Ambient Air Quality in the Surat Basin

Overview of study design

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March 2017

Report for the Gas Industry Social and Environmental Research Alliance (GISERA), Project No G.3

Citation

Lawson, S.J., Hibberd, M and Keywood, D. (2017) GISERA Ambient Air Quality in the Surat Basin – Overview of study design. CSIRO, Australia.

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Acknowledgments

Glossary

Units of measurement

mg m^{-3} - milligrams per cubic metre (1 milligram = one thousandth of a gram)

µg m^{-3} – micrograms per cubic metre (1 microgram = one millionth of a gram)

ng m^{-3} – nanograms per cubic metre (1 nanogram = 1 billionth of a gram)

ppm – parts per million by volume

ppb – parts per billion by volume

L - litre

Bqm^{-3} - becquerels per cubic metre, a unit of radioactivity

Nomenclature

Aldehyde – a class of VOCs (volatile organic compounds)

Ambient air – outdoor air

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

CSG - Coal Seam Gas. A type of natural gas extracted from coal seams.

Detection Limit – the lowest measurable concentration of a pollutant for a particular analytical technique

Gas processing facility – facility which compresses and dries gas

Gathering networks – network of pipes which carry gas and water to treatment and processing facilities

Pipeline compressor stations – facilities which compress gas along a gas pipeline

Radiological surveys – measurement of radiation levels and assessment of radiation hazards in a given area

Sales gas – gas which has been processed by the gas processing facility

Sensitive place – includes but is not limited to a dwelling, library, childcare centre, medical centre, or a public park

SVOC – semi volatile organic compound

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

VOC – volatile organic compound

Water treatment facility – facility which treats produced water from the wells

Wellhead gas and water – gas and water sampled from the separator at an individual CSG wellhead

Abbreviations

APLNG – Australia Pacific Liquefied Natural Gas

BTEX – a subset of VOCs including benzene, toluene, ethylbenzene and xylenes

CO – carbon monoxide

CO_2 – carbon dioxide

CH_4 – methane

DEHP – Department of Environment and Heritage Protection

DNRM – Department of Natural Resources and Mines

DSITI – Department of Science, Innovation Technology and Innovation

EIS – Environmental Impact Statement

GPF – gas processing facility

H_2S – hydrogen sulphide

NEPM – National Environment Protection Measure

NO_x – nitrogen oxides, includes nitric oxide (NO) and nitrogen dioxide (NO_2)

NO_2 – nitrogen dioxide

NPI – National Pollutant Inventory

O_3 – ozone

PAH – polycyclic aromatic hydrocarbons

PM2.5 – particles with an aerodynamic diameter of < 2.5 µm

PM10 – particles with an aerodynamic diameter of < 10 µm

SVOC – semi volatile organic compounds

TVOC – total volatile organic compounds

TSP – total suspended particles

VOC – volatile organic compounds

WTF – water treatment facility

1 Executive Summary

A comprehensive ambient air quality study is being undertaken in the Surat Basin near the townships of Condamine, Miles and Chinchilla in Queensland. This study incorporates two components: an ambient air quality measurement network and an air quality modelling study. The purpose of the study is two-fold:

1) to measure and assess air quality,

2) to investigate the influence of coal seam gas (CSG) activities on air quality in this region.

The purpose of this report is to provide background information about the project study design and information about the project outputs. The ambient air quality measurement and modelling components of the study are discussed separately in the following two sections of the summary.

1.1   Ambient air quality measurement component

Review of potential CSG emission sources

CSIRO reviewed potential emission sources in the study area to inform a) which air pollutants to measure in the study and b) where the measurement sites should be located. This review of potential emissions sources was focussed on CSG infrastructure and processes. Emission sources were identified using information contained in APLNG and QGC Environmental Impact Statements (EIS), the National Pollutant Inventory (NPI), Queensland Globe and during inspections of Origin Energy gas infrastructure in the study area. Sources reviewed included but were not limited to gas processing facilities (GPFs), pipeline compressor plants, flaring, water treatment facilities (WTFs), gas wells and gathering networks.

Following identification of CSG-related sources, emission characteristics of these sources were reviewed using available data provided by Origin Energy. These data are provided in original form in the appendices and include

• radiological surveys of CSG infrastructure, gas and water,

• composition of CSG,

• composition of produced water from wells,

• composition of combustion emissions from gas fired compressors and engines at Talinga GPF.

Overall, the review found that CSG production in the study area is likely to be a source of nitrogen oxides, carbon monoxide, carbon dioxide, methane, VOCs (including small hydrocarbons, BTEX, aldehydes and ketones), and particles.

Selection of monitoring sites

Air quality measurements are being made at 5 ambient air monitoring stations including 3 Gas field sites and 2 regional sites. Gas field stations are called Hopeland, Miles Airport and Condamine and have been deployed in the Condamine-Miles-Chinchilla area. The Hopeland gas field site location was selected by consultants and confirmed by CSIRO. The Miles Airport gas field site and Condamine gas field sites were selected by CSIRO. Measurements started at Hopeland, Miles Airport and Condamine in Jan 2015, July 2015 and March 2016 respectively and will be made at each site for 2 years. The Gas field stations are located between 1 and 5 km from GPFs (Orana, Condabri Central and Condabri South) and are located between 100 – 450 m from commissioned CSG wells. Gas field stations have between 15 and 25 wells within a 2 km radius. These stations were selected to be situated in, or close to the area that is expected to experience the largest impact of CSG emissions, based on preliminary dispersion modelling by Day et al (2015). This modelling used a nominal methane emission rate from all areas with current or projected CSG operations to predict the future methane concentrations in the Surat Basin. Other criteria for locating gas field monitoring stations included a) suitable access, mains power and security b) emission sources lie in different directions from the site allowing impacts from different sources (CSG-related and other) to potentially be identified, c) in the vicinity of homes and townships and d) to comply with Australian Standard requirements for monitoring sites.

The 2 regional stations are called Tara Region/Ironbark (26 km SE of Condamine township) and Burncluith (20 km NE of Chinchilla). These site are 10-20 km away from major potential CSG-related emission sources. These stations were commissioned as part of the GISERA Regional Methane Flux project in Nov 2015 and July 2015 respectively, and have been utilised for air quality measurements in this project since June 2016. Due to the two predominant wind directions of east/north easterly (September-April), and south westerly (May-August), one regional site is usually 'upwind' of CSG infrastructure within the gas fields while the other regional site is usually 'downwind'. The upwind site can provide an understanding of typical concentrations of air pollutants in a region without major influence of CSG-related emissions. The site which is downwind can allow detection of any increases in concentrations of air pollutants downwind of the gas fields.

A network of Radiello passive samplers were deployed at 10 sites in the study area from September 2014 – January 2016. Passive samplers are commonly used in air quality studies both in Australia and internationally due to ease of deployment and because they require no pumps or power. Radiello passive sampler locations were originally determined by consultants and were audited by CSIRO in June 2015. The Radiello samplers were deployed at or within 2 km of the gas field ambient air monitoring sites, as well as at an additional 4 sites in and around the gas fields (Nangram, Rockwood, Greenswamp and Miles/Condabri North). Radiello passive samplers were also deployed at the two regional sites (Burncluith and Tara Region) and in the Chinchilla township. Several passive samplers were located between 500 m and 4 km from GPFs (Condabri North, Condabri South, Condabri Central, Talinga, Orana) and one sampler was deployed within 50 m of a Condamine River methane seep.

Selection of pollutants

A review of the current state of knowledge was undertaken to determine which pollutants to include in the monitoring program. Pollutants were selected where the review of emission sources and characteristics showed evidence that: a) the CSG industry is a potential source (identified using source data, industry EIS, NPI data, inspection of gas infrastructure) and/or b) CSG activities are likely to elevate pollutant levels above background levels c) the pollutant has been identified as a key pollutant within the Australian Government National Environment Protection (Ambient Air Quality and Air Toxics) Measures, and in discussions around Australia's new National Clean Air Agreement, d) the pollutant can be used as a tracer for emissions from certain sources/ activities. For example, methane can be used as a tracer for CSG emissions, while CO and CO_2 can be used as tracers for combustion sources.

The following parameters were selected for measurement in this study

- Gas field ambient air quality stations–nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), Particles < 2.5μm and < 10μm (PM2.5 and PM10), total suspended particles (TSP), methane (CH_4), total VOCs (TVOC), carbon dioxide (CO_2) and meteorology (temperature, humidity, solar radiation, wind speed and direction).

- Regional ambient air quality stations– nitrogen oxides, carbon monoxide, ozone and meteorology. Measurements of methane, carbon dioxide, carbon monoxide (Burncluith) and meteorology are being made as part of the GISERA Regional fluxes of methane in the Surat Basin project

- Radiello passive sites, including Gas field, Regional and Chinchilla township sites: 46 individual VOCs, 8 individual aldehydes and hydrogen sulphide.

Four of the 6 criteria pollutants identified in the Ambient Air NEPM are measured at gas field sites including nitrogen dioxide (as nitrogen oxides, NO_x), photochemical oxidants (as ozone), carbon monoxide (CO) and particles (as PM2.5, PM10). Four of the 5 air toxics covered by the Air Toxics NEPM are measured at the passive sampler sites including benzene, toluene, xylenes, and formaldehyde.

CSIRO undertook independent measurements of VOCs and aldehydes at Hopeland ambient air monitoring station for two weeks in July 2015, in parallel with the Radiello passive sampler VOC and aldehyde measurements made by consultants. This provides an independent check of VOC and aldehyde levels at Hopeland using a different sampling and analysis method to the Radiello Passives. The results comparing the two techniques will be presented in the Interim data summary report.

Reporting of ambient air quality data

Since 25th August 2016, preliminary air quality data from the ambient air quality sites has been streamed every hour to the Department of Environment and Heritage Protection website under South West Queensland region https://www.ehp.qld.gov.au/air/data/search.php. Data streamed includes carbon monoxide, nitrogen dioxide, ozone and PM2.5, PM10 and TSP (Hopeland, Miles Airport, Condamine) and carbon monoxide, nitrogen oxides, ozone (Burncluith and Tara Region). These pollutants have been selected for live streaming because there are air quality standards

associated with each pollutant (Air NEPM), providing context for the reported concentrations. At the time of streaming, data has not undergone validation. Data is displayed both as measured concentration values and is also converted into air quality index values (0-100) with corresponding colour coded categories (very good, good, fair, poor, very poor). The index value is the pollutant concentration expressed as a proportion of the Ambient Air Quality NEPM standard or the Queensland Environmental Protection (Air) Policy 2008 (Air EPP) objective. This allows comparison of the air quality in the South West region with other parts of Queensland. Preliminary historical carbon monoxide, nitrogen oxides, ozone and particle data from the 3 Gas field and 2 Regional stations is currently available on DEHP website, and validated data will be made available via the DEHP website in early-mid 2017.

Air quality data collected in the study will be summarised in an Interim data summary report (scheduled early to mid 2017), which will be released via the GISERA website https://gisera.org.au/project/ambient-air-quality-in-the-surat-basin/: Data to be reported includes a) passive VOCs, aldehydes and hydrogen sulphide from 10 sites from September 2014 – January 2016 (including CSIRO VOC measurements) b) carbon monoxide, nitrogen oxides and ozone from the 3 gas field and 2 regional air quality monitoring sites up until December 2016, c) particles, total volatile organic compounds and methane from the 3 gas field sites up until December 2016.

Pollutant levels will be assessed against air quality standards and where concentrations exceed or approach the air quality standard the source/s of the pollutant will be investigated. Concentrations of individual VOCs will be compared with concentrations observed in other parts of Australia. A subsequent and final data summary report will be released in early/mid 2018 which will report all remaining ambient air quality data.

