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An assessment of ambient air quality in the Surat Basin, Queensland

Interim data summary, September 2014 – December 2016

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Important disclaimer

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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

ppmC – parts per million of volume of gaseous carbon contained in one million volumes of air

ppb – parts per billion by volume

L - litre

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

Nomenclature

Aldehyde – a class of VOCs (volatile organic compounds)

Ambient air – outdoor air

BTX –benzene, toluene, xylenes (a subset of VOCs)

Coarse PM fraction – particles with an aerodynamic diameter of between 2.5 and 10 µm

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

Fine PM fraction – particles with an aerodynamic diameter of < 2.5 µm ($PM_{2.5}$)

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 receptor – 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

Vegetation fires – includes forest and grass fires (both prescribed fires and wild fires) and agricultural burning

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, Queensland

DNRM – Department of Natural Resources and Mines, Queensland

DSITI – Department of Science, Innovation Technology and Innovation, Queensland

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

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

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

PM – particulate matter

SVOC – semi volatile organic compounds

TVOC – total volatile organic compounds

TSP – total suspended particles

VOC – volatile organic compounds

WTF – water treatment facility

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. The purpose of the study is two-fold:

1) to measure and assess air quality, and

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

This report presents data from the ambient air quality measurement network for the period from September 2014 –to December 2016, with data from 2017 onwards to be presented in a final report in 2018.

Measurement site locations and pollutants

Air quality measurements are being made at 5 ambient air monitoring stations including 3 Gas field sites and 2 Regional sites (Figure 1 and Figure 2). The Gas field stations are Hopeland, Miles Airport and Condamine and measurements started in January 2015, July 2015 and March 2016 respectively. The Gas field stations are located between 1 and 5 km from gas processing facilities (Orana, Condabri Central and Condabri South) and are located 100 – 450 m from operating CSG wells. Gas field stations have between 15 and 25 wells within a 2 km radius.

The 2 Regional stations have been incorporated into the study to investigate air pollution levels outside the Gas field region. Regional stations are Tara Region/Ironbark (26 km SE of Condamine township) and Burncluith (20 km NE of Chinchilla township). These sites 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 2015 and have been utilised for air quality measurements in this project since June 2016.

As well as Gas field and Regional ambient air quality station sites, the study also includes 10 Passive Radiello sampler sites (see below).

The following pollutants and parameters are being measured in this study:

• Gas field ambient air quality stations:

- nitrogen oxides (NO_x),
- carbon monoxide (CO),
- ozone (O_3),
- Particles < 2.5 µm and < 10 µm ($PM_{2.5}$ and PM_{10}),
- total suspended particles (TSP),
- methane (CH_4),
- total VOCs (TVOC),
- carbon dioxide (CO_2)

- meteorology (temperature, humidity, solar radiation, wind speed and direction).

• Regional ambient air quality stations:

- nitrogen oxides
- carbon monoxide (Burncluith data provided by GISERA Regional methane flux project)
- ozone
- meteorology (provided by GISERA Regional methane flux project)

• Radiello passive sampler sites, including Gas field, Regional and Chinchilla township sites:

- 54 gases including VOCs, aldehydes and hydrogen sulphide

Four of the 6 objective pollutants identified in the Ambient Air NEPM are measured at Gas field sites including nitrogen dioxide, photochemical oxidants (as ozone), carbon monoxide (CO) and particles (as $PM_{2.5}$, PM_{10}). 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.

Live data streaming

Since 25th August 2016, preliminary air quality data from the ambient air quality sites has been streamed to the Department of Environment and Heritage Protection (DEHP) website under South West Queensland region (https://www.ehp.qld.gov.au/air/data/search.php). Data streamed comprises carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10} and TSP (Hopeland, Miles Airport, Condamine) and CO, NO_2, O_3 (Burncluith and Tara Region). At the time of streaming, data have 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 National Environment Protection Measures (NEPM) standard. This allows comparison of the air quality in the study region with other parts of Queensland.

Air monitoring stations: Comparison to air quality objectives and exceedances

Air quality measurements from the 5 ambient air monitoring sites were compared to relevant air quality objectives including the Queensland Government Environment Protection (Air) Policy) (Air EPP), NEPM, and DEHP Nuisance Dust Guidelines for TSP.

During the period January 2015 – December 2016:

- There were no exceedances of carbon monoxide, nitrogen dioxide or ozone air quality objectives at any of the Regional or Gas field sites.
- There were 6 exceedances of the 24 hour average PM2.5 objective, and 2 exceedances of the 24 hour average PM10 objectives at the Gas field sites. There were 8 exceedances of the 24 hour TSP hour nuisance dust objective at the Gas field sites.
- There are no PM2.5, PM10 or TSP measurements undertaken at the Regional sites.

A protocol which uses a combination of wind speed and direction, source locations, and pollutant correlation and ratios was developed to investigate the cause / source(s) of the exceedances.

Based on these investigations, the most likely cause or source/s of the exceedance events were as follows:

- All 6 $PM_{2.5}$ exceedances were attributed to smoke from local or regional vegetation fires;
- One PM_{10} exceedance was attributed to smoke from a local vegetation fire, for one exceedance the source was unknown
- One TSP event was attributed to smoke from vegetation fire, 2 events were associated with cattle farming, 1 event was associated with cattle farming and an unknown source, 1 event was attributed to unsealed roads/CSG activities, and 1 event to a combination of smoke from vegetation fire and unsealed roads/CSG activities. The source(s) of 2 events could not be determined.

A number of events where pollutant concentrations were greater than 80% of a relevant air quality objective were also identified at Gas field sites and were investigated in recognition that an exceedance may have occurred closer to the pollutant source but not at the monitoring station. The protocol was also used to determine the most likely cause or source(s) as follows:

- $PM_{2.5}$ – smoke from vegetation fires;
- PM_{10} – combination of smoke from vegetation fires and local dust, particles associated with cattle farming, unsealed roads/CSG activities and source undetermined;
- TSP – combination of smoke from vegetation fire and dust, particles associated with cattle farming, unsealed roads/CSG activities, source undetermined.
- Ozone – a regional event (source unknown)

Case studies in Section 4 provide evidence used to attribute $PM_{2.5}$ exceedances at several sites to a regional smoke event, as well as evidence used to attribute a TSP nuisance dust guideline exceedance to activities associated with cattle farming.

Methane events and implications for air quality

Methane does not have an air quality objective as it is not considered to pose a risk to human health in the ambient environment. Methane was measured at the Gas field sites as a tracer for CSG related emissions. The annual average methane concentration at Gas field sites was between 1.8 and 1.9 ppm, comparable to methane concentrations measured at the two Regional sites as part of the GISERA Regional Methane Flux study (Etheridge et al., 2017). Determination of the regional emissions of methane in the study area is being addressed as part of the GISERA Regional Methane Flux study (Day et al., 2015; Etheridge et al., 2017).

The 5 largest methane events at each Gas field site were identified and the source investigated, making a total of 15 methane events investigated. Fourteen of the 15 methane events investigated were attributed to sources or activities associated with the CSG industry, while the source of the remaining event was unknown. However, none of the 14 methane events attributed to CSG-related sources or activities were associated with an exceedance of air quality objectives. The methane event with the longest duration and highest concentrations (1 hour methane = 25 ppm) was identified by the CSG industry as an infrastructure fault. This event has been investigated and presented as a case study in Section 4. During the 14 methane events attributed to CSG-related sources, the largest methane peaks were uncorrelated with other gases associated

with combustion (carbon monoxide, carbon dioxide, nitrogen oxides) which suggests that the methane observed was un-combusted CSG released intentionally or through leaks. Using CSG composition data published previously (Lawson et al., 2017) and taking into account dilution, peak concentrations of other potential components of CSG, such as benzene, toluene and hydrogen sulphide, are expected to be well below the NEPM/Air EPP quality objectives at the measurement sites during the peak methane concentrations observed.

Radiello passive monitoring network - results

Measurements of 54 gases were made via a network of passive Radiello samplers at 10 sampling sites in the study area (Figure 2). VOC Radiello samplers were deployed for 16 months from September 2014 - January 2016 and Radiello aldehyde and hydrogen sulphide passive samplers were deployed for 7 months from June 2015 – January 2016.

The samplers were deployed:

- at or within 2 km of the 3 Gas field ambient air monitoring sites,
- at an additional 4 sites in and around the Gas fields (Nangram, Rockwood, Greenswamp and Miles/Condabri North).
- at the 2 Regional air quality station sites (Burncluith and Tara Region) and
- in the Chinchilla township.

Samplers were exposed for an average of 2 weeks and so give an integrated average 2-weekly concentration.

When considering all sites, of the 54 target gases, 31 were measured above the detection limit in 1 or more of the Radiello samples, and 23 were not measured above the detection limit in any of the samples, including hydrogen sulphide.

Concentrations at Gas field, Regional and Chinchilla sites were compared with air quality objectives including the Air (EPP), the Air Toxics NEPM, and the Texas Commission on Environmental Quality Air Monitoring Comparison Values (Texas AMCV). There were no exceedances of air quality objectives for the 54 target gases. For aldehydes and hydrogen sulphide there was less than one year of data to compare to annual air quality objectives, but given that the concentrations observed, or detection limits were well below air quality objectives it would be reasonable to assume the objective would be met with the availability of a full year of data.

Gases most frequently detected were defined by those present in ≥80% of the samples in any site category (Gas field, Regional and Chinchilla). On this basis the most frequently detected gases were BTX (benzene, toluene and xylenes), carbon tetrachloride, formaldehyde and acetaldehyde. Chinchilla had higher BTX concentrations than the Gas field and Regional sites, and Chinchilla concentrations were similar to a rural town in Victoria (Meyer et al., 2008). The benzene/toluene ratio at Chinchilla was similar to other Australian urban and rural environments, indicating the source of BTX at the Chinchilla site is likely due predominantly to motor vehicles and domestic commercial sources. BTEX concentrations at Gas field and Regional sites were most comparable to an Australian rural/coastal site (Lawson et al., 2015).

