentonite, including AMC Aus-Ben, AMC Aus-Gel and MI Swaco M-I Gel. In addition, there are a range of manufacturers who have a product simply named bentonite. The SDS for these products have varying ingredients, although in the case of bentonite these tend to be limited to impurities present at very low concentrations (other silicate minerals).

In the majority of cases these additives are made up of a single ingredient. However, they may contain small amounts of impurities or ingredients that maintain the physical properties of the additive (such as an anticaking agent). These additives are:

- acetic acid
- barite
- bentonite
- caustic soda
- citric acid
- Guar gum
- potassium chloride
- lactose
- lime
- limestone
- sodium chloride
- PAC (polyanionic cellulose)
- potassium acetate
- potassium carbonate
- potassium sulfite
- sand (proppant)
- soda ash
- sodium bicarbonate
- sodium formate
- sodium sulfite
- starch
- xanthan gum

All of these additives were appraised as a single chemical factor, unless data about other additive ingredients were available these were also appraised. The only chemical factor identified by this process as warranting further assessment was crystalline silica. In the additives listed here, the respirable form of crystalline silica is present as an impurity in mineral-based additives (such as bentonite) and is a very small component.

5.3.4 Additional chemical factors not assessed

The list of drilling and hydraulic fracturing additives and their ingredient chemicals used for the appraisal detailed in Rigby et al. (2023) was based on the data collated before mid-2020. A subsequent review of data identified 29 additional additives and additional information for ingredients in previously identified additives. This new information was derived from a re-evaluation of available data sets, data that was available but not discovered by mid-2020 and datasets made available after mid-2020.

These additional 29 additives were used in drilling in the study site and generally had low usage rates. Ingredient information was also found for six additives that had previously been identified for which composition data was not discovered before mid-2020. Additional ingredient information was found for a further 26 previously identified additives. The majority of this new information on additives and their ingredients overlapped with the chemical list identified in the pre-mid-2020 data. However, an additional 47 chemicals have been identified, and these have not been appraised as part of the H.2 project.

In summary, these chemical factors include:

- six chemical factors that are naturally occurring minerals that are impurities in bentonite (340 wells) or barite (29 wells)
- 22 chemical factors that were components of 10 additives that were newly identified, one chemical factor was used in two additives across 38 wells and the remaining 21 were used in 14 wells or less
- 26 chemical factors that were ingredients found in new information for 14 additives:
 - one chemical factor (calcium stearate, CAS RN 1592-23-0, an anticaking agent used in food) was a component of two additives and was used in 162 wells
 - two chemical factors were an ingredient of one additive that was used in the drilling of 91 wells
 - the remaining 23 chemical factors were ingredients of eight additives used in drilling or hydraulic fracturing in a small number of wells (6 wells or less)

5.3.5 Implications

The H.2 project has undertaken an exhaustive examination of data available on the chemical constituents of drilling and hydraulic fracturing fluids used in the study site. Despite this there may be some compounds used in a minority of wells that have not been discovered due to data gaps. The breadth of data examined does provide confidence that the list of drilling additives used during drilling is comprehensive, and that for the small number of wells where no data was available, or where only generic additive types were recorded, the additives used are likely to be included in the overall list of additives identified.

For workover operations, the main additives used are biocides with weighting agents (salts and clays) or loss control measures used in some circumstances. It is considered likely that the biocides used in well workover are the same biocides used in drilling.

For the additives that are generically named, their primary ingredients have inherently low hazard potential. The exception is those additives that contain c-silica as a primary ingredient (sand) or as an impurity (along with other silicate minerals). These have been included in the silica and silicates appraisals.

For the ingredients that have no unique chemical identifier, some can be included with known chemical groups (the polyacrylamides for example). However, the majority cannot be appraised.

The confidence that can be placed in the data for hydraulic fracturing additives is high, particular for wells hydraulically fractured from 2011 onwards due to the mandated hydraulic fracturing fluid statements.

For the chemical factors that have been appraised as warranting further assessment for hazard potential to human health at the study site, with the exception of c-silica, they are ingredients in specialist drilling and hydraulic fracturing additives. These additives have readily identifiable names for which the ingredients and usage data is of good quality.

6 Chemical factors – air emissions

The H.2 air study was completed by CSIRO, and the results are available in the report *Identification and screening of air pollutant emissions from coal seam gas (CSG) activity in the Surat Basin, Queensland* (Dunne, 2021). Section 6 is drawn from that report.

6.1 Air emissions appraisal process

The objectives of the H.2 air study were to:

- identify potential sources of emissions to air from CSG activities in the study site
- screen available source composition data and information to identify potential air pollutants present in CSG industry emissions
- identify and describe plausible pathways by which the community may be exposed to air emissions from CSG activities in the study site
- summarise available information on the occurrence of identified pollutants in ambient air in the study site

The information presented here is not designed to assess actual human exposure to chemical or physical factors. The purpose of the H.2 air study report is to identify potential CSG industry air emissions that have a potential pathway to community exposure via inhalation and to provide a synthesis on the available information on the occurrence of air pollutants in ambient air for the study site.

Potential exposure via deposition of air pollutants to surface materials then ingestion via food was not assessed here. Potential emissions to air from breakdown products of drilling and hydraulic fracturing fluids, or emissions to air of geogenic contaminants in produced water were not assessed here.

6.1.1 Limitations and assumptions

CSIRO used available source composition data and information to identify potential air pollutants present in CSG industry emissions. This data informed decisions on which pollutants associated with CSG production may impact air quality and should therefore be included in the ambient monitoring program.

This report has utilised industry data that was collected in a variety of ways and in many cases was not designed for health study purposes. The industry data reported here reflects the data that was available or that was able to be obtained in a suitable format within the timeframe of the H.2 air study. Discrepancies between datasets and data collection and reporting techniques presented further challenges.