1.2   Air Quality Modelling component

CSIRO will use an air quality model to investigate the degree to which CSG emissions contribute to air pollution levels in the Surat Basin. The model will simulate the emission, transport and transformations of pollutants in the air over the Surat Basin at up to 1 km resolution every hour for the year of 2015. This was chosen as the base year for the Surat Basin model because meteorological and/or ambient air monitoring data is available from 2015 from Hopeland, Miles Airport, Tara region and Burncluith monitoring stations. This allows important validation of the model output by comparing observed and simulated meteorology and pollutant concentrations. The year 2015 had the highest rate of CSG production in the region at the time this study commenced (https://publications.qld.gov.au/dataset/queensland-petroleum-and-coal-seam-gas).

Representing emissions in the model

The release or emission of pollutants from all sources, including the CSG industry is represented in the model using an emission inventory. Developing the emission inventory has involved identifying sources then quantifying emission rates and characteristics of every pollutant, in every km^2 of the model domain (300 by 300 km) every hour, for 2015. The following pollutants will be simulated in the model: carbon monoxide, nitrogen oxides, ozone, primary and secondary particle mass,

primary and secondary particle composition (including elemental carbon, sulphate, nitrate, organic aerosol), ammonia, some individual and grouped VOCs and sulphur dioxide. Emission sources were identified using Qld Government department and agency databases, Queensland Globe, the National Pollutant Inventory (NPI) database, industry Environmental Impact Statements, and aerial photography. Emission sources identified include the CSG industry, power stations, quarries, mines, livestock production (including feedlots), motorvehicles, domestic and commercial sources, domestic wood heaters, bushfires and prescribed burning, wind-blown dust and vegetation. CSG – related emissions identified include but are not limited to: GPF emissions including compressors, engines, venting, flares and leaks, WTF emissions, field emissions including wellhead engines/microturbines, wellhead leaks, water and gas gathering networks and vehicles. Emissions from APLNG, QGC, Arrow and Santos and other producers have been included in the inventory with emission data sourced both from industry and from publicly reported data.

The detailed emissions inventory has been developed for an area larger than the measurement region so that transport of emissions from outside the measurement area are included in simulations. Longer range transport of emissions from Brisbane will also be included.

Model validation

Validation of the simulated meteorology in the model has been undertaken by comparing with observations from ambient air quality stations and Bureau of Meteorology stations. The model will be run with all sources initially and the output will be compared with 2015 ambient air quality data collected as part of this study, as well as using data from other sources such as the DEHP air monitoring network. This validation will ensure that the model is correctly representing the emission, transport and reaction of pollutants in the Surat Basin.

CSG contribution

Following validation, the air quality model will be run in two modes, 1) with all sources *including* the CSG industry, and 2) all sources *excluding* the CSG industry. The difference between the two model outputs will provide an estimate of the contribution of the CSG industry to air pollutant levels. The model will also allow an understanding of the distribution of pollutants over a much larger area and also at a denser spatial scale than can be determined by fixed monitoring sites alone. A report will be released via the GISERA website in late 2017 which will detail findings and methodology of the Air Quality Modelling study.

2 Introduction

CSG production has rapidly expanded in the Surat Basin in Queensland in recent years and this rapid growth has raised community concerns about the potential impact on the air quality in the region. The purpose of this project is to address these concerns by:

1. measuring and assessing ambient air quality in the Chinchilla-Miles-Condamine region of the Surat Basin (Figure 1) and

2. investigating the influence of CSG activities on air quality in this region.

Air quality is a measure of the state of outdoor or ambient air, which is determined by the level of pollutants in the air. Pollutant levels are commonly referenced against air quality standards, such as the National Environment Protection (Ambient Air Quality) Measure (NEPM, 2016).

The purpose of this report is to provide background information about the project study design and information about the project outputs. The ambient air quality measurement and modelling components of the study are discussed separately in the following two sections of the summary.
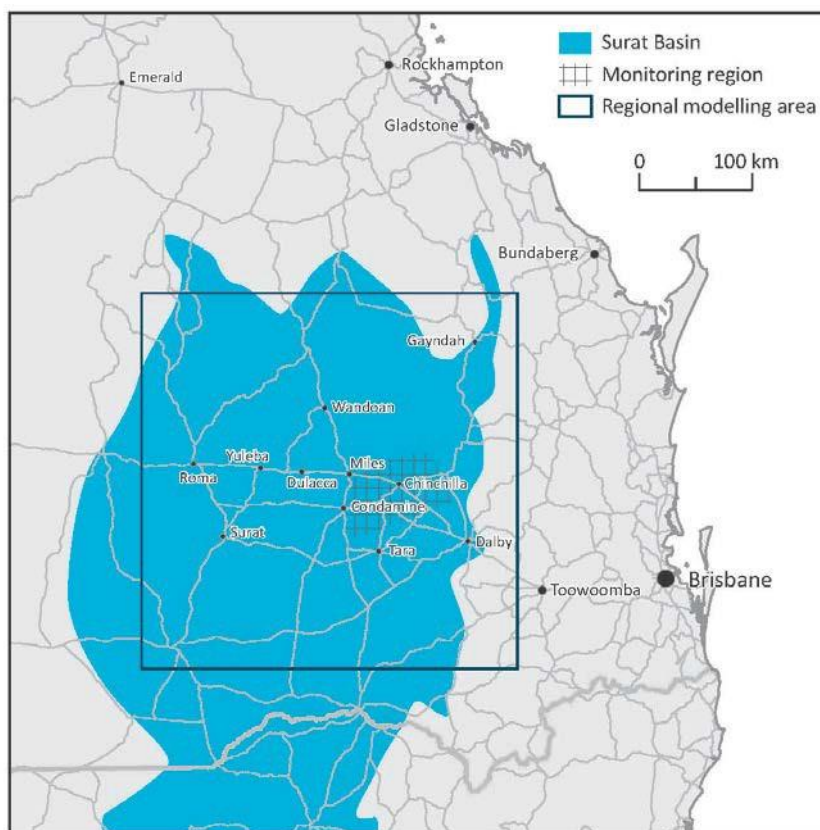
Figure 1. Study area

2.1 Relationship to other studies

There are synergies between this project and the GISERA Regional fluxes of methane in the Surat Basin project (Project No GAS1315) (Day et al., 2015). Both projects are housed within the GISERA Greenhouse Gas Footprint Research area and both projects are investigating the impact of CSG production on atmospheric composition in the Surat Basin by measuring a variety of atmospheric gases at fixed monitoring sites. Two of the monitoring sites (Tara Region /Ironbark and Burncluith) are common to both projects and atmospheric methane is being measured in both projects. However the purpose of the methane measurements differs between projects. The Regional fluxes of methane in the Surat Basin project is investigating whether there is regional enhancement of methane by making measurements of methane both upwind and downwind of the intensive CSG production area around Condamine-Miles-Chinchilla. In contrast, methane measurements in this air quality study will be used as a tracer for local CSG-related emissions and for other components present in CSG. As methane is also emitted from non-CSG sources such as livestock, measurements such as wind direction will be used to investigate the direction and likely identity of sources.

The ambient air quality data obtained in this project may inform any possible future human health studies in this region, and will be compared to air quality standards, which are determined by regulatory bodies to safeguard human health and the environment. However it is important to note that this current project does not include a human health study.

3 Summary of emission sources

3.1 Potential emission sources

CSIRO assessed the potential emission sources in the region to inform a) which atmospheric pollutants to measure in the study and b) where the measurement sites should be located.

A primary aim of this study is to examine the impact of CSG on air quality, as such, this review of potential emissions sources is focussed on CSG infrastructure and processes. A variety of other man-made (anthropogenic) and natural sources are likely to influence air quality in the study area; these additional sources are included in the air quality modelling study (Section 7).

This section provides an overview of CSG-related and other emission sources in the monitoring area. Emission sources were identified primarily using information contained in APLNG and QGC Environmental Impact Statements (EIS), the National Pollutant Inventory (NPI), from inspection of Origin Energy gas infrastructure and review of gas and water composition data provided by Origin Energy.

Potential CSG-related emission sources considered include:

- Gas processing facilities (GPFs)
- Pipeline gas compressor plants
- Flaring
- Water treatment facilities (WTFs)
- Gas wells
- Gathering networks (including high point vents)
- Drilling
- Camps, generators
- Vehicles

The main gas infrastructure in the Condamine-Miles-Chinchilla region includes GPFs at Talinga, Orana, Kenya, Condabri North, Central and South, and associated wells, gathering networks, compressor stations and WTFs. Petroleum leases (which include extraction of CSG) in the vicinity of air quality stations include APLNG, QGC, and Arrow (Qld Globe 2016). Major gas infrastructure in the study area at the time of the project commencement was operated by APLNG and QGC.

3.2 Measurement of emissions from CSG industry

Sampling and analysis of gas and water from Origin Energy CSG infrastructure was undertaken by qualified consultants engaged by Origin Energy. The consultant reports were provided to CSIRO by Origin Energy for use in this study. The reports show results of measurements of gas composition, composition of gas combustion emissions and water composition. These measurements were performed by accredited laboratories and were subject to standard QA/QC procedures (see A.3).

This data includes:

- radiological surveys of CSG infrastructure, gas and water,

- the composition of CSG,

- the composition of produced water from gas wells,

- the composition of combustion emissions from gas fired compressors and engines at Talinga GPF.

CSIRO has utilised the data to inform which pollutants associated with CSG production may impact air quality and should therefore be included in the ambient monitoring program. Note that this analysis does not consider the number of each emission source type, only the pollutants emitted from each source. Also note that while this is among the first published data showing composition of CSG-related emissions in the study area, the sample size of measurements from wellheads and GPFs is too limited for the data to be considered representative of all CSG-related sources in the study region. Several other methods were used to identify whether to include a pollutant for measurement in this study (see Section 5). Similarly the radiological survey results published here may not be representative of all CSG operations in the study area.

There are currently no targeted measurements available of atmospheric emissions associated with drilling and hydraulic fracturing of wells in the Surat Basin. The impact of hydraulic fracturing on air, water and soil will be undertaken as part of a recently approved GISERA study (W.11) (Keywood et al 2016), which will involve measurements of contaminant concentrations before, during and after hydraulic fracturing, and will investigate pathways and environmental fate of contaminants. As drilling and hydraulic fracturing occurs over timeframes of several days, the atmospheric emissions from these activities are likely to be transient. Particles, VOCs, methane and combustion gases (nitrogen oxides and carbon monoxide) may all be emitted during well drilling and hydraulic fracturing. Depending on the location of the activities, pollutants associated with these activities will potentially be captured by the air quality measurements in this study.

Table 1 summarises composition measurements reviewed as part of this study. The components summarised in Table 1 are a subset of the total components measured and have been selected because of their likely impact on air quality. Links to full composition data are provided in Appendix A.1 of this report. Of the water-phase components, the summary focusses on components which may transfer into the gas phase and therefore enter the air. Research into surface and groundwater impacts is being undertaken in other GISERA projects.

Note that data summarised in Table 1 is from CSG infrastructure within the monitoring area including Talinga GPF and WTF and Talinga and Orana wellheads. Data from other CSG

infrastructure outside the monitoring area in the Surat Basin (Spring Gully, Peat, Strathblane and Taloona GPFs and WTFs) is also provided in the reports in Appendix A.1. Gas and water samples were analysed according to relevant standards (see Appendix A.3 for summary of methods used by consultants).

A summary of the key components and findings of the available CSG composition and emission data is provided below.

Radiological surveys

Radiological survey measurements in count rate and dose rate mode recorded for Talinga GPF, WTF and wells were comparable with the natural background measurements. Analysis of process waters and sludge identified activity concentrations consistent with levels encountered in the natural environment. The full radiological survey reports are presented in A1.1.

CSG composition

- The study area is located in the high permeability Walloon coal measures, which includes the Talinga and Orana fields.

- The gas from 19 individual wellheads in the Orana (16) and Talinga (3) fields were sampled, in addition to gas at the Talinga GPF

- Methane comprised 96-98 % of the CSG

- VOCs that were detected in the CSG include ethane, propane, butane isomers and pentane isomers. Concentrations ranged from 0.012% (ethane) to 0.0002% (*i*- butane), corresponding to 120 ppm (147,000 $\mu g\ m^{-3}$) to 2 ppm (4745 $\mu g\ m^{-3}$). No other VOCs were detected above the detection limit of 0.0001% (1 ppm)

- Semi volatile organic compounds (SVOCs) such as polyaromatic hydrocarbons (PAHs) were not detected (detection limit 0.01 mg m^{-3}) in Orana wellhead gas.