Carbon tetrachloride, formaldehyde and acetaldehyde concentrations were similar across Chinchilla, Regional and Gas field sites. The concentrations of carbon tetrachloride measured in

this study are at background levels typical of other parts of Australia (Fraser et al., 2015, AGAGE et al., 2017)) and do not indicate the presence of a local source.

The formaldehyde and acetaldehyde concentrations measured in the Regional, Gas Field and Chinchilla sites in this study are most comparable to an Australian rural/coastal site (Lawson et al., 2015).

While the CSG industry is a known source of several of these gases including BTX, formaldehyde and acetaldehyde (Lawson et al., 2017), levels of VOCs and aldehydes in the study region were well below air quality objectives and were comparable to rural/regional concentrations elsewhere in Australia.

CSIRO undertook independent measurements of VOCs and aldehydes alongside the Radiello Passive measurements made by consultants at Hopeland monitoring station in June-July 2015. CSIRO measurements indicated low levels of VOCs and aldehydes at Hopeland during the method comparison, comparable with concentrations from other rural areas in Australia. Where direct comparison was possible between the different techniques, the CSIRO and Radiello measurements agreed in most cases within 5-15%. Overall this method comparison provides support for the use of the Radiello Passive technique for monitoring VOCs and aldehydes in this study.

Next steps

Data from the ambient air monitoring stations from January 2017 – February 2018 will be reported using a similar approach in a final report in 2018.

In 2017 CSIRO undertook a 6 month particle measurement validation study at the Miles Airport site to ensure the $PM_{2.5}$ and PM_{10} data collected at the Gas field sites is equivalent to data obtained by Australian Standard Methods. These results will be presented and assessed in the final report.

An overall assessment of air quality in the study area from 2014-2018 will be presented at the conclusion of the study.

While the measurements of air quality undertaken for this CSIRO project were scheduled to finish at Regional and Gas field sites at the end of February 2018 there is a likelihood of industry funding to extend air quality monitoring at Regional sites until mid-2018, and at Gas field sites until the end of 2018. This additional monitoring is beyond the scope of CSIRO's work in this study and will not be incorporated into reporting for this project.

Part I Air Quality monitoring stations

1 Introduction

A comprehensive ambient air quality study is being undertaken in the Surat Basin near the townships of Condamine, Miles and Chinchilla in Queensland (Figure 1). 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.

This report provides data from the ambient air quality measurement network.

The purpose of Part 1 of this report is to present and discuss measurements collected via a network of ambient air quality sites. Data from Gas field and Regional sites from February 2015-December 2016 are presented here, with data from 2017 onwards to be presented in a follow up final report.

A detailed overview of the rationale for site selection and pollutant selection is given in Lawson et al. (2017). A brief overview is provided here.

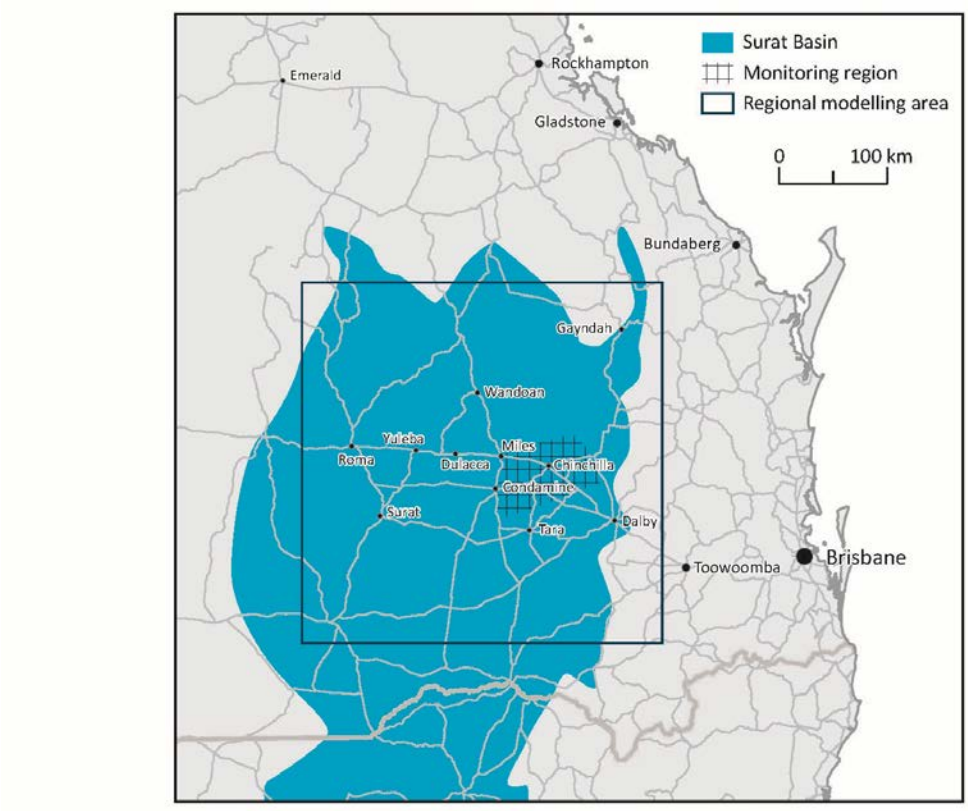

Figure 1 Study area (source: Lawson et al., 2017)

1.1 Location of air 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 Hopeland, Miles Airport and Condamine are located in the Condamine-Miles-Chinchilla area (Figure 2). Measurements started at Hopeland, Miles Airport and Condamine in January 2015, July 2015 and March 2016 respectively. The Gas field stations are located between 1 and 5 km from gas processing facilities (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 (Table 1).

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 and projected CSG operations to predict the future methane concentrations in the Surat Basin. Other factors considered when locating Gas field air quality monitoring stations included a) suitable access, mains power and security b) that emission sources lie in different directions from the site allowing impacts from different sources (CSG-related and other) to potentially be identified, c) to be in the vicinity of homes and townships and d) to comply with Australian Standard requirements for monitoring sites.

The 2 Regional stations, Tara Region/Ironbark (26 km SSE of Condamine township) and Burncluith (20 km NE of Chinchilla) 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 November 2015 and July 2015 respectively, and have been utilised for air quality measurements in this project since June 2016.

1.1.1 Compliance with AS/NZ 2016

The Hopeland, Miles Airport, Burncluith and Tara Region/Ironbark sites comply with Australian Standard siting requirements for monitoring sites (AS/NZ 2016).

The Burncluith site is on a residential property and has a house chimney within 50 m to the south east of the site. This is only expected to influence the data intermittently (at night in winter, and in south easterly or light winds) and would predominantly cause peaks in the CO measurement. The Burncluith site also has trees within 10 m to the north but the air sampling inlet height of 10 m above ground ensures clear sky angle of 120 degrees. This site therefore meets the recommended inlet positioning objective in the Australian Standard.

The Condamine site does not meet all the siting requirements of the standard due to a small tree (approx. 4 m high) 3 m to the south east of the station, since the sampling inlet is approximately 3.5 m above ground. However, wind measurements at Condamine, made via on a 10 m mast some 6 m above the top of the tree, show winds from the SE are infrequent at this site (see A.3.3). As such the tree is not expected to have a large impact on measurements made at this site.

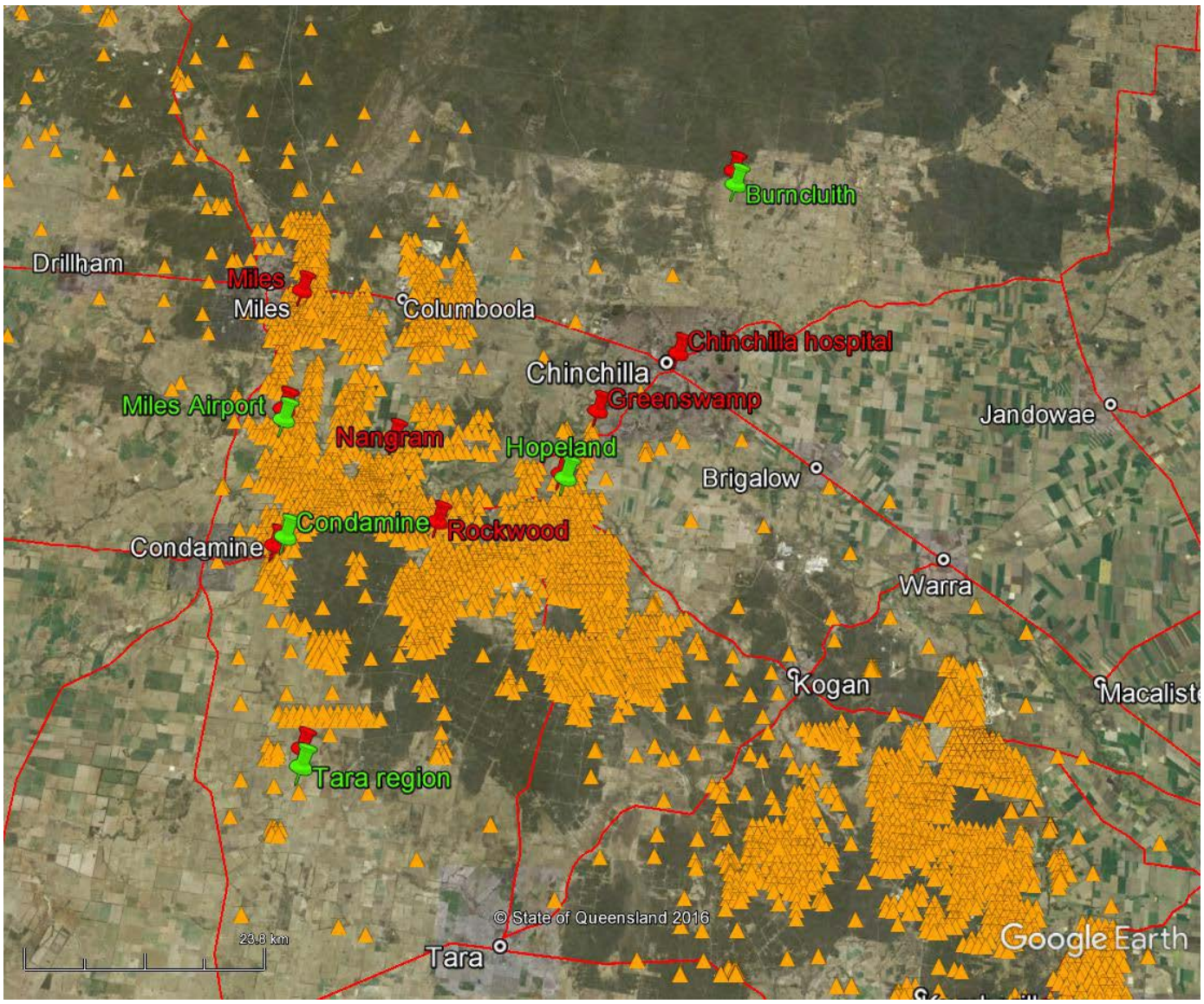

Figure 2 Location of monitoring sites. Town names in white text, green pins are ambient air monitoring sites, red pins are passive gas sites (see Part 2 of report), orange triangles are CSG wells. Source: Lawson et al., (2017).