The selected location of the study site is an area of intensive coal seam gas production and processing, with large scale CSG infrastructure and associated air emissions occurring within it. However, it is important to note that the study site is situated within a wider region of very intensive coal seam gas development and CSG industry emissions that occur outside the boundary of the study site also impact the ambient air quality the community is exposed to within the study site.

The data on air pollutant concentrations in the study site were compared with current relevant air quality guidelines which are subject to change as new information on health impacts of air pollutants becomes available, and the data in this report may be revisited as new health guidelines are developed.

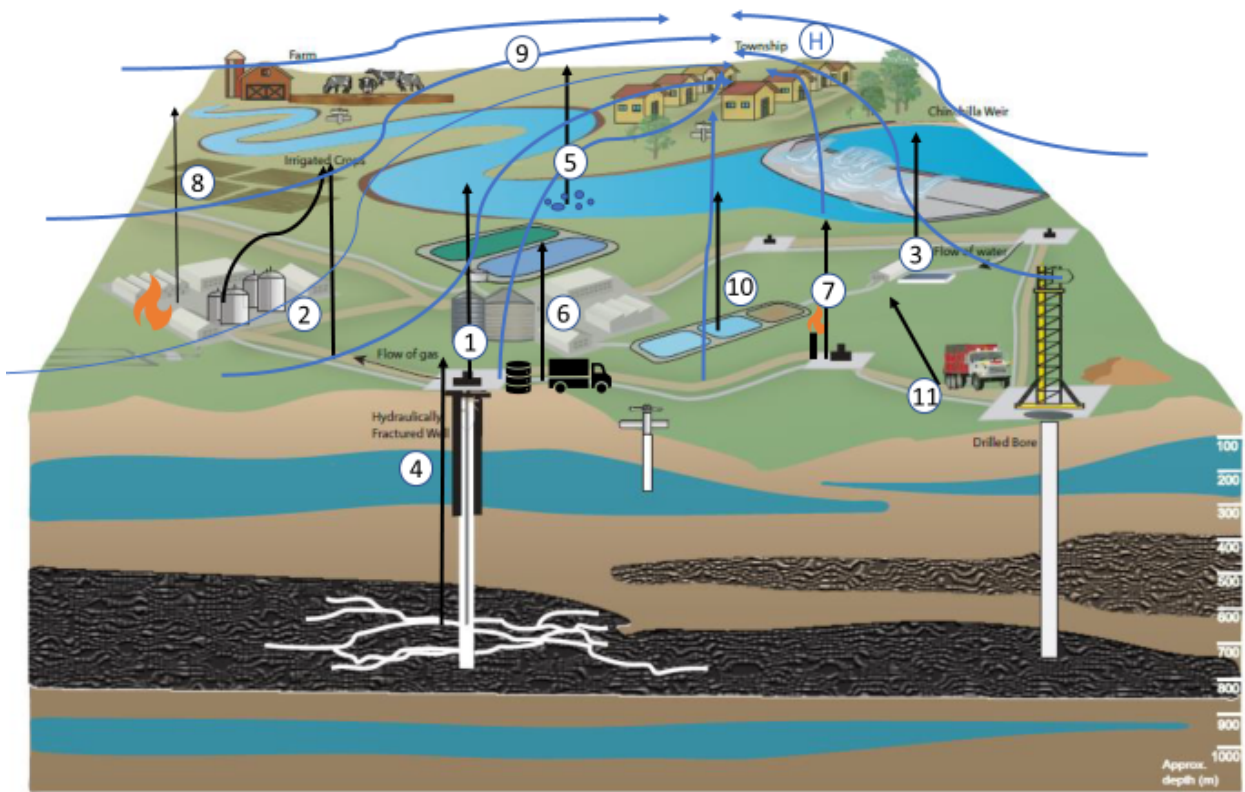
6.1.2 Overview of CSG air emissions

As outlined in section of 4.2 of this report, the study site contains intensive coal seam gas production and processing, with large scale associated infrastructure including over 2400 wells, around 4600 km of gathering pipelines, eight central processing plants and 35 flares (Table 1). Sources of air emissions are present all along the process chain from well pads to central processing facilities to export pipelines.

6.2 Potential exposure pathways

Unlike emissions to soil and water, the CSG industry's emissions to air represent a direct and well-recognised pathway of community exposure to potentially hazardous substances via inhalation. Sources of emissions and the pathways for community exposure from CSG activities in the study site are shown in the conceptual site model in Figure 10.

The key substances identified in CSG industry air emissions have atmospheric lifetimes ranging from hours, such as nitric oxide and some of the more reactive VOCs, to many weeks for CO, mercury and radon. Overall, the impact of CSG industry emissions on local and regional ambient air quality, which community members in the study site may be exposed to depends on their proximity to these variety of sources, the quantity of substances emitted in a given time, substance's atmospheric lifetime and fate, contributions from other sources of emissions (natural, domestic, other industry) and meteorology and local topography. The levels of pollutants in ambient air represents the combined sum of these processes.



- | | | | |
|---|--|----|--|
| 1 | CSG releases from well pad infrastructure | 7 | Combustion emissions from well head microturbines/engines and flares |
| 2 | CSG releases from gathering network, valves, CPP and other infrastructure | 8 | Gas combustion emissions from power generation at CPPs and WTFs |
| 3 | CSG releases from high point vents and low point drains in gathering network | 9 | Secondary formation of air pollutants in the atmosphere |
| 4 | CSG releases via new connections with subsurface strata e.g., wells | 10 | Emissions from produced waters/ brine ponds |
| 5 | CSG releases via existing connections with subsurface strata e.g., seeps, legacy bores | 11 | Fugitive dust from movement of equipment and vehicles |
| 6 | Emissions of drilling and hydraulic fracturing fluids, breakdown products and flowback waters during transport, storage and handling and use | H | Exposure Pathway – Transport via the atmosphere and exposure of population via inhalation of gaseous and particulate air pollutants |

Figure 10: Conceptual site model showing plausible pathways of community exposure to air emissions from CSG industry activities, from Dunne (2021).