- Radon-222 in wellhead gas at Orana and wellhead and sales gas at Talinga ranged from 41-184 bq m^{-3}.

- Total mercury concentration ranged from 20-170 ng m^{-3}

- Hydrogen sulphide (H_2S) was measured using two different techniques (Stain Detector tube test (Dräger) and Wet Chemistry). Hydrogen sulphide by the Wet Chemistry technique ranged from 0.03-0.16 ppm and by the Dräger technique 0.07-0.2 ppm. Other sulphur gases including carbonyl sulphide (COS), carbon disulphide (CS_2) and mercaptans were not detected. Detection limits varied and are provided in A.1.2 and A.1.4

Wellhead and WTF water composition

- Produced water was sampled at 19 individual wellheads (Orana and Talinga) and at the Talinga WTF

- VOCs including BTEX were not detected. Detection limits were <0.001-0.003 mg L^{-1}

- SVOCs including phenols were not detected (detection limits 10-20 µg L^{-1}), PAHs were not detected (detection limit 1 µg L^{-1}), see A.1.2 and A.1.4

- The most volatile fraction of total recoverable petroleum hydrocarbons ($C_6 – C_9$ fraction), which would be most likely to transfer into the air were below the limit of <10 µg L^{-1} in all cases except for one sample where the concentration was 30 ug L^{-1}.

Combusted gas composition (gas fired engines/compressors)

The Talinga GPF is powered by a series of gas-powered engines and compressors. CSIRO requested additional measurements be undertaken of gas combustion emissions including a wide range of VOCs and aldehydes from the Talinga GPF combustion engines which are reported here. It should be noted that several of the GPFs in the study area are powered by electricity rather than gas and so will have significantly lower emissions than the gas-powered Talinga engines and compressors. The composition of combustion emissions from the gas powered compressors and engines depend on the burn characteristics of the engines which may differ between GPFs.

VOCs in the combustion emissions are likely to be mainly un-combusted or incompletely combusted components of the gas.

- The composition of emissions varied between engines types, but the largest measured component of the combustion gas were nitrogen oxides (107-10,805 mg m^{-3}), carbon monoxide (149-4862 mg m^{-3}) and methane (445-513 mg m^{-3}). A wide range of VOCs were measured in the combustion emissions, with the largest concentrations generally reported for aldehydes (including formaldehyde, acrolein), alkanes and alkenes (including ethane, ethene, propane, propene, butane, butene) and the aromatic hydrocarbons (including benzene, toluene and xylenes). The full range of VOCs measured, and emission rates are also provided in A.1.3.

Flaring emissions

- Major components of flaring emissions have not been measured, but have been estimated using the National Pollutant Inventory Emission estimation technique manual for Oil and Gas Extraction and Production Version 2.0, July 2013 (NPI 2013). Note that the amounts of pollutants emitted is based on the gas composition and flare characteristics. The emissions of pollutants from flaring are likely to be either unburnt gas or by-products of the combustion process. Carbon monoxide, nitrogen oxides, methane, VOCs and particles (PM2.5 and PM10) have been identified as the main pollutants emitted from gas flaring.

Summary

A review has been undertaken of the emissions of a range of air pollutants from CSG production sources. Direct measurement data, and reported emissions were used in this review. Overall, this review has found that CSG production in the study area is likely to be a source of nitrogen oxides, carbon monoxide, carbon dioxide, methane, VOCs (including small hydrocarbons, BTEX, aldehydes and ketones), and particles.

Table 1. Summary of reported measurements of gas composition, gas combustion composition and water composition from samples taken in the monitoring area. Full reports are available in A.1

	Location/substrate	Species measured	Date	Appendices
Radiological survey/ Naturally Occurring Radioactive Materials	Talinga GPF, field wells and water treatment facilities (water and sludge)	Gamma, alpha, beta radiation uranium-238 (as thorium-234), radium-226, lead-210, radium-228 and thorium-228, and other detectable natural radionuclides.	2010, 2013	A.1.1
	Talinga and Orana wellhead gas	Radon-222	2011, 2013, 2014, 2016	A.1.2, A.1.4
CSG composition	Talinga sales gas, Talinga and Orana wellhead gas	Methane, Carbon dioxide, Volatile organic compounds (VOCs) including ethane propane, *i* and *n* butane *i* and *n* pentane, benzene, toluene, ethylbenzene, xylenes (BTEX); Semi volatile organic compounds (SVOC) as poly aromatic hydrocarbons (PAHs). Sulfur-containing gases; Total mercury	2011, 2013 2014, 2016	A.1.2 A.1.2, A.1.4
Wellhead and WTF water composition	Talinga WTF inlet water Orana wellhead water	VOCs including BTEX, SVOCs including PAHs, phenols, and persistent organic pollutants (POPs) Total recoverable petroleum hydrocarbons Metals	2011, 2016	A.1.2 A.1.4
Combusted gas composition (gas fired engines/ compressors)	Talinga gas processing facility (screw and reciprocating compressor and power generator emissions)	Oxides of nitrogen (NOx), carbon monoxide (CO), carbon dioxide, methane Volatile organic compounds (VOCs) including BTEX halogenated hydrocarbons aldehydes, ketones and alcohols	2014, 2015	A.1.3
Gas Flaring	NPI - Emission estimation technique manual for Oil and Gas Extraction and Production (2013)	Carbon monoxide (CO), oxides of nitrogen (NOx), methane, volatile organic compounds, particles PM2.5 and PM10	n/a	NPI (2013)

4 Site selection

This section describes the rationale behind selection of the 5 ambient air monitoring sites and 10 Radiello passive sites. A description of the pollutants measured at each of these sites is provided in Section 5.

4.1 Ambient air quality monitoring stations

Ambient air measurements are being made at 3 ambient air monitoring stations in the gas fields in the Condamine-Miles-Chinchilla area(Figure 1). The monitoring stations are called Hopeland, Miles Airport and Condamine. Air monitoring stations are also situated at 2 regional stations outside the main CSG production area, called Burncluith and Tara Region/Ironbark. Table 2 shows the name and location of the 5 air monitoring stations, major emission sources within 5 km and gas wells within a 2 km radius of the stations. Each station will collect data for 2 years. Note that the monitoring start date at each station differs because the process of assessing and identifying a suitable site which met all requirements took several months for each station (see site selection criteria below).

The project budget allowed for 3 gas field sites. The Hopeland gas field site location was selected by consultants and assessed by CSIRO to be suitable. The Miles Airport gas field site and Condamine gas field site locations were selected by CSIRO. The location of the two regional sites were selected by CSIRO as part of the GISERA Regional Fluxes of methane in the Surat Basin project. Further details about site selection criteria is provided below.

Table 2. Summary of ambient air quality station locations, nearby emission sources and proximity and status of nearby wells

Station name	Date AQ measure-ments commenced	Location of station	Emission sources < 5 km	Gas wells drilled within 2 km radius at time measurements commenced	Gas well drilled within 2 km radius as of March 2016
Hopeland	Jan 2015	Gas fields	Orana GPF (< 5 km SE) Nearest well 100 m	1 (0 commissioned)	15 (14 commissioned)
Miles Airport	July 2015	Gas fields	Condabri Central GPF (1.5 km NW) Miles Airport (3.5 km E) Feedlot (2. 3km NE/E) Nearest well 450 m	20 (all commissioned)	20 (all commissioned)
Condamine	Mar 2016	Gas fields	Condabri South GPF (1 km SE) Condaminetownship (8 km E) Nearest well 230 m	25 (23 commissioned)	25 (24 commissioned)
Tara Region	June 2016	Regional	Nearest well 1 km	1 (plugged and abandoned)	1 (plugged and abandoned)
Burncluith	June 2016	Regional	n/a	0	0

4.1.1 Gas field sites – Hopeland, Miles Airport, Condamine

A primary aim of this study is to assess the impact of CSG on air quality in the Surat Basin. As such the gas field site locations were selected to be in or as close as possible to the area which is expected to experience the highest impact of CSG related emissions now and in the future. These area of highest impact were identified using some preliminary dispersion modelling work by Day et al (2015). This modelling used a nominal methane emission rate from all areas with current or projected CSG operations to predict the future methane concentrations in the Surat Basin. The nominal emission rate used (10 L min^{-1} km^{-2}) was the best available estimate and was based on some ground monitoring. The results of this modelling and the location of the 3 gas field air monitoring sites is shown in Figure 2. One limitation of using this modelling work is that the actual methane emission rates will vary and could differ significantly from the estimate used in the modelling. A second limitation is that increases in methane concentrations may not correspond to increases in other pollutants emitted from the CSG industry (such as nitrogen oxide). The modelling study will use a detailed emissions inventory to assess the representativeness of these sites to air quality in the wider Surat Basin (see Section 7).

The gas field stations are located between 1 and 5 km from GPFs (Orana, Condabri Central and Condabri South) and the nearest commissioned well is between 100m- 450 m from the stations. Gas field stations have between 15 and 25 wells within a 2km radius. At the Hopeland station, 14 wells within a 2km radius were commissioned during the monitoring period, while at Miles Airport and Condamine most or all of the wells surrounding the stations were already commissioned at the time the monitoring began.

In addition to situating the gas field stations in the area of highest expected CSG impact, the sites were selected to meet the following objectives:

- Sites must have suitable access, power and security. A major challenge was finding sites with access to mains power. Stations also needed to be sited in areas that could be frequently accessed by technicians for instrument calibration and repair.

- Sites are located so that emissions sources lie in different directions from the site allowing impacts from different sources (CSG and non-CSG) to potentially be identified. The predominant wind direction at Miles (selected to be representative of the wider basin) is east/north easterly (September-April), and south westerly (May-August) see Figure 3 (Day et al. 2015). The variable seasonal wind direction means that different sources within the gas field are likely to impact the sites at different times of the year.

- Sites should be located in the vicinity of sensitive places (e.g. dwellings) so that the air quality at these places can be assessed.

- The locations of the gas field sites were selected in accordance with requirements for Neighbourhood and Background sites in AS/NZS 3580.1.1:2007: Guide to siting air monitoring equipment (AS/NZS 2007). Sites should comply with the AS/NZS 3580.1.1:2007 (AS/NZS 2007) in terms of inlet height, distance from trees, nearby roads and clear sky angle.