Table 1 Summary of ambient air quality station locations, nearby emission sources and proximity and status of nearby wells.

Station name	Date AQ measurements commenced	Location of station	Emission sources < 5 km	Gas wells drilled within 2 km radius at time measurements commenced	Gas wells drilled within 2 km radius as of March 2016
Hopeland	January 2015	Gas fields	Orana GPF (< 5 km SE) Nearest well 100 m	1 (0 commissioned)[1]	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	March 2016	Gas fields	Condabri South GPF (1 km SE) Condamine township (8 km E) Nearest well 230 m	25 (23 commissioned)	25 (24 commissioned)
Tara Region (Ironbark)	June 2016	Regional	Nearest well 1 km	1 (plugged and abandoned)	1 (plugged and abandoned)
Burncluith	June 2016	Regional	Dwelling	0	0

[1]Commissioned refers to operational wells

1.2 Pollutants measured

A review of the current state of knowledge was undertaken (Lawson et al., 2017) 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 Environmental Impact Statements, National Pollutant Inventory 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 (Lawson et al., 2017).

The following parameters were selected for measurement in this study (see also Table 2)

• Gas field ambient air quality stations– nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), Particles < 2.5 µm and < 10 µm ($PM_{2.5}$ and PM_{10}), 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 carbon dioxide, carbon monoxide (Burncluith) and meteorology are being provided for use in this study by the GISERA Regional Methane Flux project (Day et al., 2015, Etheridge et al., 2017). There are no particle measurements at Regional sites due to budget constraints.

A summary of measurement technique and analytical methods is presented in A.1.

Four of the 6 objective 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 $PM_{2.5}$, PM_{10}). 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. For pollutant selection criteria see Lawson et al., (2017).

A brief description of the CSG industry-related sources of the pollutants measured is provided in Table 2 below.

Table 2 Air Measurements selected for Gas field and Regional stations. Source: Study Design Report, Lawson et al., 2017

Pollutant/parameter	Gas fields stations	Regional stations	CSG industry-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 < 2.5 µm and < 10 µm ($PM_{2.5}$ and PM_{10})	Yes	No	gas fired engines, gas flaring, diesel exhaust associated with transport, drilling, generators, dust associated with vehicles, maintenance and construction activities
Methane (CH_4)	Yes	Yes*	Major component of CSG (venting/fugitive emissions)
Total VOCs	Yes	No	gas fired engines, gas flaring, diesel and petrol vehicles, CSG venting/fugitive emissions
Carbon dioxide (CO_2)	Yes	Yes*	Source tracer (combustion and biological processes)
Meteorology (solar radiation, wind speed, wind direction, rainfall, temperature, humidity)	Yes	Yes*	Assists in determination of sources and ventilation of airshed

^measurement made at Burncluith as part of GISERA Regional Methane fluxes project and made available for use in this project

* measurements made at Tara Region (Ironbark) and Burncluith sites as part of GISERA Regional Methane Fluxe project. Methane data from Regional sites will be reported as part of the GISERA Regional Methane Flux Project (Etheridge et al 2017, Day et al 2015)

Carbon monoxide

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. CO is also emitted from many other sources of combustion including bushfires, other industry (for example power plants), and motor vehicles.

Nitrogen dioxide

Nitrogen dioxide (NO_2) is a gas produced mainly from fuel combustion, including combustion of diesel, biomass, gas, and coal, as well as from natural processes. Nitrogen oxides (NO_x) are a key pollutant identified in CSG industry EIS (QGC 2010, APLNG 2010). CSG related sources include combustion of gas via flaring and gas combustion engines and diesel engine emissions.

Ozone

Ground level ozone is a secondary pollutant, meaning that it is not directly emitted to the atmosphere but rather is formed through reactions in the atmosphere. Ozone formation requires the presence of precursors VOCs, and nitrogen oxides, and sunlight.

PM2.5, PM10 and TSP

The mass concentration of particles <2.5 µm in size ($PM_{2.5}$) and the mass of particles <10 µm in size (PM_{10}) 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 of particles include diesel exhaust, combustion and dust emissions, relating mostly to construction activities, along with gas fired boilers, engines and flares. Other sources of particles in the study area include agricultural sources and fires. $PM_{2.5}$ the smallest size fraction measured in this study is emitted mainly from combustion and secondary formation. The larger size fraction, PM_{10} includes particles from all the $PM_{2.5}$ sources but also from other non-combustion sources including wind-blown dust. TSP, the largest size fraction includes all $PM_{2.5}$ and PM_{10} particles, and includes larger particles such as those from earthworks and construction.

Methane

Methane is an odourless gas that typically makes up 96-98% of CSG composition in the study region (Lawson et al., 2017). Emissions of CSG may occur from several sources including from wells, pipelines, gathering networks, separators, processing facilities and storage facilities and from ground and river seeps not necessarily related to the CSG production industry. CSG emissions occur both via intentional release (for example pneumatically driven gas and water separators on well heads) and unintentional release for example via leaks.

Methane is considered non-toxic and only poses a risk to human health when at very high concentrations where it can act as an asphyxiant or explosive hazard. Consequently, there are no ambient air quality objectives for methane. Methane was included in this study as a tracer for other components of CSG which do have air quality objectives such as air toxics present in trace quantities in CSG. In addition to CSG, methane is also emitted from other sources such as livestock, combustion and coal mines.

The methane data from the Regional sites (Burncluith and Tara Region/Ironbark) are being collected as part of the GISERA Regional Methane Flux project (Day et al., 2015; Etheridge et al., 2017), and data are reported as part of that project. Determination of the Regional emissions of methane in the study area is being addressed as part of the GISERA Regional Methane flux project (see https://gisera.csiro.au/project/methane-seepage-in-the-surat-basin/).

Total volatile organic compounds (TVOC)

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 (see A.1) provides an

approximation for the sum of all individual VOCs present. In the study region, CSG-related emissions of VOCs include fuel and gas combustion, and some VOCs such as ethane and propane are present in small quantities in CSG and so are likely to be associated with leaking and venting of CSG (Lawson et al., 2017). Other sources of VOCs in the study area include vegetation and soils, vegetation fires, agriculture and domestic commercial sources.

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.

In addition to the TVOC measurement at the Gas field sites, a network of passive VOC samples was deployed over the study area which provided fortnightly integrated measurements of individual VOCs (see Section 6).

1.3 Role of measurement service providers and CSIRO/QA QC – data management

The instruments used to measure air quality at the 5 ambient air quality stations are operated by Ecotech Pty Ltd (see A.1 for instrument details). Ecotech is a NATA-accredited laboratory which means it meets all objective 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 validated data used in this report has been approved by CSIRO. Data that was removed due to issues with instrument performance or other issues are not presented in this report. The reasons for removal of data for each measurement and each site are provided in the footnotes of the data summary tables for each pollutant and more details can be found in A.4.1.

Data availability (%) reported in Tables 6-11 and 13-22 are based on the proportion of the total month that validated data was captured. Data statistics (including average and maximum concentrations) are only reported in the monthly statistics tables for each pollutant when the monthly data availability exceeded 75%, as per NEPM technical paper no. 5 (PRC 2001). All valid data (even for months where data availability was below 75%) are included in the time series plots (Figure 3 - Figure 10).

Some data which has been used in this report does not comply with Australian Standard measurement methods. This indicative data has been assessed as being of acceptable quality for

use in this report using instrument checks, calibrations, and comparing data obtained with other co-located or nearby instruments (see A.4.2 for more details).

1.4 Live data streaming

Since 25th August 2016, preliminary air quality data from the ambient air quality sites has been streamed to the Department of Environment and Heritage Protection website under South West Queensland region https://www.ehp.qld.gov.au/air/data/search.php. At the time of streaming, data has not undergone data validation procedures (see above). Data streamed includes carbon monoxide, nitrogen dioxide, ozone and $PM_{2.5}$, PM_{10} and TSP (Hopeland, Miles Airport, Condamine) and carbon monoxide, nitrogen dioxide, ozone (Burncluith and Tara Region). These pollutants have been selected for live streaming because there are air quality objectives associated with each pollutant (Air NEPM), providing context for the reported concentrations. Data is displayed both as measured concentration values and as an 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 (see Table 3). This live data streaming allows comparison of the air quality in the SW region with other parts of Queensland.

1.5 Data included in Part 1 of this report

Data from Gas field and Regional ambient air monitoring sites from February 2015-December 2016 are presented in this report, with data from January 2017 – February 2018 to be presented in a follow up final report in 2018.

Section 2 of this report presents air quality objective and assesses concentrations of carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10} and TSP against the relevant objectives (NEPM, Air EPP). Statistics and time series plots are presented for each pollutant.

A.6 provides plots of daily concentrations for each site for carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10} and TSP.

Section 3 of this report presents statistics and time series plots of methane and total volatile organic compounds (TVOCs) from the 3 Gas field sites.