6.3 Identifying chemical factors in CSG air emissions

Data on the air emissions from CSG industry operations are available from a number of sources. as follows.

National Pollutant Inventory (NPI)

Under the National Environment Protection (National Pollutant Inventory) Measure (NEPC, 2008), Australian industries are required to report any emissions of 93 substances. These substances have been identified due to their known effects on human health and the environment if they exceed defined thresholds. Data are made publicly available via the NPI website (<http://www.npi.gov.au/about-npi>). For the study site, the two operators report emissions data to the NPI for 6 CSG facilities. The NPI reported emissions data from CSG facilities typically includes wells, field compressor stations and central processing plants.

These data show that in 2019/2020, the largest emissions were for oxides of nitrogen, CO, particulate matter, total volatile organic substances, and formaldehyde Figure 10.

Air quality modelling emission inventories

Detailed air emissions inventories were developed for the year September 2015 - August 2016 as part of a previous GISERA study *Modelling Ambient Air Quality in the Surat Basin, Queensland* (Noonan et al., 2019) which modelled the impact of CSG industry emissions on air quality for an area that encompasses the study site. The modelling covered production (well field) and processing (processing plant and flares) emissions. The modelled emissions inventory estimates the largest air emissions are associated with combustion in both the production and processing phases and are dominated by emissions of NO_x, CO and VOCs.

Environmental impact statements for CSG developments

EIS for CSG developments provide information on the anticipated composition and magnitude of air emissions for the proposed facilities. An EIS is similarly required as part of the application process for mining projects in Queensland. Air Quality impacts were explicitly considered as part of the EIS process for both operators with assets in the study site.

The industry EIS reviewed in the H.2 air study identified five key air pollutants likely to be emitted from their CSG developments, with the largest releases to air associated with combustion emissions of NO_x, as well as significant quantities of, CO, sulfur dioxide, particulate matter with an aerodynamic diameter less than 10 microns (PM₁₀), and hydrocarbons (a class of VOCs).

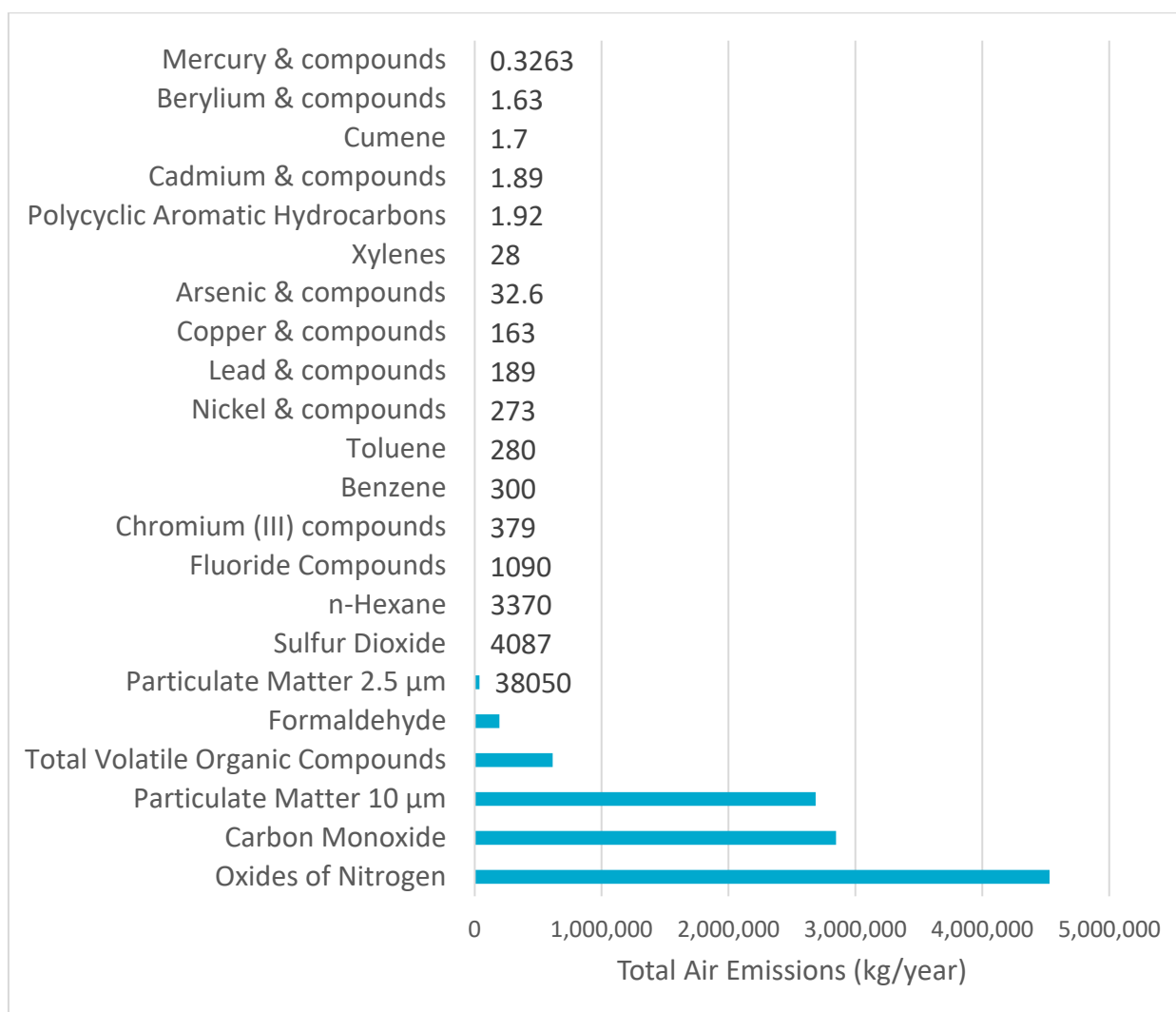


Figure 11 : Total annual air emissions for the year 2019/20 reported to the NPI from 6 CSG facilities in the health study site. (Source: <http://www.npi.gov.au/resource/total-volatile-organic-compounds>). See Dunne (2021) for further detail.