The Miles Airport site has infrequent traffic and is sufficiently far away from the Miles Airport ambient air station (~3km) that aircraft are not expected to have a major influence on pollutant levels at the site. Gas field sites are 8-20 km from the townships of Condamine, Miles and Chinchilla. Photographs of the air quality stations Hopeland and Miles Airport are shown in Figure 4 and Figure 5. The location of the 3 gas field and 2 regional air quality stations in relation to CSG wells and towns is shown in Figure 6, with data taken from Queensland Globe. Ambient air quality site stations may be moved to a suitable alternative location if there is sufficient justification, for example to be closer to a sensitive place such as a dwelling/s.
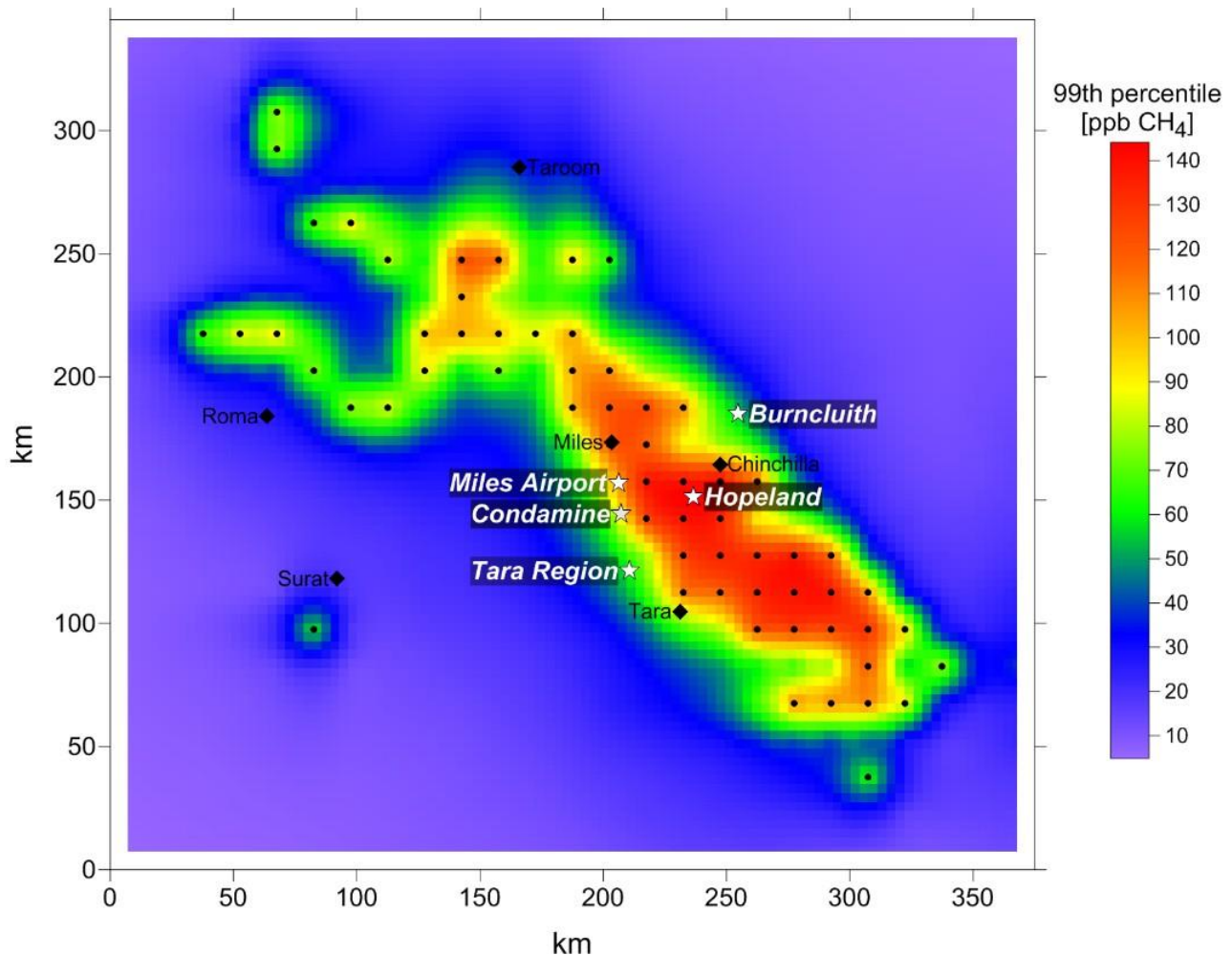
Figure 2. Location of the three gas field sites, Hopeland, Miles airport and Condamine and two regional sites Burncluith and Tara Region. Colours refer to modelled 99th percentile methane concentrations discussed in the text (Day et al 2015).
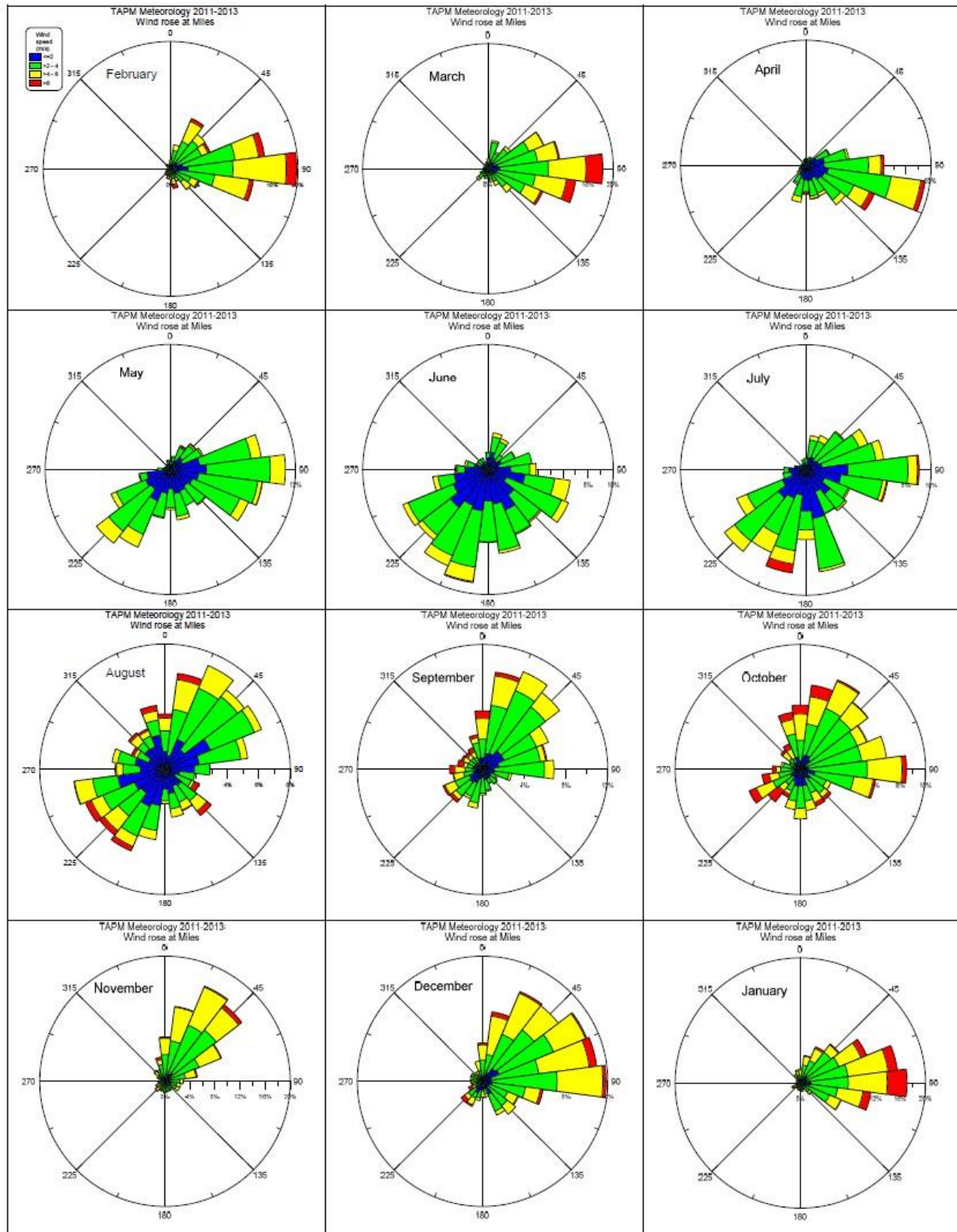
Figure 3. Monthly wind roses at Miles derived from TAPM meteorological modelling for the three years 2011-2013. Taken from Day et al (2015)

4.1.2 Regional sites

Regional sites have been utilised in this study to measure regional levels of air pollutants in an area 10-20 km away from major potential CSG-related emission sources (see Table 2 and Figure 6). Sites were selected and deployed as part of the GISERA Regional fluxes of methane in the Surat Basin project (Day et al 2015). The Tara Region/Ironbark site is some 26 km SE of the town of Condamine, and was commissioned for the Methane Flux project in November 2014 and the Burncluith site is 20 km NE of Chinchilla, commissioned for the Regional Fluxes of Methane in the Surat Basin project in July 2015 (see Table 2.)

Due to the two predominant wind directions (Figure 3) of east/north easterly (September-April), and south westerly (May-August), the Tara Region and Burncluith sites have been selected so that one is usually 'upwind' of the region of concentrated CSG infrastructure while the other is usually 'downwind' (see Figure 6). The upwind site can provide an understanding of typical levels of air pollutants in a region without major influence of CSG-related emissions. The site which is downwind can allow detection of increases in levels of air pollutants downwind of the gas fields.

Figure 4. Hopeland ambient air monitoring station
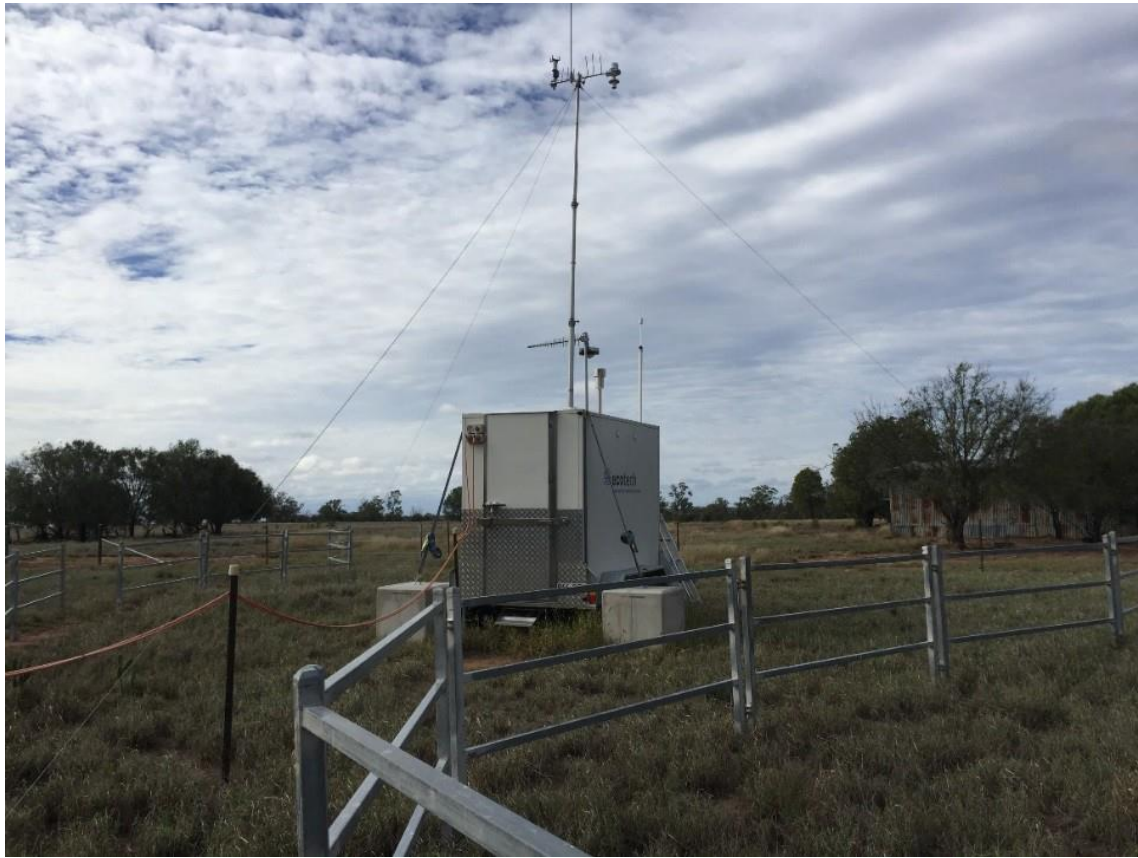
Figure 5. Miles Airport ambient air monitoringstation
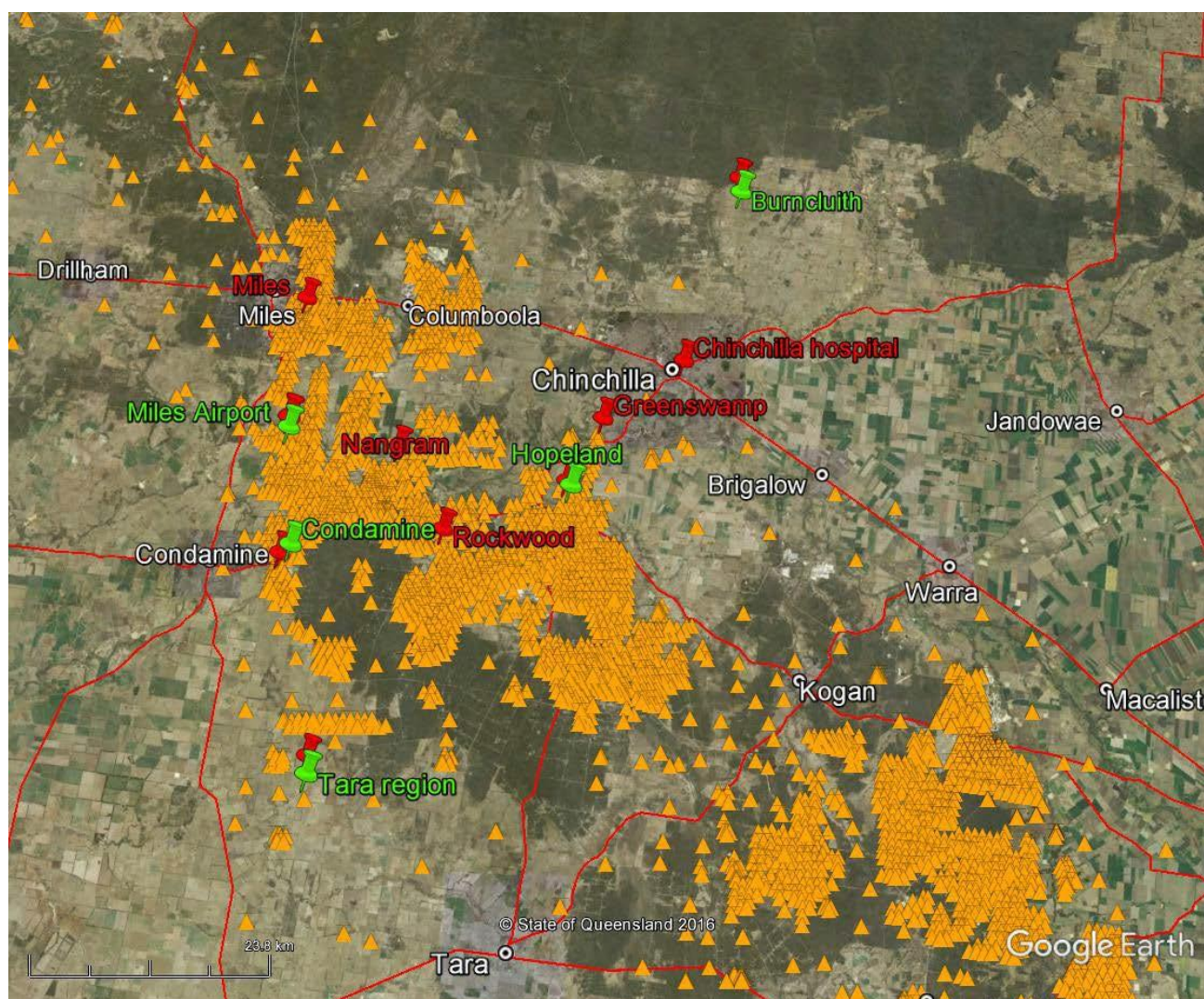
Figure 6. Ambient air monitoring stations shown as green pins, passive sampler sites as red pins, townships names in white text. Orange triangles represent individual wellheads. Information Source: Queensland Globe, 2016.