Section 4 of this report presents an investigation of pollution events. The protocol for identifying and investigating events involving carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10}, TSP and methane is presented. Events are summarised and the potential source(s) investigated according to the protocol, and 3 case studies of events are presented.

1.6 References

AS/NZS 3580.1.1:2016 “Methods for sampling and analysis of ambient air – guide to siting air monitoring equipment”

Stuart Day, Cindy Ong, Andrew Rodger, David Etheridge, Mark Hibberd, Eva van Gorsel, Darren Spencer, Paul Krummel, Robyn Fry, Mark Dell’Amico, Stephen Sestak, David Williams, Zoë Loh and Damian Barrett (2015) Characterisation of regional fluxes of methane in the Surat Basin, Queensland: Phase 2: A pilot study of methodology to detect and quantify methane sources. CSIRO, Australia. https://gisera.csiro.au/project/methane-seepage-in-the-surat-basin/

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2 Data summary: Carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10} and TSP measurements– Gas field and Regional sites

The purpose of this section is to

- Present air quality objective used for assessing pollutant concentrations
- Compare pollutant concentrations with air quality objective, and document any exceedances
- Present statistics and time series plots of each pollutant

Data from Gas field and Regional sites from February 2015-December 2016 are presented. An analysis of the likely source of each exceedance is presented in Section 4

2.1 Compliance with air quality objective

The air quality objective used to assess the pollutant concentrations are presented in Table 3. Air quality objectives for carbon monoxide, ozone, nitrogen dioxide, $PM_{2.5}$ and PM_{10} are all based on the values from the Air EPP (2008) and the NEPM (2016). In the absence of a relevant Australian objectives the air quality objective for TSP is based on the New Zealand Ministry for the Environment's nuisance trigger level for high sensitivity areas (MFE 2016), and the use of this objective is recommended by Queensland's DEHP.

Table 3 Air quality objectives used to assess concentrations in this report.

Air pollutant	Averaging Period	Objective
Carbon monoxide	8-hour	9 ppm (not to be exceeded on more than one day per year)[a,b]
Ozone	4-hour	0.08 ppm (one day per year)[a,b]
	1-hour	0.10 ppm (one day per year)[a,b]
Nitrogen dioxide	Annual	0.03 ppm[a,b]
	1-hour	0.12 ppm (one day per year)[a,b]
PM_{10}	Annual	25 µg m^{-3} [a]
	24-hour	50 µg m^{-3} [a,b]
$PM_{2.5}$	Annual	8 µg m^{-3} [a,b]
	24-hour	25 µg m^{-3} [a,b]
TSP	Annual	90 µg m^{-3} [b]
	24-hour	60 µg m^{-3} (high sensitivity environment) [c]

[a] NEPM (2016)
[b] Air EPP (air) (2008) Queensland
[c] DEHP TSP guidelines based on MFE (2016)

Table 4 shows the number of exceedances for of the relevant carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$ and PM_{10} objective for the time period covered in this report (2015 -2016). There were no exceedances for carbon monoxide, nitrogen dioxide or ozone at any sites. There were PM_{10} exceedances at 2 of the Gas field sites (Hopeland and Miles Airport) and $PM_{2.5}$ exceedances at all 3 gas field sites (Hopeland, Miles Airport and Condamine). Note that PM_{10} and $PM_{2.5}$ were not measured at the Regional sites. Table 5 shows the number of times 24-hour TSP concentrations exceeded the air quality guideline for 2015-2016, the period covered by this report.

Table 4 Number of exceedances of Air EPP objectives and NEPM objectives for carbon monoxide, nitrogen dioxide, ozone, PM_{10} and $PM_{2.5}$ for the period covered in this report, 2015-2016

Air pollutant	Averaging Period	Exceedances				
		Hopeland	Miles Airport	Condamine	Burncluith	Tara Region
Carbon monoxide	8-hour	0	0	0	0	0
Nitrogen dioxide	Annual	0	0	0	0	0
	1-hour	0	0	0	0	0
Ozone	4-hour	0	0	0	0	0
	1-hour	0	0	0	0	0
PM_{10}	Annual	0	0	0	nm	nm
	24-hour	1	1	0	nm	nm
$PM_{2.5}$	Annual	0	0	0	nm	nm
	24-hour	3	2	1	nm	nm

nm = not measured

Table 5 Number of times 24 hour TSP concentrations exceeded the DEHP- recommended air quality guideline for 2015-2016, the period covered by this report.

Air pollutant	Averaging Period	Above objectives				
		Hopeland	Miles Airport	Condamine	Burncluith	Tara Region
TSP	Annual	0	0	0	nm	nm
	24-hour	1	5	2	nm	nm

nm = not measured

2.2 Summary of measured ambient concentrations

2.2.1 Carbon monoxide

The NEPM/EPP 8-hour air quality objective for carbon monoxide is 9 ppm. There were no exceedances of the Air EPP/NEPM (air) 8-hour average air quality objective for carbon monoxide at any of the sites in this study for 2015 or 2016. A time series showing the maximum 8-hour concentration of carbon monoxide at the three Gas field and 2 Regional sites is shown in Figure 3. All values are well below the air quality objectives.

Gas field and Regional statistics of the carbon monoxide concentrations for each month from 2015 and 2016 are shown in Table 6 and Table 7, including the maximum 8 hour, average 8 hour and average 1 hour value for each month. Note that the 1 hour average values do not have a relevant air quality objectives for comparison and are provided for information. Carbon monoxide measurements did not begin at Condamine and Tara Region sites until 2016. Carbon monoxide measurements from Burncluith are made as part of the GISERA Regional Methane Flux project (Etheridge et al., 2017, Day et al., 2015) and data has been provided for use in this project.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

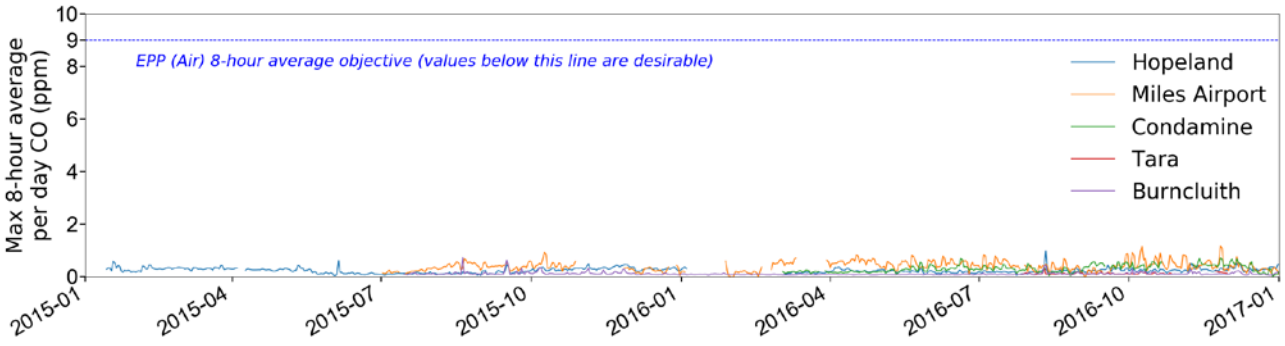

Figure 3 Daily maximum 8 hour averages for carbon monoxide for all 5 sites

Table 6 Ambient concentrations of carbon monoxide. Monthly maximum and average 8-hour concentrations and monthly 1-hour average concentration for all sites for 2015 (ppm).

CO - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 8-hour	0.6	0.4	0.4	0.3	0.4	0.6	0.2	0.2	0.4	0.4	0.5	0.4
Average 8-hour	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2
Average 1-hour	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2
% Data Avail	83	94	94	78	95	94	93	95	96	92	94	94
Miles Airport												
Max 8-hour							0.3	0.7	0.6	0.9	-	-
Average 8-hour							0.1	0.3	0.3	0.3	-	-
Average 1-hour							0.1	0.3	0.3	0.3	-	-
% Data Avail							77	94	95	84	11[a,b]	74[a,b]
Condamine												
No data												
Burncluith												
Max 8-hour							-	0.7	0.6	0.3	0.3	0.1
Average 8-hour							-	0.1	0.1	0.1	0.1	0.1
Average 1-hour							-	0.1	0.1	0.1	0.1	0.1
% Data Avail							52[c]	97	98	98	99	99
Tara Region												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 7 Ambient concentrations of carbon monoxide. Monthly maximum and average 8-hour concentrations and monthly 1-hour average concentration for all sites for 2016 (ppm).

CO - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 8-hour	-	-	0.2	0.4	0.3	0.2	0.2	1	0.4	0.3	0.5	0.5
Average 8-hour	-	-	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Average 1-hour	-	-	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.3
% Data Avail	10[d]	0[d]	86	96	95	96	95	96	94	96	94	94
Miles Airport												
Max 8-hour	-	-	-	0.8	0.8	0.8	0.8	0.7	0.9	1.1	1.2	0.7
Average 8-hour	-	-	-	0.5	0.3	0.3	0.3	0.2	0.1	0.4	0.3	0.2
Average 1-hour	-	-	-	0.5	0.3	0.3	0.3	0.2	0.1	0.4	0.3	0.2
% Data Avail	16[a,d]	74[d,b]	35[a,d]	93	91	93	83	92	92	90	89	95
Condamine												
Max 8-hour			-	0.2	0.5	0.7	0.5	0.4	0.5	-	-	0.7
Average 8-hour			-	0.1	0.2	0.2	0.2	0.1	0.3	-	-	0.2
Average 1-hour			-	0.1	0.2	0.2	0.2	0.1	0.3	-	-	0.2
% Data Avail			73[c]	93	95	96	96	95	86	51[b]	66[b]	96
Burncluith												
Max 8-hour	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.3	0.3	0.2
Average 8-hour	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Average 1-hour	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
% Data Avail	100	99	100	99	94	99	100	98	100	95	100	100
Tara Region												
Max 8-hour							-	0.3	0.2	0.2	-	-
Average 8-hour							-	0.1	0.1	0.1	-	-
Average 1-hour							-	0.1	0.1	0.1	-	-
% Data Avail							13[b]	89	84	78	18[a,b]	0[a]

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.2.2 Nitrogen dioxide

The Air EPP/NEPM (air) 1-hour air quality objective for nitrogen dioxide is 120 ppb (0.120 ppm)and the annual objective is 30 ppb (0.03 ppm). There were no exceedances of the annual and 1-hour average air quality objectives for nitrogen dioxide at any of the sites in this study during 2015 or 2016. All values are well below the air quality objectives.