CSG industry emissions monitoring data for gas processing facilities

As part of the design of the previous GISERA study of Ambient Air Quality in the Surat Basin (Lawson et al., 2017), data from emissions monitoring undertaken at Talinga gas processing facility (GPF) were provided to CSIRO to assist in identifying target air pollutants for ambient monitoring. At the time these monitoring data were collected in 2014-15, the Talinga GPF operated a series of gas-powered engines and screw compressors. It should be noted that several of the GPFs in the study site are powered by electricity rather than gas and so will have significantly lower combustion emissions than the gas-powered Talinga engines and compressors.

Data were reported for oxides of nitrogen, CO and a suite of VOC species including several aldehydes. The composition of emissions differed between engines types, but the largest concentrations detected in exhaust emissions were reported for NO_x (107 – 10 805 mg /m³), CO (149 – 4862 mg/m³) and methane (445 - 513 mg m³). More than 50 VOC species were reported to be present in one or more combustion emissions samples examined, with the largest emissions generally reported for aldehydes (formaldehyde, acrolein), aliphatic hydrocarbons (including ethane, ethene, propane, propene, butane, butene) and the aromatic hydrocarbons (including benzene, toluene and xylenes). The original monitoring reports are available publicly at:

<https://gisera.csiro.au/project/ambient-air-quality-in-the-surat-basin/> and are summarised in the H.2 air study in Dunne (2021).

Secondary atmospheric pollutants

As described in the previous section, airborne particles are emitted directly from CSG industry sources (e.g., gas combustion, diesel exhaust, dust). However, secondary particles can also be formed in the atmosphere from reactions of gas phase precursors such as ammonia, NO_x, SO₂ and VOCs. These secondary aerosol particles almost wholly occur in the fine particle size fraction measured as particles with diameters < 2.5 µm (PM_{2.5}). The CSG industry emits large quantities of NO_x and VOCs primarily from gas combustion, as well as significant quantities of methane, and is therefore a potential source of O₃ and secondary aerosol production in the study site.

Composition of fugitive CSG emissions

Fugitive CSG emissions result from planned or unplanned releases of CSG to the atmosphere. The CSG infrastructure in the study site is targeting the Walloon coal measures. CSG from the region is predominantly composed of methane (95 - 97%) with small amounts (~1 -4%) of nitrogen (N₂), carbon dioxide (CO₂), and hydrocarbons always present. Minor to trace amounts of other organic and inorganic substances may also be present.

Information on the chemical composition of fugitive CSG emissions of relevance to the H.2 air study presented here are collated from three sources:

- APLNG/Origin provided chemical composition data from CSG samples collected in the study site (over 130 samples)
- QGC/Shell provided sales (processed) gas composition data as a flow weighted average for contribution of gas from all upstream fields
- (Day et al., 2016) reported data from a more sensitive analysis of organic compounds present in gas collected from CSG wells in the Gloucester and Camden regions of New South Wales. These data were incorporated to provide a more comprehensive list of substances which may be present in CSG.

Across the 3 CSG composition datasets examined here, 131 substances were analysed and the data can be summarised as follows:

- methane comprised 96 - 98 % of the CSG with small amounts (~1 - 4%) of nitrogen, carbon dioxide always present
- VOCs that were detected in the CSG included C₂ – C₈ alkanes and cycloalkanes, and aromatic VOCs (Benzene, Toluene, Xylenes)
- no other hydrocarbon VOCs were detected above their respective limits of reporting
- no halogenated compounds were detected above their respective limits of reporting
- poly aromatic hydrocarbons (PAHs) were not detected (detection limit 10 µg m⁻³)
- hydrogen sulfide (H₂S) levels in CSG samples ranged from 140 - 230 µg /m³
- other sulfur gases (carbonyl sulfide, and carbon disulfide) were not detected above their limits of reporting

- radon-222 was detected in CSG samples with levels ranging from 34 - 330 Bq/m³
- total mercury concentrations in CSG samples ranged from 0.002 – 0.23 µg /m³

6.3.1 Chemical factors in air emissions summary

The CSG industry operations are a source of potentially hazardous emissions to air of known pollutants. The key chemical factors identified in CSG industry air emissions were:

- nitrogen oxides (NO_x)
- carbon monoxide (CO)
- particulate matter (PM₁₀ and PM_{2.5})
- VOC
- ozone (O₃) – secondary production from emissions of NO_x and VOCs
- inorganic gases - including hydrogen sulfide, radon and mercury

6.4 Chemical factors in air emissions – screening assessment

The chemical factors in air emissions are generally known, as is their potential to be hazardous. This differs from the chemical factors in drilling additives where more effort was required to identify chemical factors.

The information presented in Dunne (2021) demonstrates that the substances listed satisfy the criteria for progression past stage three of the CSG health study framework (Keywood et al., 2018) as:

- these substances have known impacts on human health, as evidenced by the existence of legislated ambient air quality objectives (NEPC, 2011, 2021), national emissions reporting requirements (NEPC, 2008) and other national and state-based guidelines for the environmental levels of these substances
- these substances are highly mobile and persistent enough in the environment to ensure plausible pathways of community exposure via inhalation pose a realistic hazard

These substances are emitted by a range of activities in Australia and are subject to routine monitoring and reporting requirements, along with limits on emissions. This means that many of the chemical factors have already been identified and data on emissions is available for a screening assessment.