4.2 Passive sampler sites

A network of Radiello passive samplers have been deployed to assess the spatial variability and levels of individual VOCs, aldehydes and hydrogen sulphide in the study area. Radiello Passive samplers are a portable air quality sampler that allow sampling of different gases without the need for power. Samplers are mounted on poles where the air is sampled for a defined period, before the samplers are sealed and sent to the laboratory for analysis. Further discussion of the passive sampler technique and gases measured are provided in Section 5.2.

In this study, Radiello passive samplers were deployed at 10 sites in the study area from September 2014 – January 2016. Passive sampling recommenced in October 2016 as part of the recently approved GISERA project *Investigating air, water and soil impacts of hydraulic fracturing* (Keywood et al 2016). The Radiello passive samplers were deployed at or within 2km of the gas field ambient air monitoring sites, as well as at an additional 4 sites in and around the gas fields (Nangram, Rockwood, Greenswamp and Miles/Condabri North). Radiello passive samplers were also deployed at the two regional sites (Burncluith and Tara Region) and in the Chinchilla

township. The locations of the 10 passive sampler sites as of January 2016 in relation to wells and ambient air monitoring stations are shown in Figure 6 (red pins). Passive samplers were located within 500 m of Condabri North GPF (Miles/Condabri North passive site), within 2km of Condabri South GPF (Condamine passive site), within 3km of Condabri Central GPF (Miles Airport passive site), within 4km of Talinga GPF (Rockwood passive site) and within 4km of Orana GPF (Hopeland passive site). The Greenswamp passive sampler site was located within 50m of a Condamine River gas seep.

Radiello passive sampler measurement sites were originally determined by consultants. In June 2015 CSIRO audited the site locations and sampler deployment using the same principles used to select location of ambient air monitoring stations (without the requirement for access to mains power). As a result of the audit some samplers were moved between 10 m to 1 km from the original site to ensure sufficient distance from trees and roads to ensure compliance with the Australian Standard (AS/NZS 2007). In July 2015 the Miles Airport passive site was moved 3 km to be located near a sensitive place. The new site locations were all still within the previously stated distance to GPFs and Condamine River methane seep. As a result of the audit CSIRO also recommended alternative mounting procedures to meet requirements of AS/NZS (2007), and samples were mounted on poles 2 m above the ground in June 2015. A comparison between the previous and new mounting techniques has been undertaken and will be discussed when data is reported (see Section 6). A photograph of a Radiello sampler mounted on a pole is shown in Figure 7.

Figure 7. Radiello passive sampler at Condamine passive gas site

5 Pollutants selected for measurement in study

This section discusses which pollutants have been selected for inclusion in the monitoring program, both as part of the 5 ambient air quality stations, and in the passive gas sampler network. Details of the sources of each pollutant selected for the monitoring study is also discussed.

5.1 Pollutants selected for measurement at ambient air monitoring sites

The focus of this study is to assess the impact of CSG production on air quality. As such, pollutants were selected to be incorporated into the monitoring program where the review showed evidence that:

- the CSG industry is a potential source (identified using source data (Section 3,) industry EIS, NPI emissions, inspection of infrastructure) and/or

- CSG activities are likely to elevate pollutant levels above background levels

Additionally, the following factors were considered:

- the pollutant has been identified as a key pollutant within the Australian Government National Environment Protection (Ambient Air Quality and Air Toxics) Measures (NEPM, 2011, 2016) and in discussions around Australia's new National Clean Air Agreement (Commonwealth of Australia, 2015).

- the pollutant can be used as a tracer for emissions from certain sources/ activities. For example, methane can be used as a tracer for CSG fugitive emissions and venting, while carbon monoxide and carbon dioxide can be used as tracers for combustion sources.

Previous studies which have investigated pollutant levels in this region were also reviewed (DSITIA 2013, Queensland Health 2013, DSITI 2015).

The pollutants included in this study were assessed as most important according to criteria above. If measurements of selected pollutants exceed air quality standards and/or additional information about pollutants or sources in the study area becomes available, the suite of pollutants selected will be reviewed and additional pollutant measurements will be considered for inclusion in this study.

The measurement program at ambient air quality stations includes 4 of the 6 criteria pollutants identified in the Ambient Air NEPM (2016), including nitrogen dioxide (as NO_x), photochemical oxidants (as ozone), carbon monoxide and particles (as PM2.5, PM10). These pollutants are included in the NEPM due to their potential to impact human health, wellbeing and/or the environment. All of the instruments at the ambient air sites log data at a time resolution of hourly or better, which allows assessment of changes in pollutant levels throughout the day. The ambient air measurement are undertaken by Ecotech who are a NATA-accredited laboratory that meet all criteria of ISO17025 for competence of a laboratory to carry out sampling, tests and calibrations

using validated test methods. A summary of the methods used to measure each pollutant is provided in Appendix A.3.

Pollutants selected for monitoring at the three gas field and two regional stations are shown in Table 3. Pollutants will be measured at each site for 2 years.

Table 3. Measurements selected for gas field and regional stations

Pollutant/parameter	Gas fields stations	Regional stations	CSG related Sources
Oxides of nitrogen (NO_x)	Yes	Yes	gas fired engines gas flaring diesel exhaust
Carbon monoxide (CO)	Yes	Yes^	gas fired engines gas flaring diesel exhaust
Ozone (O_3)	Yes	Yes	n/a Secondary pollutant (precursors NO_x and VOCs)
Particles < 2.5μm and < 10μm (PM2.5 and PM10)	Yes	No	gas fired engines, gas flaring, diesel exhaust associated with transport, drilling, generators, dust
Methane (CH_4)	Yes	Yes*	Major component of CSG (venting/fugitive emissions)
Total VOCs	Yes	No	gas fired engines, gas flaring, diesel exhaust, CSG venting/fugitive emissions
Carbon dioxide (CO_2)	Yes	Yes*	Source tracer (combustion biological processes)
Meteorology (solar radiation, wind speed, wind direction, rainfall)	Yes	Yes*	Assists in determination of sources

^measurement made at Burncluith as part of GISERA Regional fluxes of methane in the Surat Basin project.

* measurements made at Tara Region and Burncluith sites as part of GISERA Regional fluxes of methane in the Surat Basin project.

Some detail is provided below about likely sources of each of the selected pollutants.

Nitrogen oxides (NOx)

Nitrogen dioxide (NO_2) is one of the 6 key criteria air pollutants identified by the Ambient Air Quality NEPM (NEPM 2016). Nitrogen oxides (NO_x) includes nitrogen oxide and nitrogen dioxide and are gases produced from fuel combustion, including diesel, biomass and gas, coal, as well as natural processes. Nitrogen oxides is a key pollutant identified in CSG industry Environmental Impact Statements (EIS) (QGC 2010, APLNG 2010). CSG related sources include combustion of gas via flaring and gas combustion engines and diesel engine emissions. Nitrogen oxides is also a precursor of tropospheric ozone (see below).

Carbon monoxide (CO)

Carbon monoxide (CO) is one of the 6 key pollutants identified by the Ambient Air Quality NEPM (NEPM 2016). CO is a gas formed from incomplete combustion of carbon-containing fuel. Carbon monoxide was identified as a key pollutant in CSG Industry EIS (QGC 2010, APLNG 2010). CSG related sources include combustion of gas in flares and engines, and diesel engine emissions. Nitrogen oxides and carbon monoxide are co-emitted from many of the same combustion sources in the project area, when measured in parallel their ratios could potentially be used to distinguish between emissions from combustion of CSG, bushfire smoke, and diesel emissions etc.

Particles: PM2.5 and PM10

Particles are one of the 6 key air pollutants in the Ambient Air Quality NEPM (NEPM, 2016). The mass of particles <2.5 µm in size (PM2.5) and the mass of particles <10 µm in size (PM10) as well as total suspended particles (TSP) are being measured at the three gas field sites. Airborne primary particles are emitted directly from the source (e.g. dust, diesel and smoke emissions), while secondary particulates are formed from reactions of gas phase precursors in the atmosphere. Particles have been identified by CSG industry EIS as a key pollutant (QGC 2010, APLNG 2010). CSG related sources include diesel exhaust, combustion and dust emissions, relating mostly to construction activities, along with gas fired boilers, engines and flares. Agricultural and background sources typically make a significant contribution to PM in rural regions. Measurement of both PM10 and PM2.5 may allow differentiation of sources of particles, for example road dust (predominantly PM10) and combustion, diesel emissions and secondary particles (predominantly PM2.5). If particle air quality standards are regularly exceeded, samples to determine the chemical composition of the particles could be taken to assist in determining the sources. CSIRO are undertaking a 6 month particle measurement validation study at the Miles Airport site to ensure the PM data collected at the gas field sites is equivalent to data obtained by Australian Standard Methods. PM is not being measured at the two regional sites due to project budget constraints.