A time series showing the maximum 1-hour concentration of nitrogen dioxide at the three Gas field and 2 Regional sites is shown in Figure 4. Statistics of the nitrogen dioxide concentrations for each month from 2015 and 2016 are shown in Table 8 and Table 9, including the maximum 1-hour and average 1-hour concentration for each month, as well as annual average. Nitrogen dioxide measurements did not begin at Condamine, Tara Region or Burncluith until 2016.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

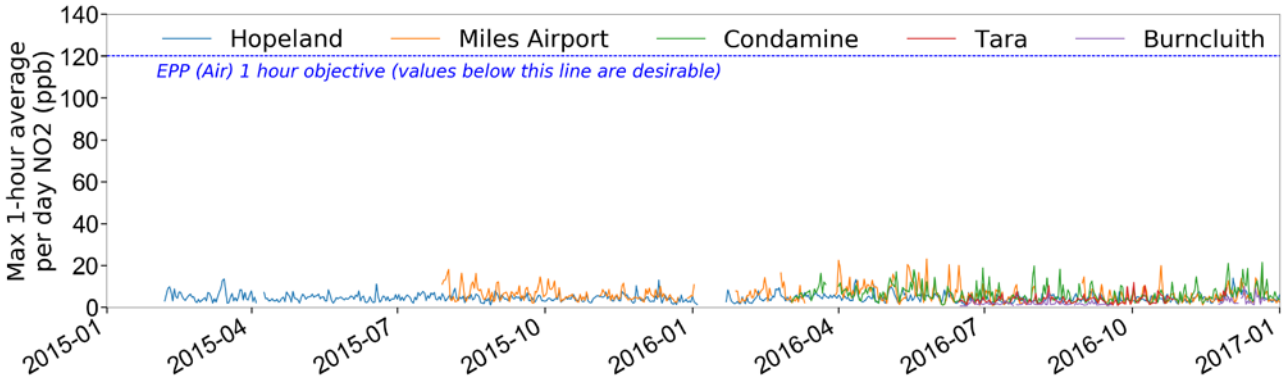

Figure 4 Daily maximum 1 hour concentration of nitrogen dioxide for all sites. Note that concentrations in this figure are in parts per billion (ppb) (where 1 ppb = 0.001 ppm)

Table 8 Ambient concentrations of nitrogen dioxide. Annual average and monthly maximum and average 1-hour concentrations (ppm) for all sites for 2015.

NO_2 - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 1-hour	-	0.01	0.014	0.008	0.008	0.011	0.008	0.009	0.007	0.008	0.01	0.013
Average 1-hour	-	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002
% Data Avail	0[b]	76	95	78	95	96	95	96	96	93	94	95
Annual Average	0.002											
Miles Airport												
Max 1-hour							-	0.018	0.015	0.014	0.012	-
Average 1-hour							-	0.004	0.004	0.003	0.003	-
% Data Avail							7[e]	95	96	85	81	74[a,b]
Annual Average												
Condamine												
No data												
Burncluith												
No data												
Tara Region												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 9 Ambient concentrations of nitrogen dioxide. Annual average and monthly maximum and average 1-hour concentrations (ppm) for all sites for 2016

NO_2 - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 1-hour	-	0.009	0.007	0.013	0.01	0.009	0.009	0.006	0.007	0.006	0.009	0.017
Average 1-hour	-	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.003
% Data Avail	41[d]	92	95	96	95	96	96	95	95	96	95	95
Annual Average	0.002											
Miles Airport												
Max 1-hour	-	-	-	0.022	0.023	0.02	0.011	-	0.015	0.02	0.013	0.018
Average 1-hour	-	-	-	0.002	0.003	0.002	0.002	-	0.002	0.002	0.002	0.002
% Data Avail	16[a,b]	74[d,e]	35[a,d]	93	95	96	90	5[b]	95	95	91	96
Annual Average	0.002											
Condamine												
Max 1-hour			-	0.012	0.018	0.019	0.015	0.02	0.012	0.012	0.021	0.021
Average 1-hour			-	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.003
% Data Avail			67[b]	93	96	96	96	95	94	96	94	96
Annual Average	0.002											
Burncluith												
Max 1-hour						-	0.004	0.007	-	-	-	-
Average 1-hour						-	0.001	0.001	-	-	-	-
% Data Avail						44[c]	87	87	53[a,b]	0[a,b]	20[a,b]	61[f]
Annual Average												
Tara Region												
Max 1-hour						-	0.007	0.01	0.01	0.012	-	-
Average 1-hour						-	0.002	0.002	0.002	0.002	-	-
% Data Avail						45[c]	87	89	87	78	19[a,b]	0[a]
Annual Average												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.2.3 Ozone

The Air EPP/NEPM (air) 1-hour and 4- hour air quality objectives for ozone are 100 ppb (0.1 ppm) and 80 ppb (0.08 ppm) respectively. There were no exceedances of the 1-hour and 4-hour average air quality objectives for ozone at any of the sites in this study during 2015 or 2016.

Time series showing the maximum 4-hour and maximum 1-hour concentration of ozone at the three Gas field and 2 Regional sites is shown in Figure 5 and Figure 6. Statistics of the ozone concentrations for each month from 2015 and 2016 are shown in Table 10 and Table 11, including the maximum and average 1-hour and maximum and average 4-hour concentration for each month.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

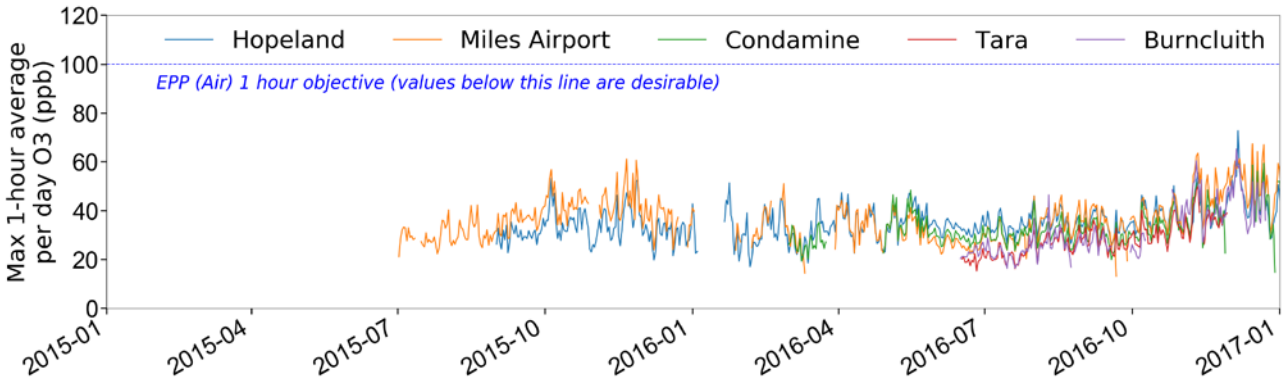

Figure 5 Daily maximum 4-hour concentrations of ozone for all sites. Note that concentrations in this figure are in parts per billion (ppb) (where 1 ppb = 0.001 ppm)

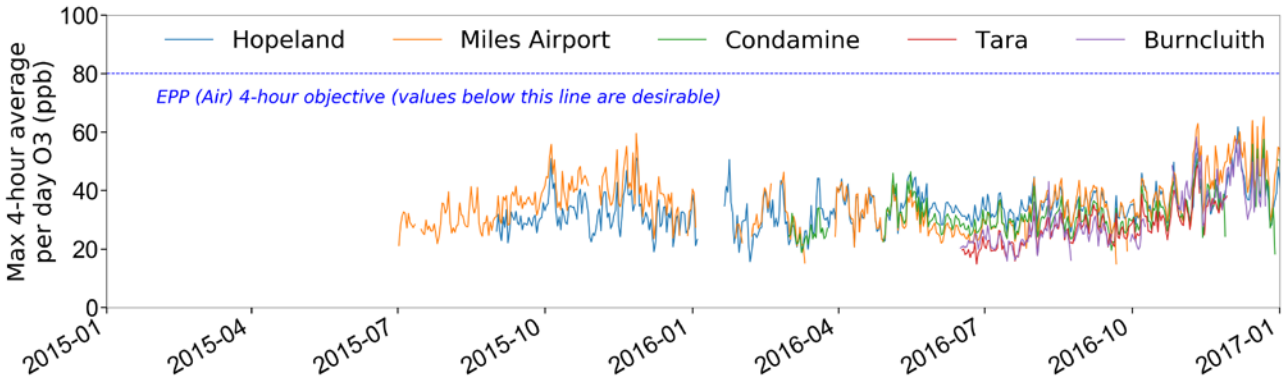

Figure 6 Daily maximum 1 hour average concentration of ozone for all sites. Note that concentrations in this figure are in parts per billion (ppb) (where 1 ppb = 0.001 ppm)

Table 10 Ambient concentrations of ozone. Monthly maximum and average 4-hour and 1-hour concentrations (ppm) at all sites for 2015.

O_3 - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 4-hour									0.036	0.051	0.051	0.037
Max 1-hour									0.037	0.053	0.052	0.037
Average 4-hour									0.02	0.024	0.024	0.02
Average 1-hour									0.02	0.024	0.024	0.02
% Data Avail									100	95	96	94
Miles Airport												
Max 4-hour							0.036	0.041	0.041	0.056	0.059	0.045
Max 1-hour							0.036	0.042	0.043	0.057	0.061	0.046
Average 4-hour							0.02	0.022	0.026	0.032	0.032	0.025
Average 1-hour							0.02	0.023	0.026	0.033	0.032	0.025
% Data Avail							78	95	94	84	81	77
Condamine												
No data												
Burncluith												
No data												
Tara Region												
No data												

Table 11 Ambient concentrations of ozone. Monthly maximum and average 4-hour and 1-hour concentrations (ppm) at all sites for 2016.