6.4.1 Relevant air quality objectives

National, state and territory governments have agreed to the National Environment Protection Measures (NEPM) legislation, which are designed to protect human health and the environment. Some States, including Queensland, also have their own environment protection policies in relation to air quality. The standards considered include:

- National Environment Protection (Ambient Air Quality) Measure –2021 (NEPC, 2021)

- National Environment Protection (Air Toxics) Measure –2011 (NEPC, 2011)
- Queensland Environmental Protection (Air) Policy (EPP) –2019 (Queensland Government, 2019)
- Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) 2017. Radiation Protection in Existing Exposure Situations, Radiation Protection Series G-2. (Australian Radiation Protection and Nuclear Safety Agency 2017)
- Western Australia Dept of Health, Hydrogen Sulfide and Public Health (WA Department of Health, 2016)
- Texas Commission on Environmental Quality Air Monitoring Comparison Values and Effects Screening Levels (TCEQ, 2021). Australian federal or state ambient air quality objectives are not available for many of the VOCs that have been reported in CSG emissions, so international standard have been consulted.

6.4.2 Chemical factors in air emissions – screening data – existing observation and modelling studies

Dunne (2021) provides a summary available observation and modelling studies of ambient air quality collected in gas field and community locations in the study site. These include:

- The GISERA Surat Basin Ambient Air Quality Study (Lawson, Powell, Noonan, Dunne, et al., 2018) was undertaken in the Condamine, Miles and Chinchilla region of Queensland from 2015 – 2018, to assess overall regional air quality and investigate the influence of CSG activities on air quality (<https://gisera.csiro.au/project/ambient-air-quality-in-the-surat-basin/>). This is the most extensive air quality monitoring study ever undertaken for this region spanning 10 monitoring sites across the region and collecting ~4 years of continuous monitoring data on NEPM Ambient Air Pollutants and Air Toxics as well as a large suite of other VOCs.
- Modelling of Ambient Air Quality in the Surat Basin reported in (Noonan et al., 2019), as part of the GISERA Surat Basin Ambient Air Quality Study.
- Measurements of air quality were undertaken at well development sites in the Miles-Condamine region in 2016-17 and Roma-Yuleba region in 2017 as part of the GISERA Study of Air, Soil and Water Impacts of Hydraulic Fracturing (Phase 1 & 2) and the data were provided in the following reports:
 - *Measurements of VOCs by passive Radiello sampling at a hydraulic fracturing site in the Surat Basin, Queensland* (Dunne et al., 2018)
 - *Measurements of air quality at a hydraulic fracturing site in the Surat Basin, Queensland* (Dunne et al., 2019)
- *Wieambilla Estates Odour Investigation Results: July-December 2012*. (Queensland Department of Science, Information Technology, Innovation and the Arts, 2013).

6.4.3 Chemical factors in air emissions – screening data discussion

Analysis of extensive monitoring data from the study site found air quality in relation to NO_x, CO, VOCs and hydrogen sulfide were always well within relevant health based air quality objectives (Dunne et al., 2019; Dunne et al., 2018; Lawson, Powell, Julie, et al., 2018; Lawson, Powell, Noonan, Dunne, et al., 2018; Lawson, Powell, Noonan, Selleck, et al., 2018; Queensland Department of Science, Information Technology and Innovation, 2015, 2016; Queensland Department of Science, Information Technology, Innovation and the Arts, 2013), Analysis of the O₃ monitoring data from the study site found levels were occasionally close to (>80%) the NEPM air quality objectives, however, modelling studies indicated, that during these peak events, CSG-related emissions contributed 3 – 7 % to the total O₃ concentration (Noonan et al., 2019). Occasional exceedances of PM_{2.5} air quality objectives were observed in monitoring data from the study site. Modelling studies indicated, that during these peak events, CSG-related emissions contributed 4 - 37 % to 24-hour PM_{2.5} concentrations (Noonan et al., 2019) and analysis of satellite data and other trace species in the monitoring studies were used to show that high PM_{2.5} events were typically associated with smoke from local and regional fires (Dunne et al., 2019; Lawson, Powell, Julie, et al., 2018; Lawson, Powell, Noonan, Dunne, et al., 2018; Lawson, Powell, Noonan, Selleck, et al., 2018).

Airborne particulate matter as PM₁₀ and total suspended particulates was the most common cause of observed exceedances of National and Queensland state air quality objectives reported in monitoring studies in the Surat Basin. In most cases these National and Queensland state air quality objectives exceedances were attributable to fugitive soil dust emissions from CSG industry activities including vehicle movements, construction, etc. (Dunne et al., 2019; Lawson, Powell, Julie, et al., 2018; Lawson, Powell, Noonan, Dunne, et al., 2018; Lawson, Powell, Noonan, Selleck, et al., 2018) plus contributions from smoke and other rural activities that re-entrain dust. It is a requirement of Queensland Government Environmental Authority conditions that companies do not cause environmental nuisance from dust at a sensitive place (e.g., residences, community buildings, public parks etc.) unless a formally agreed alternative arrangement is in place. Environmental authorities also often include specified monitoring requirements for releases to air for the company to demonstrate they are complying with their EA requirements. More about reporting an environmental nuisance caused by dust can be found on the Queensland Government's Reporting environmental nuisance website (Queensland Government, n.d.).

Radon and mercury were both detected in analysis of CSG samples collected from wells in the study site. However, only limited data exists on the ambient levels of radon and mercury for the study site. Observed ambient concentrations of radon and mercury were always well below guidelines for households and workplaces (Dunne et al., 2019; Tait et al., 2013). Combined with more data on the composition of CSG over the lifetime of the CSG developments, the air emissions of mercury, radon, VOCs and H₂S via fugitive CSG releases could be inferred using previously determined estimates of fugitive methane emissions from the CSG industry in the region (Luhar et al., 2018; Luhar et al., 2020).