Ozone (O3)

Ozone is another of the 6 key pollutants identified by the Ambient Air Quality NEPM (NEPM, 2016). Ground level ozone is a secondary pollutant, meaning that it is not directly emitted to the atmosphere but rather is formed through reactions between other pollutants in the atmosphere. Ozone formation requires the presence of precursors VOCs, and nitrogen oxides, and sunlight. The CSG industry emits nitrogen oxides primarily from gas combustion. As discussed in Section 3.2, the composition of CSG in the study region is predominantly methane with small amounts of ethane and propane. These hydrocarbons have relatively low ozone formation potential, so the ozone

formation potential from CSG activities alone is likely to be low. However, other natural and man-made sources of reactive VOCs in the airshed could combine with nitrogen oxides from CSG activities and under certain conditions, could contribute to ozone production.

Methane (CH$_4$)

Methane typically makes up 96-98% of CSG composition in the study region (see Section 3.2) Methane is also emitted in significant quantities from other sources such as livestock. Methane is a potent greenhouse gas and is long lived in the atmosphere (average global lifetime 9 years) (Dlugokencky et al. 2003). Methane is only a direct concern for human health at very high concentrations where it can act as a simple asphyxiant (displacing oxygen) and as an explosive gas at concentrations of 5-15% (50,000-150,000 ppm). These very high concentrations are only likely to be reached if there was a significant source of methane in an enclosed space. The measurement of methane in this study is being undertaken as a tracer for emissions of CSG, and its presence will be used to infer the likely presence other minor components present in the CSG such as VOCs.

Total Volatile Organic Compounds

Total volatile organic compound (TVOC) measurements are made at the 3 gas field sites. VOCs are a group of gases which are relatively short lived and participate in photochemical reactions in the atmosphere. The TVOC measurement method employed in this study provides a good approximation for the sum of all individual VOCs present. In the study region VOCs are emitted as by-products of fuel and gas combustion as well as natural sources. VOCs such as ethane and propane are also present in small quantities in CSG and so are likely to be associated with leaking and venting of CSG (see Section 3.2). Hydrocarbons, a subset of VOCs, are identified as a key group of pollutants in the APLNG and QGC EIS (QGC 2010, APLNG 2010). Total VOC measurements may provide an indication of whether an elevation of VOCs from combustion or CSG leakage and venting occurs.

A network of passive VOC samples was deployed which provided fortnightly integrated measurements of individual VOCs (see Section 4.2, 5.2 and Appendix A.2). Measurements of individual VOCs will provide an indication of the composition of the total VOCs observed.

Carbon dioxide (CO$_2$)

Carbon dioxide is long lived greenhouse gas, and is unreactive and not directly harmful to health except at very high concentrations. Carbon dioxide measurements are included in this study as a useful tracer for combustion and biological processes which will assist with identification of sources.

5.2 Pollutants selected for measurement in passive sampler network

The Radiello passive sampler network of 10 sites provides concentrations of a range of individual gases over a larger spatial area than covered by the ambient air quality stations. Passive samplers are commonly used in air quality studies both in Australia and internationally due to ease of deployment and because they require no pumps or power. As such they are suitable for deployment in remote locations. Samplers are configured differently according to the types of gases targeted for sampling. The passive sampler has a diffusive surface, which gases pass through

at a known rate, and an absorbing surface which traps the gas until the sample is analysed. An alternative sampling method, known as 'active' sampling uses a pump to draw air through an absorbing material, and is the sampling technique used by CSIRO in the passive sampler VOC and aldehyde inter-comparison at Hopeland (see Section 5.2.1). Passive samplers provide an 'average' concentration over the period they are deployed.

Individual VOCs, aldehydes (a subset of VOCs) and hydrogen sulphide were measured with Radiello passive samplers (Table 4). Appendix A.2 lists individual VOCs and aldehydes measured using the passive sampler technique. The passive sampler network allowed measurement of 4 of the 5 gases identified in the Air Toxics NEPM, namely benzene, toluene, xylenes and formaldehyde, and several other VOCs reported in the NPI (see Section A.2). Radiello passive samplers were deployed by consultants SGS Leeder. Each set of samplers were exposed in the field for a period of approximately two weeks and were analysed by SGS Leeder in Mitcham, Melbourne.

Table 4. Summary of measurements made in the passive sampler network

Pollutant	Dates	Sources relating to CSG production
VOCs (46 individual VOCs)	Sep 2014 – Jan 2016	Gas and fuel combustion, CSG venting and leakage
Aldehydes (8 individual aldehydes)	Jul 2015 – Jan 2016	Gas and fuel combustion
Hydrogen sulphide	Jul 2015 – Jan 2016	CSG venting and leakage

Volatile Organic Compounds (VOCs)

46 Individual VOCs are measured using the Radiello passive technique which cover a wide range of VOCs potentially emitted from man-made and natural emission sources. This technique allows measurement of a number of VOCs listed in the Air Toxics NEPM (benzene, toluene and xylenes), and several additional VOCs reported by the NPI (see Section A.2). It also allows measurement of a number of VOCs measured in CSG emissions sources, such as gas combustion (see Section 3.2). Available CSG composition data (Section 3.2) indicates that ethane and propane make up the largest component of VOCs in CSG in the monitoring area, which are not measured via this passive sampler technique. However, ethane and propane and other VOCs not measured with the passive samplers will be measured by the TVOC instrument at the 3 gas field sites. Radiello passive samplers VOC measurements began in September 2014 (Table 4).

Aldehydes

The Radiello passive sampling technique measures 8 individual aldehydes. The review presented in Section 3.2 indicates that the main source of aldehydes from the CSG industry is likely to be

combustion of gas in compressors and engines and flares. The technique enables measurement of formaldehyde (listed in the Air Toxics NEPM (NEPM 2016)) as well as several other aldehydes identified in gas combustion emissions including acetaldehyde. Aldehyde measurements we re incorporated into the passive sampler network in July 2015.

Hydrogen sulphide

Hydrogen sulphide is a highly odorous gas with an odour of rotten eggs. Available CSG composition data suggests hydrogen sulphide levels in the CSG in the study region are low (Section 3.2) and so when the CSG emissions are diluted in the atmosphere the hydrogen sulphide is expected to rapidly drop below the odour threshold of 8 ppb (11 µg m^{-3}) (WHO 2003). However, because of community concern about odour in the study region (DSITIA 2013) hydrogen sulphide measurements were incorporated into the passive sampler network in July 2015.

5.2.1 CSIRO VOC and aldehyde measurements

CSIRO undertook independent measurements of VOCs and aldehydes at Hopeland ambient air monitoring station for two weeks in June-July 2015. CSIRO used an active sampling technique in which air was drawn through each sample tube for 12 hours before being sent to CSIRO's Aspendale laboratory for analysis. These measurements were made in parallel with the SGS Leeder passive Radiello VOC and aldehyde measurements. The purpose of CSIRO's measurements was to make an independent check of VOC and aldehyde levels at Hopeland station using a different sampling and analysis method to the Radiello Passive method. This also allows comparison of the methods used by SGS Leeder and CSIRO. The results of the CSIRO VOC and aldehyde measurements, and passive sampler intercomparison study will be provided in the first data summary report (see Section 6) in early-mid 2017.

5.3 Role of measurement service providers and CSIRO

At the beginning of the study, CSIRO recommended instruments and methods to measure pollutants at the air quality stations and passive sampler sites.

The instruments used to measure air quality at the 5 ambient air quality stations are operated by Ecotech Pty Ltd. Ecotech is a NATA-accredited laboratory which means it meets all criteria of ISO17025 for competence of a laboratory to carry out sampling, tests and calibrations using validated test methods. Ecotech are responsible for instrument installation, calibration and maintenance. Ecotech perform daily data checks on all the instruments remotely to ensure correct operation of instruments. If data checks identify issues with instrument performance, these are conveyed to Ecotech field technicians who visit the sites to repair instruments. CSIRO also undertake an independent daily check of instrument performance remotely for all sites, and convey issues to Ecotech for action.

Ecotech are responsible for quality checking and processing data each month. Ecotech quality check and validate data by flagging data affected by instrument faults, calibrations and other maintenance activities, ensuring compliance with relevant Australian standards. Ecotech then provide monthly validated data to CSIRO who then compare all raw and validated datasets, and

independently assess any adjustments to data (for example due to changes in instrument performance) or removal of data. The final data set is approved by CSIRO – this data is then included in data summary reports.

SGS Leeder are responsible for deployment and analysis of Radiello passive samplers in the study, and provide final concentration data to CSIRO. SGS is a NATA-accredited laboratory which means it meets all criteria of AS ISO/IEC 17025-2005 for competence of a laboratory to carry out sampling, tests and calibrations using validated test methods. CSIRO have undertaken an audit of passive sampler deployment and recommended some changes to sample mounting to comply with Australian standards. Recommendations were implemented. CSIRO has visited SGS Leeder staff in their laboratory in Melbourne to audit the passive sampler measurement and analysis technique, and have undertaken an independent assessment of the suitability of the technique for individual VOCs (see section 5.2.1).

Measurements reported in A.1 including gas, water and combustion gas emission composition, were undertaken by consultants. Samples were taken from Origin Energy infrastructure and consultants were engaged by Origin Energy. These consultant reports were provided to CSIRO by Origin Energy for use in this study. A summary of methods used for measurement of air pollutants at ambient air quality stations and passive sites, as well as measurements of gas and water composition is provided in A.3.

6 Reporting of air quality data

Air quality data from the monitoring study will be made available via live data streaming and summary reports (see below).

6.1 Live data streaming

Preliminary carbon monoxide, nitrogen dioxide, ozone and particle data from the Hopeland, Miles Airport, Condamine, Burncluith and Tara Region ambient air quality sites is streamed every hour to the Department of Environment and Heritage Protection website. These pollutants have been selected for live streaming because there are air quality standards associated with each of these pollutants (Air NEPM), which provides context for the reported concentrations. Data streaming began on 25 August 2016. Instrument performance is checked daily by Ecotech and CSIRO however at the time of streaming, data has not yet undergone validation procedures (see Section 5.3). Meteorological data from the gas field sites began streaming in December 2016. The data from the 5 stations is displayed under the South West Queensland Region. Air quality data is displayed both as measured concentration values and is also converted into air quality index values (0-100) with corresponding colour coded categories (very good, good, fair, poor, very poor). The index value is the pollutant concentration expressed as a proportion of the Ambient Air Quality NEPM standard or the Environmental Protection (Air) Policy 2008 (Air EPP) objective. This allows comparison of the air quality in the South West region with other parts of Queensland. The live data can be viewed at: https://www.ehp.qld.gov.au/air/data/search.php. A screenshot of the website showing live-streamed data from five ambient air quality sites is shown in Figure 8.