O_3 - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 4-hour	-	0.043	0.044	0.044	0.046	0.038	0.041	0.045	0.04	0.05	0.054	0.062
Max 1-hour	-	0.045	0.045	0.047	0.047	0.038	0.041	0.046	0.042	0.05	0.056	0.073
Average 4-hour	-	0.019	0.019	0.022	0.024	0.025	0.024	0.025	0.025	0.027	0.028	0.03
Average 1-hour	-	0.02	0.019	0.023	0.024	0.025	0.024	0.025	0.025	0.027	0.028	0.031
% Data Avail	42[d,f]	90	95	96	98	94	94	94	93	94	93	94
Miles Airport												
Max 4-hour	-	-	-	0.043	0.042	0.03	0.036	0.044	0.042	0.046	0.063	0.065
Max 1-hour	-	-	-	0.044	0.043	0.03	0.036	0.046	0.044	0.047	0.064	0.067
Average 4-hour	-	-	-	0.024	0.022	0.019	0.021	0.027	0.027	0.028	0.034	0.035
Average 1-hour	-	-	-	0.024	0.022	0.019	0.022	0.027	0.027	0.028	0.034	0.036
% Data Avail	16[a,b]	56[b,d]	35[a,d]	93	95	96	90	94	82	93	93	95
Condamine												
Max 4-hour			-	-	0.046	0.033	0.037	0.041	0.036	0.043	0.051	-
Max 1-hour			-	-	0.048	0.034	0.037	0.044	0.037	0.044	0.052	-
Average 4-hour			-	-	0.02	0.02	0.019	0.02	0.02	0.022	0.026	-
Average 1-hour			-	-	0.021	0.02	0.019	0.021	0.02	0.022	0.026	-
% Data Avail			72[b]	5[b]	95	96	96	95	94	96	86	44[b]
Burncluith												
Max 4-hour						-	0.029	0.043	-	-	0.058	-
Max 1-hour						-	0.03	0.046	-	-	0.060	-
Average 4-hour						-	0.016	0.019	-	-	0.029	-
Average 1-hour						-	0.016	0.019	-	-	0.030	-
% Data Avail						44[c]	91	86	56[a,b]	41[f]	90	67[f]
Tara Region												
Max 4-hour						-	0.028	0.033	0.035	0.04	0.049	-
Max 1-hour						-	0.029	0.034	0.036	0.04	0.05	-
Average 4-hour						-	0.014	0.019	0.02	0.021	0.026	-
Average 1-hour						-	0.015	0.019	0.02	0.021	0.026	-
% Data Avail						42[c]	90	89	86	91	82	0[a]

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.3 Particles ($PM_{2.5}$, PM_{10}, TSP)

There were 6 exceedances of the 24-hour air quality objective for $PM_{2.5}$, 2 exceedances of the air quality objective for PM_{10} and 8 exceedances of the 24-hour TSP nuisance dust guideline (MFE 2016) observed at the Gas fields sites from 2015-16 (Table 4). Annual air quality objectives were not exceeded. Particle measurements were made at the three Gas field sites (Hopeland, Miles Airport and Condamine) but were not made at the two regional sites (Burncluith and Tara Region) due to budget constraints.

In the following section, the observed $PM_{2.5}$, PM_{10} and TSP concentrations are compared with ambient air quality objectives, and the number of exceedances is reported. Table 12 shows the 24-hour exceedance values for PM_{10}, $PM_{2.5}$ and TSP according to site. In Section 4, the results of investigations into the circumstances that led to any exceedances will be presented.

Time series of 24-h average concentrations, and summary statistics for the years 2015 -2016 for PM_{10}, $PM_{2.5}$ and TSP are presented in Sections in 2.3.1 – 2.3.3 below.

Table 12 Exceedances for PM (values are 24 hour average in µg m^{-3}).

	PM_{10} Air EPP/NEPM 24h objective is 50 µg m^{-3}			**$PM_{2.5}$ Air EPP/NEPM 24h objective is 25 µg m^{-3}**			**TSP MFE 24h objective is 60 µg m^{-3}**		
Date	**Hopeland**	**Miles Airport**	**Condamine**	**Hopeland**	**Miles Airport**	**Condamine**	**Hopeland**	**Miles Airport**	**Condamine**
7/10/15		67.1						120.9	
5/11/15				27.3	29.6				
2/5/16									68.0
11/8/16	59			55.8			61		
15/10/16								62.1	
7/11/16								93.7	
23/11/16								73.2	
2/12/16								60.1	
6/12/16				35.9	25.7	28.1			66.5

2.3.1 PM_{10}

A plot of daily 24 hour average PM_{10} concentrations is shown in Figure 7 for the 3 Gas field sites with the Air (EPP) (2008) 24-hour air quality objective shown. Concentrations are generally well below the air quality objectives. Table 13 and Table 14 show summary statistics of maximum 24-hour and average 1-hour PM_{10} concentrations for each month for 2015 and 2016, as well as the annual averages. Particle (PM_{10}, $PM_{2.5}$ and TSP) monitoring did not begin at Condamine until 2016. Note that the 1-hour average values do not have a relevant air quality objectives for comparison and are provided for information.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

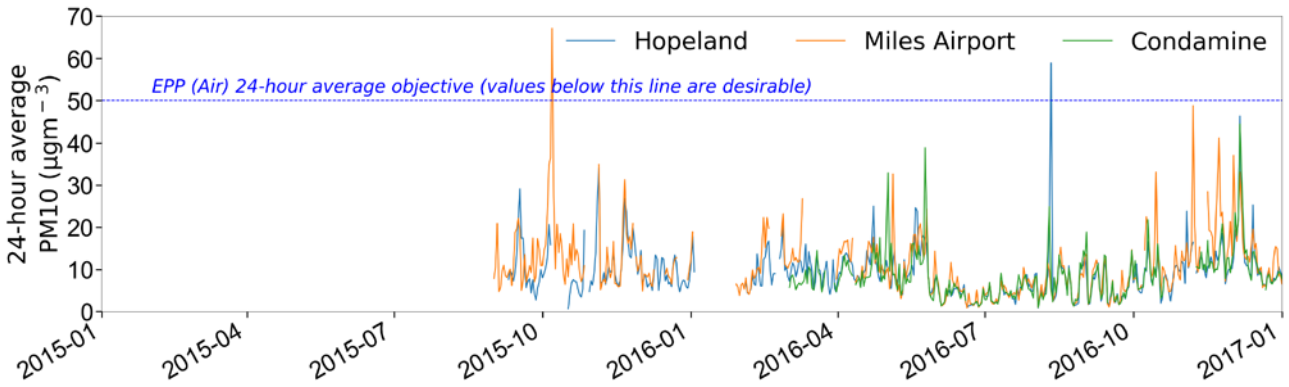

Figure 7 24 hour average PM_{10} concentrations from Gas field sites

Table 13 Ambient concentrations of PM_{10}. Monthly maximum 24-hour average and monthly average 1-hour average concentrations (µg m^{-3}) at all sites for 2015.

PM_{10} - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour									-	-	34.1	14.5
Average 1-hour									-	-	13	8.3
% Data Avail									70[c]	67[b]	98	99
Miles Airport												
Max 24-hour									22.1	67.1	34.8	-
Average 1-hour									11.4	17.1	13.6	-
% Data Avail									100	89	86	63[a,b]
Condamine												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 14 Ambient concentrations of PM_{10}. Monthly maximum 24-hour average, monthly average 1-hour average and annual average concentrations (µg m^{-3}) at all sites for 2016

PM_{10} - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour	-	20.9	16	25	24.6	8.7	8.8	59	14.1	16.6	23.8	46.3
Average 1-hour	-	10	9.3	10.9	10.8	3.5	4.6	8.4	5.8	8.3	12.3	12.7
% Data Avail	12[d,f]	84	99	100	100	100	100	100	100	100	99	99
Annual Average	8.8											
Miles Airport												
Max 24-hour	-	23.2	-	17.6	32.6	11.7	10.5	15.2	14.6	33.1	48.8	37
Average 1-hour	-	12.1	-	12.4	12	4.4	5	6.7	6.9	10.7	18.9	14.2
% Data Avail	17[a,b]	82	37[a,d]	98	100	100	100	100	100	99	89	100
Annual Average	10.3											
Condamine												
Max 24-hour			14.5	17.5	38.8	8.7	9.1	24.8	18.9	-	-	44.4
Average 1-hour			7.8	9.6	11.6	3.9	4.7	7.3	6.4	-	-	13.1
% Data Avail			84	98	100	93	100	100	98	66[b]	74[b]	98
Annual Average	8.5											

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.3.2 $PM_{2.5}$

A plot of daily 24-hour average $PM_{2.5}$ concentrations is shown in Figure 8 for the 3 Gas field sites with the Air (EPP) (2008) 24-hour air quality objective shown. Concentrations are generally well below the air quality objectives. Table 15 and Table 16 show summary statistics of maximum 24-hour and average 1 hour $PM_{2.5}$ concentrations for each month for 2015 and 2016, as well as the annual averages. Particle (PM_{10}, $PM_{2.5}$ and TSP) monitoring did not begin at Condamine until 2016. Note that the 1-hour average values do not have a relevant air quality objective for comparison and are provided for information.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