A case study of an actual CSG release event was used, along with CSG composition data, to demonstrate the likely impact of an unintentional CSG release event on the airborne levels of contaminants such as VOCs, radon, mercury and hydrogen sulfide that are found in CSG. The results of this analysis showed that, while the methane concentrations during this event were

significantly elevated above background concentrations (~80 ppm) the low levels of other gases in the CSG were estimated to have made only a minor contribution to ambient air pollutant concentrations, well below air quality objectives, once the released CSG was diluted in ambient air.

7 Physical factors – noise and light

Three physical factors were considered in the H.2 project – dust, noise and light. Dust has been appraised as part of the H.2 air study discussed in section 6. This section addresses noise and light.

7.1 Physical factor identification

CSG activities generate noise and light through the operation of plant and equipment and flares. These noise and light sources may be transient (of short duration) or continuous. Transient noise and light sources include:

- drilling activities (days)
- well workover activities (days)
- hydraulic fracturing activities (days)
- operation of flares (hours to days)
- traffic

Continuous noise and light sources are related to stationary plant, and include

- water treatment plant
- gas processing facilities
- field compression stations

The nuisance value or impacts on psychosocial stress of noise and light emissions were out of scope for the H.2 project. These impacts may indirectly lead to physical health impacts, however, the confounding factors from other sources of psychosocial stress make an appraisal of this pathway impractical.

7.2 Physical factor – light – appraisal

The primary sources of light from CSG activities are from lights at CSG facilities and from the operation of flares. The operation of flares in the study site has decreased in terms of frequency and duration (see Figure 7). CSG infrastructure does have lighting for night-time operations, however, this is designed to minimise the spill of light away from the facility.

For light to have a direct physical impact on human health, it would need to be at a high enough exposure level to cause direct glare and this is not considered likely. Obtrusive light (light entering habitable rooms) is also expected to be limited and would constitute an environmental nuisance, which would be a breach of Environmental Authority conditions.

Light from CSG facilities and flares can also cause sky glow, which is the brightening of the night sky caused from scattering of radiation in the atmosphere (Standards Australia, 2019). Sky glow

may be due to natural or artificial sources (such as outdoor lighting) of radiation. Sky glow may be exacerbated by atmospheric effects such as low cloud or rain.

Night-time light levels have been linked to changes in sleep habits, which may lead to impacts on physical health (Chepesiuk, 2009; Mason et al., 2018; Ohayon & Milesi, 2016). However, most of these studies focus on urban environments and/or the use of artificial light. There is a greater understanding of light pollution and its impact on wildlife and there are national guidelines on this topic (Commonwealth of Australia, 2020).

Based on the low levels of light pollution at the study site and limited evidence for physical health impacts from these, light as a physical factor was appraised to have inherently low hazard potential to human health.

7.3 Physical factor – noise – appraisal

Noise emissions are subject to strict conditions on Environmental Authorities for CSG activities. Authority holders must have a Noise Management Plan that include how noise will be assessed, management practices, community liaison procedures, complaints procedures, records management, control or abatement measures and predicted noise levels at sensitive receptors.

Environmental Authorities also set out measured noise limits at sensitive receptors (Table 10). Sensitive receptors include residences and other community facilities.

Table 10: An example of measured noise limits at sensitive receptors from an Environmental Authority in the study site.

| Time Period | Metric | Short Term Noise Event | Medium Term Noise Event | Long Term Noise Event |
|---|-----------------------------|---|-------------------------|-----------------------|
| 7:00 am – 6:00 pm | L _{Aeq,adj,15 min} | 45 dBA | 43 dBA | 40 dBA |
| 6:00 pm – 10:00 pm | L _{Aeq,adj,15 min} | 40 dBA | 38 dBA | 35 dBA |
| Noise from drilling activities undertaken from 10:00pm – 7:00am | L _{Aeq,adj,15 min} | 30 dBA (measured indoors at any sensitive receptor) | | |
| Noise from fixed plant in gas fields undertaken from 10:00pm – 7:00am | L _{Aeq,adj,15 min} | 28 dBA (measured indoors at any sensitive receptor) | | |

Noise limits in Table 10 are taken to be measured noise levels outside a sensitive receptor unless stated otherwise.

L_{Aeq,adj,15 min}: means the A-weighted sound pressure level of a continuous steady sound, adjusted for tonal character, that within any 15 minute period has the same square sound pressure as a sound level that varies with time

Measured noise limits at sensitive receptors are:

7:00 am - 6:00 pm: 35 dBA

6:00 pm – 10:00 pm: 30 dBA

10:00 pm – 6:00 am: 25 dBA

6:00 am – 7:00 am: 30 dBA

In addition to noise levels, the noise quality (tonal or impulsive characteristics) are also considered with adjustments made to the measured noise level (an increase). There are also limits on low frequency noise.

Authority holders are also able to enter into “alternative arrangements” with residents who may be impacted by noise above these limits even for short periods of time. These may include financial compensation, temporary relocation of residents or installation of sound proofing.

There is evidence that continued exposure to noise pollution can potentially have an impact on health, although there is some uncertainty around the levels of noise pollution, along with the

characteristics of noise that would have an impact (enHealth, 2018). The enHealth (2018) review of the impacts of environmental noise in Australia found:

- Although the evidence is still emerging, it is sufficient to show that noise adversely affects health, particularly in regard to sleep quality and cardiovascular health.
- The evidence base supports the following suggested noise limits for residential land uses:
 - 55 dB(A) at the facade using the $L_{eq,night}$, or similar metric over an eight-hour night-time period, and
 - 60 dB(A) at the facade using the $L_{eq,night}$, or similar metric over a 16 hour night-time period.
- That there is limited research on environmental noise exposure and health impacts in rural areas.