Preliminary historical carbon monoxide, nitrogen dioxide, ozone and particle data from the Hopeland, Miles Airport, Condamine, Burncluith and Tara region ambient air quality sites is available on the DEHP website for comparison with air quality standards. Validated data will be made available via the DEHP website once the first data summary report has been released (see below).
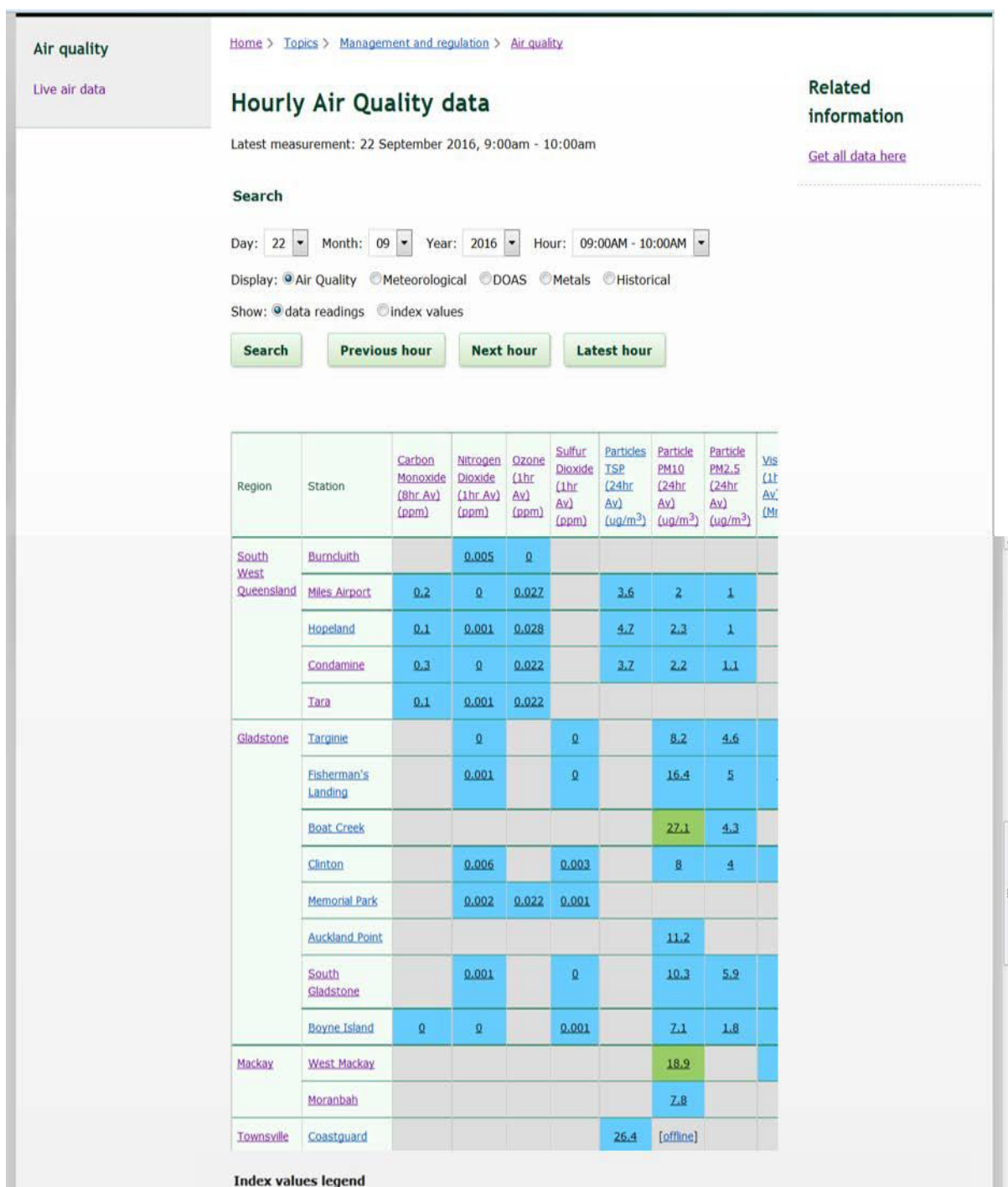
Figure 8. Screenshot of DEHP website showing hourly air quality data for Queensland. The stations in this study are reported in the South West Queensland region. See http://www.ehp.qld.gov.au/air/data/search.php

6.2 Data summary reports

The following reports will be released as part of this project and will be made available to the public via the GISERA website, https://gisera.org.au/project/ambient-air-quality-in-the-surat-basin/:

6.2.1   Interim data summary report (scheduled early-mid 2017)

All air quality data collected in the study will be summarise including a) passive VOCs, aldehydes and hydrogen sulphide from 10 sites from September 2014 – January 2016 (including CSIRO VOC measurements) b) carbon monoxide, nitrogen oxides and ozone from the 3 gas field and 2 regional air quality monitoring sites up until December 2016, c) particles, total volatile organic compounds and methane from the 3 gas field sites up until December 2016. Note that results from the subsequent round of Radiello passive gas measurements recommenced in October 2016 as part of the GISERA Hydraulic fracturing study (Keywood et al 2016) will be reported as part of that project.

Pollutant levels will be assessed against air quality standards. Where concentrations exceed 80% of the air quality standard (for relevant averaging periods) an investigation of the source(s) will be undertaken.

Methods used to investigate the source(s) will include investigation of source(s) upwind of measurement sites and analysis of pollutant ratios and comparison with source emission ratios where possible. Concentrations of individual VOCs measured as part of this study will be compared with concentrations observed in other parts of Australia.

6.2.2   Final data summary report (scheduled early-mid 2018)

Subsequent carbon monoxide, nitrogen oxides, ozone, particles, methane, total volatile organic compounds will be summarised from the period Jan 2017-March 2018, as per the methodology for the Interim data summary report above.

7 Modelling air quality in the Surat Basin

CSIRO is developing an air quality model for use in this study to explore the degree to which CSG emissions contribute to air pollution levels in the Surat Basin. The model will simulate the emission, transport and transformations of pollutants in the air over the Surat Basin at up to 1 km resolution for every hour of 2015. A meteorological model (CCAM) and a chemical transport model will be coupled to perform this modelling, which is being undertaken by CSIRO. The year 2015 was chosen as the base year for the Surat Basin model because meteorological and ambient air monitoring data from Hopeland, Miles Airport, Tara region and Burncluith is available for all or part of that year to compare with model output. This data from the air quality stations will be used to validate the model's performance and output. Furthermore, the year 2015 had the highest rate of CSG production in the region at the time the study commenced (Figure 9).

The following pollutants will be simulated in the model: carbon monoxide, nitrogen oxides, ozone, primary and secondary particle mass, ammonia, VOCs and sulphur dioxide. While the CSG industry has not been identified as a major source of some of these pollutants such as sulphur dioxide, it is important to include pollutants from all sources in the region, so that the rate and spatial distribution of emissions, atmospheric concentrations and transformation of each pollutant are accurately represented.

Figure 9. Queensland CSG production in the Surat Basin for 6 month periods from 1997-2015.
Source: https://publications.qld.gov.au/dataset/queensland-petroleum-and-coal-seam-gas

7.1   Representing emissions in the model

The release or emission of pollutants from all sources, including the CSG industry is represented in the model using an emission inventory. Building an emission inventory involves identifying sources of pollutants such as carbon monoxide, nitrogen oxides, particles, ammonia, VOCs and sulphur dioxide within the model domain shown in Figure 1.

Once emission sources have been identified, the emission rate and characteristic of every pollutant will be quantified, in every km^2 of the model domain, every hour, for the year 2015.

Sources identified include a wide variety of natural and man-made (anthropogenic) emissions including the CSG industry, power stations, quarries, mines, livestock production (including feedlots), motor vehicles, domestic and commercial sources, domestic wood heaters, bushfires and prescribed burning, wind-blown dust and vegetation. Emission sources were identified using a range of different information sources, including Qld Government department and agency databases, Queensland Globe, the National Pollutant Inventory (NPI) database, industry Environmental Impact Statements, and aerial photography.

Specific emissions identified from the CSG industry include but are not limited to: GPF emissions including compressors, engines, venting, flares and leaks, WTF emissions and field emissions including wellhead engines/microturbines, wellhead leaks, water and gas gathering networks and vehicles. Emissions from APLNG, QGC, Arrow and Santos and other producers will be included in the inventory.

The building of the emissions inventory is a joint effort between Katestone Environmental consultants and CSIRO. Katestone are leading the development of the man-made (anthropogenic) emission inventory, including the CSG Industry. Emissions from the CSG infrastructure are being obtained directly from each CSG company where possible, to ensure the emissions are represented as accurately as possible. Publicly reported emission data such as the NPI are also being used. CSIRO are providing estimates of natural emissions such as those from bushfires, soil and vegetation. The emissions inventory is being reviewed by a third party prior to being used in the model to independently verify the representation of emissions in the inventory. The methodology for the emission inventory, including the sources identified, emission rates, and source information will be provided in the report of model findings (see below).

The emissions inventory has been developed for an area 300 by 300 km which is larger than the Condamine-Miles-Chinchilla air quality monitoring region. This area was chosen as emissions from outside the monitoring area are likely to be transported into the study area, and so emissions in the surrounding area must be included. The air quality modelling will also include transport of pollutants from the South East Queensland region incorporating Brisbane, to account for impact of long range transport on local pollutant levels.

7.2   Model output

7.2.1   Validation

The simulated meteorology in the model has been compared with meteorological measurements from Hopeland, Tara Region/Ironbark and Burncluith air quality stations and Bureau of Meteorology stations at Roma and Dalby airports. The model performed well in simulating the correct wind direction, wind speed and temperature on a season basis.

The model will be run with all sources initially and the output will be compared with 2015 ambient air quality data collected as part of this study, from Hopeland, Miles Airport and Burncluith. Additional data from the DEHP air monitoring network, as well as monitoring data collected by government and industry will be utilised where available for the comparison. This validation will ensure that the model is correctly representing the emission, transport and reaction of pollutants in the Surat Basin.

7.2.2   CSG contribution

Following validation, the air quality model will be run in two modes, 1) with all sources *including* the CSG industry, and 2) all sources *excluding* the CSG industry. The difference between the two model outputs will provide an estimate of the contribution of the CSG industry contribution to air pollutant levels. The model will also allow an understanding of the distribution of pollutants over a much larger area and also at a denser spatial scale than can be determined by fixed monitoring sites alone.

Details of the modelling and inventory methodology, validation study and findings will be made available via a separate report in late 2017.

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9 Appendices

A.1 Measurements of CSG-related sources and emissions

A.1.1 Radiological surveys

A.1.1.1 Talinga February 2010

A.1.1.2 Talinga August 2013

A.1.2 Talinga GPF gas composition and WTF water composition

A.1.2.1 June 2011

A.1.2.2 Nov 2013

A.1.3 Emissions Monitoring: Talinga gas combustion emissions

A.1.3.1 May 2014

A.1.3.2 Sep 2015 VOC and aldehyde emissions

A.1.3.3 Sep 2015

A.1.4 Orana and Talinga wellhead gas and water composition

A.1.4.1 Talinga April 2014

A.1.4.2 Orana February 2016

A.1.4.3 Orana March 2016

A.1.4.4 Orana May 2016

A.1.4.5 Orana July 2016

A.2 Gases measured in passive sampler network

A.2.1 Species reported from Radiello passive VOC samplers

VOC name	CAS Number	
Benzene	71-43-2	Air toxic NEPM & NPI
Bromochloromethane	74-97-5	
Butanol	35296-72-1	
2-butoxyethanol	111-76-2	
Butyl acetate	123-86-4	
Carbon tetrachloride	56-23-5	
Chlorobenzene	108-90-7	NPI
Cyclohexane	110-82-7	NPI
Cyclohexanone	108-94-1	
n-decane	124-18-5	
14-Dichlorobenzene	106-46-7	
12-Dichloroethane	107-06-2	NPI
1,2-Dichloropropane	78-87-5	
Ethyl acetate	141-78-6	NPI
Ethylbenzene	100-41-4	NPI
2-ethylhexanol	104-76-7	
Ethyl-tert-butyl ether	637-92-3	
n-Heptane	142-82-5	
n-Hexane	110-54-3	NPI
Isobutanol	78-83-1	
Isooctane	540-84-1	

Isopropylbenzene	98-82-8	
1-Methoxy-2-propanol	107-98-2	
1-Methoxy-2-propyl acetate	108-65-6	
Methyl methacrylate	80-62-6	
Methylcyclohexane	108-87-2	
Methylcyclopentane	96-37-7	
Methylethylketone	78-93-3	NPI
Methylisobutylketone	108-10-1	NPI
2-Methylpentane	107-83-5	
3-Methylpentane	96-14-0	
Methyl-ter-butyl ether	1634-04-4	
Naphthalene	91-20-3	
N-Nonane	111-84-2	
N-Octane	111-65-9	
n-Propylbenzene	103-65-1	
Styrene	100-42-5	
Tetrachloroethylene	127-18-4	NPI
Toluene	108-88-3	Air toxic NEPM & NPI
1,1,1-Trichloroethane	71-55-6	
Trichloroethylene	79-01-6	NPI
Trichloromethane	67-66-3	
124-Trimethylbenzene	95-63-6	
N-Undecane	1120-21-4	
o-Xylene	95-47-6	Air toxic NEPM & NPI
m&p-Xylenes	108-38-3 / 106-42-3	Air toxic NEPM & NPI