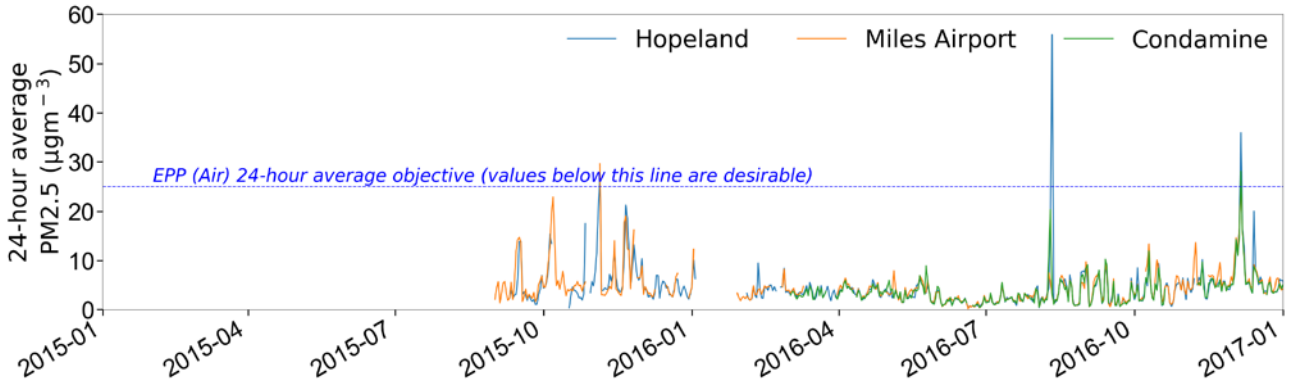

Figure 8 Daily 24 hour average $PM_{2.5}$ concentrations from Gas field sites

Table 15 Ambient concentrations of $PM_{2.5}$. Monthly maximum 24-hour average and monthly average 1-hour average concentrations (µg m^{-3}) at all sites for 2015

$PM_{2.5}$ - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour									-	-	27.3	10.4
Average 1-hour									-	-	8.9	4.1
% Data Avail									70[c]	67[b]	98	99
Miles Airport												
Max 24-hour									14.7	22.9	29.6	-
Average 1-hour									4.9	6.9	8.3	-
% Data Avail									100	89	86	63[a,b]
Condamine												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 16 Ambient concentrations of $PM_{2.5}$. Monthly maximum 24-hour average, monthly average 1-hour average and annual average concentrations (µg m^{-3}) at all sites for 2016

$PM_{2.5}$ - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour	-	9.5	5.6	6	6.1	4.1	4.7	55.8	9.2	9.7	10.2	35.9
Average 1-hour	-	4.1	3.4	3.9	3.3	1.5	2.2	5.7	3.4	4.1	5.2	8
% Data Avail	12[d,f]	84	99	100	100	100	100	100	100	100	99	99
Annual Average	4.1											
Miles Airport												
Max 24-hour	-	8.3	-	6.4	7.9	3.5	5.1	7.5	9.7	13.3	13.6	25.7
Average 1-hour	-	3.9	-	4.1	3.7	1.6	2.3	3.5	3.6	4.7	6.1	7.5
% Data Avail	17[a,b]	82	37[a,d]	98	100	100	100	100	100	99	89	100
Annual Average	4.1											
Condamine												
Max 24-hour			4.8	5.9	8.9	4.8	5.6	20.4	10.3	-	-	28.1
Average 1-hour			3.2	3.7	3.6	1.7	2.2	4	3.5	-	-	7.1
% Data Avail			84	98	100	93	100	100	98	66[b]	74[b]	98
Annual Average	3.8											

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.3.3 TSP

A plot of daily 24-hour average TSP concentrations is shown in Figure 9 for the 3 Gas field sites with the DEHP 24-hour nuisance dust guideline shown. Table 17 and Table 18 show summary statistics of max 24 hour and average 1 hour TSP concentrations for each month for 2015 and 2016, as well as the annual averages. Particle (PM_{10}, $PM_{2.5}$ and TSP) monitoring did not begin at Condamine until 2016. Note that the 1 hour average values do not have a relevant air quality objectives for comparison and are provided for information.

Where data availability was <75% for a month, the specific reason is provided in the footnote of the table. More details on reasons for low data availability is provided in A.4.

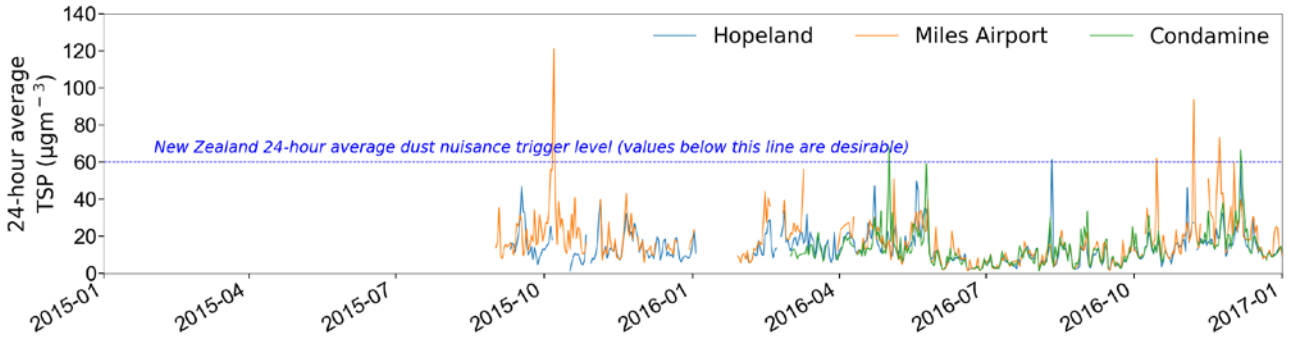

Figure 9 Daily 24 hour average TSP concentrations from Gas field sites

Table 17 Ambient concentrations of TSP. Monthly maximum 24-hour average and monthly average 1-hr average concentrations (µg m^{-3}) at all Gas field sites for 2015

TSP - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour									-	-	39.5	19.7
Average 1-hour									-	-	16.8	11.5
% Data Avail									70[c]	67[b]	98	99
Miles Airport												
Max 24-hour									35.4	120.9	43.0	-
Average 1-hour									18.7	28.4	18.9	-
% Data Avail									100	89	83	63[a,b]
Condamine												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 18 Ambient concentrations of TSP. Monthly maximum 24-hour average, monthly average 1-hr average and annual average concentrations (µg m^{-3}) at all Gas field sites for 2016

TSP - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 24-hour	-	34	32	47.2	49.6	13.1	14.5	61.3	24	22.1	46.1	58.1
Average 1-hour	-	15.7	15.3	17.7	18.9	5.4	6.8	10.8	8.3	12.3	19.5	16.6
% Data Avail	12[d,f]	84	99	100	100	100	100	100	100	100	99	99
Annual Average	13.4											
Miles Airport												
Max 24-hour	-	44.3	-	30.4	50.9	22.7	17	23.1	24.8	62.1	93.7	60.1
Average 1-hour	-	20.8	-	20.5	19.5	7	7.4	10	10.3	16.7	32.6	20.6
% Data Avail	17[a,b]	82	37[a,d]	98	100	100	100	100	100	99	89	100
Annual Average	16.5											
Condamine												
Max 24-hour			21.8	33.7	68	13.3	14.8	30.3	33.4	-	-	66.5
Average 1-hour			12	15.6	19.6	5.9	7.1	11.2	9.9	-	-	19.2
% Data Avail			84	98	100	93	100	100	98	66[b]	74[b]	98
Annual Average	13.3											

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

2.4 Summary

Time series plots and statistical tables are presented for carbon monoxide, nitrogen dioxide and ozone from all 5 sites and $PM_{2.5}$, PM_{10} and TSP from the 3 Gas field sites for 2015- 2016.

At all 5 sites, there were

- no exceedances of objectives for carbon monoxide, nitrogen dioxide or ozone.
- no exceedances of annual air quality objectives for any of the pollutants measured.

At the Gas field sites there were

- 6 exceedances of the 24-hour air quality objective for $PM_{2.5}$ (Air EPP/NEPM (air)
- 2 exceedances of the 24-hour air quality objective for PM10 (Air EPP/NEPM (air), and
- 8 exceedances of the 24-hour TSP nuisance dust guideline (MFE)

An investigation of the likely contributing source(s) of $PM_{2.5}$, PM_{10} and TSP to the air quality exceedances is presented in Section 4.5, including case studies of 2 PM exceedance events on the 15/10/2016 and 6/12/2016.

2.5 References

APLNG (2010) Environmental Impact Statement, Volume 2, Gas fields
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Environment Protection (Air) Policy (2008)
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QGC (2010) Environmental Impact Statement, Volume 3 – Environmental Impact of Gas fields
http://www.bg-group.com/725/qgc/sustainability/environment/environmental-impact-management/

3 Data summary: methane and total VOCs: Gas field sites

The purpose of this section is to present statistics and time series plots of methane and total VOCs from the 3 Gas field sites for the period February 2015 to December 2016.

An analysis of the likely source of the 5 largest methane concentration events for each site is presented in Section 4.

3.1 Methane

Figure 10 shows a time series of hourly methane concentrations from the three Gas field sites from 2015-2016. Table 19 and Table 20 show methane statistics from the same period including maximum and average monthly values, as well as annual average values. Note that methane measurements began at Condamine in 2016.

The annual average values were 1.8 – 1.9 ppm at the Gas field sites, in agreement with methane concentrations measured at Regional sites Burncluith and Tara Region/Ironbark, where monthly methane values are in the range of 1.8 to 1.9 ppm, or between 1800 and 1900 ppb (parts per billion) (Etheridge et al., 2017). It should be noted that methane measurements reported here cannot be directly compared with the methane measurements from Burncluith and Tara Region (Ironbark) reported in Etheridge et al., (2017) and other reports from that study for the reasons outlined below.

The methane measurements employed at the Gas field sites were designed to detect relatively large changes in methane concentrations which may be caused by emissions from local CSG sources. The measurement systems employed for this purpose can detect changes in methane of 0.1 ppm. In contrast, in the GISERA Regional Methane Flux project, high sensitivity methane measurements were employed to allow detection of very small changes in methane (down to about 1 ppb, or 0.001 ppm) between sites and over time. As such, methane concentrations between the Gas field sites and Regional sites can only broadly be compared to the level of 0.1 ppm.

The background concentrations of methane at this latitude vary seasonally by about ±20 ppb (0.02 ppm). At the Gas field sites the background concentration of methane of between 1.8 ppm – 1.9 ppm can be seen in Figure 10, with higher concentrations visible in the form of peaks. The 5 largest methane events at Gas field sites were identified using these hourly methane concentrations (Section 4.2.2) and are investigated in Section 4.4. The largest methane concentrations observed in this study until the end of 2016 were at Condamine, visible as the largest green peaks in March 2016. This event is investigated as a case study in Section 4.5.1.