Based on this evidence, transient noise sources are considered to have inherently low hazard potential to human health at the study site. The duration and intensity of these noise sources are unlikely to cause human health impacts. The noise levels of continuous sources at the Surat Basin study site, if maintained within the conditions of Environmental Authorities, have been appraised to be below levels that could cause physical harm. They are well below the limits suggested by enHealth (2018).

While there is limited publicly available data on noise levels in the study site, the evidence indicates that noise limits prescribed in Environmental Authorities are not exceeded often. There is one enforcement action originally recorded in TEP MAN19660 and subsequent amendments (MAN19720 and MAN19760) relating to noise. Monitoring at a residence approximately 5.5 km from QGC's Kenya GPF showed instances where noise levels were above the night-time noise limits (in Environmental Authority EPPG00878413). This limit is 28 dBA L_{Aeq} between 10:00 pm and 6:00 am. The operator, QGC, installed an acoustic barrier that successfully reduced the noise levels to below the stipulated limits.

Part IV Conclusions



8 Conclusions

The H.2 project looked at factors associated with CSG activities at a study site in the Surat Basin, southeast Queensland and appraised them to determine whether they had potential to be a hazard to human health in the broader community. The key findings are:

- 97 unique chemical factors were identified as components of additives used in the drilling of over 2400 wells and in hydraulic fracturing of over 60 wells.
- Of these 97 chemical factors:
 - 40 chemical factors were identified to be of inherently low hazard potential to local communities.
 - 32 were appraised through a rigorous and systematic approach to have low hazard potential to local communities.
 - 25 chemical factors (in eight groups) were identified as warranting further assessment. Four groups (one group of three chemical factors and three individual chemical factors) were appraised to be COPCs. Four groups (one group of 16 chemical factors and three individual chemical factors) were identified as having knowledge gaps that prevent a complete appraisal. The H.2 project is not a full HIA as it does not establish risk, risk mitigations and residual risks associated with each of these chemicals. These chemicals are summarised in Table 11, along with aspects for consideration when assessing their risk.
- Nineteen unique chemical factors were identified from water treatment facilities and one chemical factor was identified for gas processing facilities, including six that were also identified in drilling and hydraulic fracturing additives, and two that are known environmental degradation product of chemical factors used in drilling and hydraulic fracturing. The appraisal of these chemical factors found that they have inherently low hazard potential or were appraised to have little to no evidence of toxicity potential.
- Noise and light emissions from CSG activities do not pose a hazard to physical health in the study site.
- The CSG industry is a source of potentially hazardous emissions to air of known pollutants. Available data from a number of sources indicates the levels of these chemical factors in air in the study site are within air quality objectives and are unlikely to pose a hazard to human health. These chemical factors are:
 - nitrogen oxides (NO_x)
 - carbon monoxide (CO)
 - particulate matter (PM₁₀ and PM_{2.5})
 - VOC
 - ozone (O₃) – secondary production from emissions of NO_x and VOCs
 - inorganic gases - including hydrogen sulfide, radon and mercury
- CSG and its components are also unlikely to pose a hazard to human health.

- Occasional exceedances of PM_{2.5} air quality objectives were observed in monitoring data from the study site. Modelling indicates that during these peak events, CSG-related emissions contributed between 4 - 37 % to the 24-hour observed PM_{2.5} concentrations. Analysis of satellite data and other trace species in the monitoring studies show that high PM_{2.5} events were typically associated with smoke from local and regional fires.
- A key component of this project was developing a detailed understanding of the study site and the activities that are conducted within it. This component was significantly more challenging than anticipated due to the scale and complexity of the activities. Researchers conducting similar studies in the future should consider close engagement with experts in those activities, which in the case of site-specific CSG activities, are the operators.
- The regulatory requirements in Queensland for recording drilling additive use do not require the additives to be uniquely identified or for their ingredients to be listed. This created challenges in identifying the chemicals used in the drilling process. Recent changes to reporting requirements will improve this by requiring additives data to be submitted in a standard format (Queensland Government, 2022b). However, there is no requirement to include chemical identification data. This contrasts to the reporting requirements for hydraulic fracturing where a hydraulic fracturing fluid statement is required that lists the additives used, their quantities, concentrations and the name of any chemical compound contained in the hydraulic fracture fluid.
- A potential pathway for CSG activities to impact the broader community is through inadvertent releases. Conditions on Environmental Authorities for CSG activities in Queensland require operators to report incident data to the regulator. This reporting data is not publicly available. Access to these data would assist in assessing the likelihood of pathways associated with these events. Based on data provided to the H.2 project by industry, such incidents are infrequent and of low consequence within the study site.

Table 11: Summary of chemical factors identified as warranting further appraisal.