A.2.2   Species reported from Radiello passive aldehyde samplers

Aldehyde	CAS number	
Formaldehyde	50-00-0	Air toxic NEPM & NPI
Acetaldehyde	75-07-0	NPI
Propanaldehyde	123-38-6	
Butanaldehyde	123-72-8	
Pentanaldehyde	110-62-3	
Hexanaldehyde	66-25-1	
Benzaldehyde	100-52-7	
Glutaraldehyde	111-30-8	NPI

A.3 Summary of methods used

Air Quality measurements

Parameter	Instrument/s	Method/s	Description
Continuous sampling/insitu analysis			
Nitric oxide (NO) Nitrogen dioxide (NO$_2$) Nitrogen oxides (NO$_x$)	Ecotech Serinus 40 or Ecotech EC9841T	Australian standard method AS 3580.5.1-2011	Methods for sampling and analysis of ambient air. Method 5.1: Determination of nitrogen oxides – chemiluminescence method
		Ecotech laboratory method	In-house method 6.1 Nitrogen oxides by chemiluminescence
Carbon monoxide (CO)	Ecotech Serinus 30 or Ecotech EC9830T	Australian standard method AS 3580.7.1-2011	Methods for sampling and analysis of ambient air. Method 7.1: Determination of carbon monoxide - direct reading instrumental method
		Ecotech laboratory method	In-house method 6.3 Carbon monoxide by gas filter correlation spectrophotometry
Ozone (O$_3$)	Ecotech Serinus 10	Australian standard method AS/NZS 3580.6.1-2011	Methods for sampling and analysis of ambient air. Method 6.1: Determination of ozone–Direct reading instrumental method
		Ecotech laboratory method	In-house method 6.7 Ozone by UV photometry
TVOC	Baseline 9000	Australian standard method AS 3580.11.1-2013	Methods for sampling and analysis of ambient air. Method 11.1 Determination of volatile organic compounds – Methane and non-methane volatile organic compounds – Direct reading instrument method
		Ecotech laboratory method	In-house method 6.6 Hydrocarbons – methane, non-methane, total by flame ionization detection (FID)
TSP, PM10, PM2.5 (Fidas)	Fidas 200	Ecotech laboratory method based on Fidas instrument manual	In-house method 7.7 – PM10 and PM2.5 Particles – Light Scattering Method Using Palas Fidas® 200 Series Monitors
Carbon dioxide/methane	Picarro G2301 or LGR GGA	Ecotech laboratory methods	Methane and Carbon dioxide by Cavity Ring-Down Spectroscopy (CRDS). Laser absorption spectroscopy method.
Meteorology measurements (continuous sampling/insitu analysis)			
Vector Wind Speed (Horizontal)	RM young 85000	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.1 Wind speed (Horizontal) by anemometer (ultrasonic)
Vector Wind Direction	RM young 85000	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.3 Wind direction by anemometer (ultrasonic)
Temperature	MetOne 062MP	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological

			monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.4 Temperature ambient by thermoelectric techniques
Relative Humidity	Vaisala HMP155	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.5 – Relative humidity by hygrometer
Rain	Hydrological Services TB6	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.7 – Rainfall by tipping bucket rain gauge
Solar and net radiation	Middletone Solar Pyranometer SK-01-D2	Australian standard method AS 3580.14-2014	Methods for sampling and analysis of ambient air. Method 14: Meteorological monitoring for ambient air quality monitoring applications
		Ecotech laboratory method	In-house method 8.6 – Global solar radiation and Net radiation by pyranometer and net pyradiometer
Integrated passive sampling/off-site analysis			
Individual volatile organic compounds (VOCs)	Radiello cartridges: white diffusive body code 120; adsorbing cartridge code 130.	VOCs sampled by passive diffusion onto activated charcoal adsorbent and chemically desorbed with CS2 and analysed by GC-FID. Exposure period is recorded.	SGS laboratory method: MA-5.RAD.02 Volatile Organics in Air, reported in µg/m3 based on Radiello manual Edition 01/2006 method D1: determination of concentration in air based on exposure period, sampling rate and mass/tube.
			SGS laboratory method: MA-5.RAD.03 Volatile Organics in Air, reported in µg/tube based on Radiello manual Edition 01/2006 method D1: determination of mass of VOCs on tube. Extraction by CS2, separation using capillary gas chromatography and identification/quantification with mass spectrometry (MS)
Individual aldehydes	Radiello cartridges: blue diffusive body code 120-1; chemiadsorbing cartridge code 165.	Aldehydes sampled by passive diffusion onto 2,-4-dinitrophenylhydrazine (2,4-DNPH)-coated Florisil to form 2,4-DNP-hydrazones. Exposure period is recorded.	SGS laboratory method MA-1159.RAD.01 Aldehydes in Air, reported in µg/m3, based on Radiello manual Edition 01/2006 method C1: determination of concentration in air based on exposure period, sampling rate and mass/tube
			SGS laboratory method MA-1159.RAD.02 Aldehydes in Air, reported in µg/tube based on Radiello manual Edition 01/2006 method C1: determination of mass of 2,4-DNP-hydrazones on tube. Extraction in acetonitrile, separation using reverse phase high performance liquid chromatography and identification/quantification with selected ion monitoring (SIM) mass spectrometry (MS)
Hydrogen sulphide (H2S)	Radiello cartridges: white diffusive body code 120;	Hydrogen sulphide is sampled by passive diffusion onto zinc acetate-impregnated polyethylene to form zinc	SGS laboratory method MA-1538.RAD.01 Hydrogen Sulphide in air, reported in ppb, based on Radiello manual Edition 01/2006 method H1: determination of concentration in

	chemiadsorbing cartridge code 170	sulphide. Exposure period is recorded.	air based on exposure period, sampling rate and mass/tube
			SGS laboratory method MA-1538.RAD.02 Hydrogen Sulphide in air, in μg/tube based on Radiello manual Edition 01/2006 method H1: determination of mass of sulphide on tube. Sulfide is extracted in water and is reacted to form methylene blue, which is quantified by visible spectrometry.
Integrated active sampling/off-site analysis			
Individual volatile organic compounds (VOCs)	Markes multi-sorbent thermal desorption tubes containing Carbograph 1TD and Carbopack X sorbent	VOCs are sampled by pumping of air through a manifold and through two tubes in series, each containing a multi-sorbent bed. The sample volume is recorded.	CSIRO laboratory method: determination of speciated VOC masses. Thermal desorption of sample, separation of VOCs using gas chromatography, identification by mass spectrometry and quantification via flame ionization detection according to USEPA Compendium method TO-17
Individual aldehydes	Supleco 2,4-DNPH S10 Cartridges	Aldehydes are sampled by pumping of air through an ozone scrubber and onto a tube containing silica coated with 2,4-DNPH where they react to form 2,4-DNP-hydrazones. The sample volume is recorded.	CSIRO laboratory method: determination of mass of 2,4-DNP-hydrazones. Sample extraction in acetonitrile, separation using reverse phase ultra-high-performance liquid chromatography, quantification with diode array detection (DAD) and identification with mass spectrometry (MS). The analysis was based on EPA Method TO11A.

CSG-related sources and emissions

Radiological surveys (Appendix A.1.1)		
Parameter	Method	Description
Gamma radiation (survey and dosemeter mode)	Laboratory method	Method based on manual for Exploranium GR-130 mini spectrometer. Calibration traceable to Australian Primary Standard of Exposure maintained by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).
Alpha and beta radiation	Laboratory method	Method based on manual for Thermo 1A with DP2R/4A Probe. Calibration traceable to Australian Primary Standard of Exposure maintained by ARPANSA.
Alpha, beta and gamma radiation	Laboratory method	Method based on manual for HPI Cypher 5000 with 5505 PGM probe. Calibration traceable to Australian Primary Standard of Exposure maintained by ARPANSA.
Gamma radiation (survey and dosemeter mode)	Laboratory method	Method based on manual for Radiation Solutions RS220. Calibration traceable to Australian Primary Standard of Exposure maintained by ARPANSA.
Alpha and beta radiation	Laboratory method	Method based on manual for Ludlum Model 2360 and 43-93 alpha-beta dual phosphor probe. Calibration traceable to Australian Primary Standard of Exposure maintained by ARPANSA.

CSG composition (Appendix A.1.2., A.1.4)		
Methane	ASTM D1945 03 (2010) Bureau Veritas laboratory method	Standard Test Method for Analysis of Natural Gas by Gas Chromatography In-house Method GC-01. Analysis of natural gases by gas chromatography, based on ASTM D1945 and ISO 6974 In-house Method GC-04 - Extended gas compositional analysis, based on ASTM D1945 , ISO 6975 and ISO 23874
VOCs	ASTM D1945 03(2010) Bureau Veritas laboratory method	Standard Test Method for Analysis of Natural Gas by Gas Chromatography In-house Method GC-01. Analysis of natural gases by gas chromatography, based on ASTM D1945 and ISO 6974 In-house Method GC-04 - Extended gas compositional analysis, based on ASTM D1945 , ISO 6975 and ISO 23874

SVOCs	Envirolab/MPL laboratory method	ORG-012/017/033- In house method for PAH analysis, using filters and XAD resin sorbent tubes with solvent extraction and GCMS analysis
Radon-222	ARS laboratory method	ARS-SOP-AS201 -Preparation of radon coils ARS-SOP-AS203- Analysis of radon in gas streams by low resolution gamma ray spectrometry using charcoal coil method.

Internal method OS-03-01 method for sampling/onsite adsorption test for radon in gas. |
	Bureau Veritas laboratory method	ARS-SOP-AS201/ARS-SOP-AS203- Radon in Gas Streams by low resolution gamma ray spectrometry.
	SGS Australian Radiation Services laboratory method	
Total mercury	ISO 6978:1992 A (OS-02-01) ISO 6978:1992 B (OS-02-02)	Determination of mercury, including dimethyl mercury, elemental mercury and diethyl mercury, in natural gas.
Sulfur containing gases	ASTM D4810 (2015)	Standard Test Method for Hydrogen Sulfide in Natural Gas Using Length-of-Stain Detector Tubes
	ASTM D2385 (1990)	Standard test method for hydrogen sulphide and mercaptan sulphur in natural gas (cadmium sulfate iodometric ti tration method)

Internal method OS-06-03 - Other gases by detector tube. |
| | Bureau Veritas laboratory method | |

Wellhead and WTF water composition (atmospherically relevant components) (A.1.2 and A.1.4)		
VOCs including BTEX	Symbio Alliance laboratory method	Symbio Alliance internal method ENV105 for water testing -TPH/TRH Volatile, (C6-C9) + BTEX, based on USEPA 8020
SVOCs including PAHs, phenols	Symbio Alliance laboratory method	Symbio Alliance internal method ENV103 - PAH and Phenols based on USEPA 8270
Total recoverable petroleum hydrocarbons (C6 – C9 fraction)	Symbio Alliance laboratory method	Symbio Alliance internal method ENV105 for water testing -TPH/TRH Volatile, (C6-C9) + BTEX, based on USEPA 8020

Combusted gas emissions (gas fired engines/compressors) (A.1.3)		
Nitrogen oxides	USEPA Method 7E	Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Carbon monoxide	USEPA Method 10B	Determination of Carbon Monoxide Emissions from Stationary Source

Methane	USEPA Method 18	Determination of Volatile Organic Compounds (Sample Collection by Gas Bag)
VOCs (including hydrocarbons)	USEPA Method 18	Determination of Volatile Organic Compounds (Sample Collection by Gas Bag)
	USEPA TO-15	Determinationof Volatile Organic Compounds in Air Collected in Specially-Prepared Canisters and Analysed by Gas Chromatography/Mass Spectrometry
	NIOSH 2016	Formaldehyde. Sample collection on DNPH tubes and analysis of tubes and condensate.

A

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