| Chemical identifier | Description | Risk considerations ^a |
|---|---|--|
| <p>c- Silica CAS RN: 14808-60-7, 14464-46-1 7631-86-9 <i>Appraise as a COPC</i></p> | <p>Crystalline silica, in the form of quartz sand, is the primary ingredient in proppant in hydraulic fracturing. c-silica is present as an impurity in many drilling additives that are mineral-based. c-Silica may also be present as sediment in produced water. Hazard potential via inhalation of respirable c-silica (< 10µm).</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to dust containing respirable c-silica at hazardous levels would need to occur no environmental exposure limits exist; the occupational exposure limit in Queensland is 0.05 mg/m³ 8-hour time weighted average environmental PM₁₀ exposure guideline in Queensland is guideline for PM₁₀ is 0.10 mg/m³ (1hr avg) and 0.05 mg/m³ (24hr avg). These guidelines are infrequently exceeded in the study site CSG activities would need to create a substantial source of respirable c-silica in the study site to exceed the occupational exposure limits. Aggregation of c-silica from additives or geogenic sources through produced water is a potential mechanism for this limited information is available on the current respirable c-silica content of dust in the study site |
| <p>CMIT/MIT in a 3:1 ratio CAS RN: 55965-84-9 <i>Appraise as a COPC</i></p> | <p>CMIT/MIT (3:1) is a biocide used during hydraulic fracturing of 35 wells in the study site. It is also a trace ingredient in a drilling additive used in five wells. Hazard potential via exposure to contaminated groundwater.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by CMIT/MIT at hazardous levels would need to occur CMIT/MIT would need to be released to groundwater, either via a surface spill (although degradation in sunlight is rapid), or via connection between target coal seams and aquifers accessed by other users CMIT/MIT use has been limited to hydraulic fracturing, and fluids are contained within the well until they enter the target the coal seam. Release directly to shallow aquifers from the well is considered unlikely hydraulic fracturing fluid flows back to the surface, through the well post hydraulic fracturing, significantly larger volumes of water are produced from wells during gas production |
| <p>Nonylphenols CAS RN: Various <i>Appraise as a COPC</i></p> | <p>Nonylphenols are a surfactant used during drilling of 97 wells in 2014 and hydraulic fracturing of five wells in 2010. There is evidence that nonylphenols may occur in the study site environment from other human uses such as agriculture, industry, effluent from wastewater treatment facilities and domestic use. Hazard potential via exposure to contaminated groundwater or via exposure to crops or stock on contaminated soil.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by nonylphenols at hazardous levels would need to occur, or through consumption of crops or stock contaminated through soil nonylphenols would need to be released to groundwater, during the drilling process for the crop/stock pathway, nonylphenols would need to be released to land that is used for crops or grazing. This may occur through landspray while drilling treated water is analysed for nonylphenols (due to their wider use in other industries). never exceeded Australian Guidelines for Augmentation of drinking water supplies |
| <p>Tetrakis (hydroxymethyl) phosphonium sulfate (THPS) CAS (RN): 55566-30-8 <i>Appraise as a COPC</i></p> | <p>THPS is a broad-spectrum biocide used during the drilling of 320 wells and hydraulic fracturing of six wells in the study site. Hazard potential is via exposure to contaminated groundwater.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by THPS at hazardous levels would need to occur THPS would need to be released to groundwater, during the drilling process degradation in aerobic conditions reduces the hazard potential from surface spills ^b |

| Chemical identifier | Description | Risk considerations ^a |
|--|--|---|
| <p>Fluorobenzoic acid tracers (FBAs) CAS RN: Various, a group of 16 chemical factors</p> <p><i>Insufficient information to appraise</i></p> | <p>Fluorobenzoic acid tracers (FBAs) are a group of chemicals commonly used as tracers in water systems. They have been used during hydraulic fracturing of 10 wells in a limited geographic area by one company.</p> <p>There is limited data available on the toxicity of FBAs and no data exists on the human health effects for FBAs.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by FBAs at hazardous levels would need to occur FBAs would need to be toxic to humans. This has not been determined. use of FBAs has been limited to hydraulic fracturing, where fluids are contained within the well until they enter the target the coal seam. Release directly to shallow aquifers from the well is considered unlikely hydraulic fracturing fluid flows back to the surface, through the well post hydraulic fracturing, significantly larger volumes of water are produced from wells during gas production |
| <p>Glutaraldehyde CAS RN: 111-30-8</p> <p><i>Insufficient information to appraise</i></p> | <p>Glutaraldehyde is an antimicrobial agent used during the drilling of 289 wells in the study site. It is also commonly used as a disinfectant in hospitals, agriculture and aquaculture, food handling and water treatment plants. Glutaraldehyde degrades quickly in most conditions, however, recent research suggests the Glutaraldehyde may persist in shale gas reservoir conditions.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by glutaraldehyde at hazardous levels would need to occur. glutaraldehyde would need to persist in CSG conditions, which are not as hot and are likely to have more microbial activity than the shale conditions in which there is evidence of its persistence. glutaraldehyde would need to be released to groundwater, during the drilling process degradation in aerobic conditions reduces the hazard potential from surface spills ^b |
| <p>Polyacrylamide CAS RN: 9003-05-8</p> <p><i>Insufficient information to appraise</i></p> | <p>Polyacrylamide is a polymer used in drilling of 140 wells and hydraulic fracturing of one well. Polyacrylamide is not considered hazardous. A potential breakdown product, acrylamide is considered hazardous. It is not know whether polyacrylamide breaks down to acrylamide in the CSG environment.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> polyacrylamides would need to break down to acrylamides in the CSG setting community exposure to groundwater contaminated by the breakdown product, acrylamide, at hazardous levels would need to occur polyacrylamide would need to be released to groundwater, during the drilling process |
| <p>Tributyl tetradecyl phosphonium chloride (TTPC) CAS RN: 81741-28-8</p> <p><i>Insufficient information to appraise</i></p> | <p>TTPC is a cationic used as a biocide during hydraulic fracturing of 11 wells at the study site. There is a lack of information available on the persistence, toxicity and bioaccumulation.</p> | <p>For this hazard to result in a risk to human health in the broader community:</p> <ul style="list-style-type: none"> community exposure to groundwater contaminated by TTPC at hazardous levels would need to occur TTPC would need to be toxic to humans and persistent in the environment. This has not been determined. use of TTPC has been limited to hydraulic fracturing, where fluids are contained within the well until they enter the target the coal seam. Release directly to shallow aquifers from the well is considered unlikely |

^a This is **not** a risk assessment

^b Incident data for the study site indicate that surface spills are rare


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1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
www.csiro.au

For further information

CSIRO Energy
Cameron Huddleston-Holmes
+61 7 3327 4672
cameron.hh@csiro.au
csiro.au/energy