It should be noted that the Regional stations were deployed in locations that would not be affected by local and large sources of methane, to allow the regional emissions to be determined.

As such, methane data from the Regional sites has smaller amplitude spikes in concentrations (Etheridge et al., 2017) than reported here for the Gas field sites.

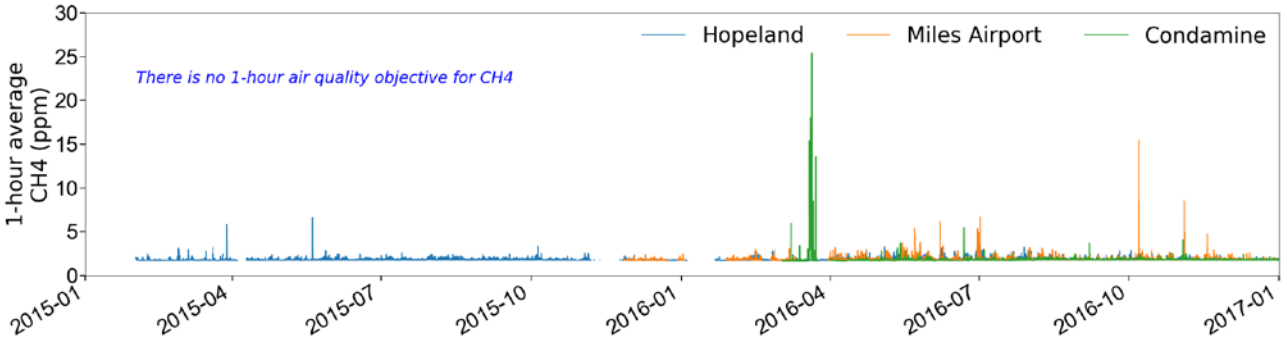

Figure 10 time series of hourly methane data at the Gas field sites

Table 19 Ambient concentrations of methane. Monthly maximum and average 1-hour average and annual average concentrations (ppm) at the three Gas field sites for 2015

CH_4 - 2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 1-hour		3.1	5.8	2.3	6.6	2.4	2.6	2.4	2.4	3.4	-	2.3
Average 1-hour		1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.8	1.8	-	1.8
% Data Avail		99	99	81	100	100	100	99	100	97	36[a,b]	89
Annual Average	1.8											
Miles Airport												
Max 1-hour											-	2.3
Average 1-hour											-	1.8
% Data Avail											13[b]	82
Annual Average												
Condamine												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 20 Ambient concentrations of methane. Monthly maximum and average 1-hour average and annual average concentrations (ppm) at the three Gas field sites for 2016

CH_4 - 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland												
Max 1-hour	-	2.7	2.3	2.8	-	3.1	3.5	2.9	2.8	2.9	2.4	2.3
Average 1-hour	-	1.8	1.8	1.9	-	1.9	1.9	1.9	1.9	1.9	1.8	1.8
% Data Avail	44[d,f]	87	78	100	65[b]	100	100	100	100	100	99	99
Annual Average	1.9											
Miles Airport												
Max 1-hour	-	3	-	3.2	5.4	6.1	6.7	3.2	2.5	15.4	8.5	2.6
Average 1-hour	-	1.8	-	1.9	2	1.9	1.9	1.9	1.8	1.9	1.9	1.8
% Data Avail	17[a,b]	82	37[a,d]	98	100	100	100	100	100	92	84	95
Annual Average	1.9											
Condamine												
Max 1-hour			-	2.2	3.7	5.5	2.9	2.4	3.7	2.6	4.1	2.4
Average 1-hour			-	1.7	1.8	1.8	1.8	1.9	1.8	1.8	1.8	1.8
% Data Avail			73[b]	98	100	100	100	99	98	100	99	100
Annual Average	1.8											

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

3.2 Total Volatile Organic Compounds (TVOC)

At the 3 Gas field sites a measurement method was employed that provides an approximation for the sum of all individual VOCs present (TVOC). There are no state or federal air quality objectives for TVOC. Total VOC measurements were included in the present study to provide an indication of whether an elevation of VOCs from combustion or CSG leakage and venting may have occurred.

The TVOC instrument has a reported measurement range of 1 – 2000 ppmC.

Table 21 and Table 22 show average monthly concentrations of TVOC where there was sufficient data capture. For all months, the concentration of TVOC was lower than the lowest reportable measurement concentration of 1 ppmC.

Several instrumental issues resulted in invalid data and overall low data capture rates for the TVOC measurement. Issues included power outages, instrument instability and calibration instability.The passive Radiello VOC sampling also employed in this study provided a more sensitive (sub-ppb), reliable method, capable of measuring the concentration of individual VOCs, including NEPM air toxics (see Part 2 of report).

Table 21 summary of monthly statistics of TVOC for 2015 (ppmC)

TVOC-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland	-	-	<1ppmC	<1ppmC	-	<1ppmC	-	-	<1ppmC	<1ppmC	<1ppmC	-
% Data Avail	-	-	85	76	69[b]	81	22[a,b]	68[a,b]	95	93	91	0[e]
Miles Airport	-	-	-	-	-	-	-	-	-	-	-	-
% Data Avail	-	-	-	-	-	-	2[a,b]	0[b]	61[e]	0[a,b]	0[a,b]	0[a,b]
Condamine												
No data												

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

Table 22 summary of monthly statistics of TVOC for 2016 (ppmC)

TVOC-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hopeland	-	-	-	-	-	-	-	-	-	<1ppmC	-	-
% Data Avail	0[d,f]	19[b]	40[e]	23[e]	0[e]	38[e]	6[e]	40[e]	28[e]	87	23[b]	0[e]
Miles Airport	-	-	-	-	-	-	-	-	-	-	-	-
% Data Avail	0[a,b]	9[d]	3[a,d]	0[e]	0[e]	20[e]	43[b,e]	5[b,e]	2[b,e]	0[b,e]	33[b]	0[b]
Condamine	-	-	-	-	-	-	-	-	-	-	-	-
% Data Avail	-	-	0[e]	0[e]	0[e]	6[e]	24[e]	61[e]	22[e]	6[e]	0[e]	0[e]

a=power outage, b= instrument fault, c=instrument commissioned during month, d=air conditioning failure, e=calibration out of tolerance, f=communication / logger failure

3.3 Summary

- Gas field average annual average methane concentrations for 2015 (Hopeland) and 2016 (Hopeland, Miles Airport and Condamine) of between 1.8 ppm and 1.9 ppm compare to concentrations observed at the Regional sites as part of the GISERA Regional Methane Flux project, reported in Etheridge et al., (2017). Note that due to differences in measurement systems, concentrations can only broadly be compared to the level of 0.1 ppm. Peaks of methane above the background concentration occur at each of the Gas field sites throughout the time series. The largest of these events are investigated further in Section 4.
- Gas field concentrations of TVOC were always lower than the lowest reportable measurement concentration of 1 ppmC. Part 2 of this report presents VOC concentrations from the passive Radiello network, which is a more sensitive (sub-ppb), reliable method, capable of measuring the concentration of individual VOCs, including NEPM air toxics.

3.4 References

APLNG (2010) Environmental Impact Statement, Volume 2, Gas fields https://www.aplng.com.au/about-us/compliance/eis.html

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4 Investigation of events

In this section events are identified, and the protocol for investigating the circumstances that resulted in these events is described. The results of the investigations are summarised and implications for air quality are discussed.

4.1 Identification of events

4.1.1 Exceedances of air quality objectives, or > concentrations 80% of air quality objectives

Events were identified for the measured pollutants for which air quality objectives or guidelines exist (carbon monoxide, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10}, TSP) in the following way:

- any exceedances of air quality objectives were identified as events. See Table 4 and Table 5 for a summary of the type and number of exceedances at each site
- pollutant concentrations greater than (>) 80% of the air quality objective, were also identified as an event in recognition that an exceedance may have occurred closer to the pollutant source or near the monitoring site. The air quality objectives, and 80% value of the objectives for ozone, PM_{10}, $PM_{2.5}$ and TSP are shown in Table 23

All exceedances of air quality objectives, or events where the concentration > 80% of air quality objective occurred at the Gas field sites. Note that all events except one related to $PM_{2.5}$ /PM_{10}/TSP and these pollutants were not monitored at Regional sites. A summary of the dates, location and type of exceedance (red text) or concentration> 80% (black text) are shown in Table 24.

Table 23 Air quality objectives, and 80% values of air quality objectives for ozone, PM_{10}, $PM_{2.5}$ and TSP.

Air pollutant	Averaging Period	Objective	80% of objective
Ozone	4-hour	0.08 ppm (one day per year) [a,b]	0.064 ppm
	1-hour	0.10 ppm (one) [a,b]	0.08 ppm
PM_{10}	Annual	25 µg m^{-3} [a]	20 µg m^{-3}
	24-hour	50 µg m^{-3} [a,b]	40 µg m^{-3}
$PM_{2.5}$	Annual	8 µg m^{-3} [a,b]	6.4 µg m^{-3}
	24-hour	25 µg m^{-3} [a,b]	20 µg m^{-3}
TSP	Annual	90 µg m^{-3} [b]	72 µg m^{-3}
	24-hour	60 µg m^{-3} (NZ)[c]	48 µg m^{-3}

[a] NEPM (2016)

[b] Air (EPP) (2008) Queensland

[c] DEHP TSP guidelines based on MFE (2016)

Table 24 Date and site of exceedances and concentrations > 80% of Air EPP/NEPM air quality objective. PM 24-hour average (µg m^{-3}), O_3 4-hour average (ppm). Red text indicate concentration exceeded air quality objectives, black text indicates concentration > 80% of air quality objectives

	Hopeland			Miles Airport				Condamine		
	$PM_{2.5}$	PM_{10}	TSP	$PM_{2.5}$	PM_{10}	TSP	O_3	$PM_{2.5}$	PM_{10}	TSP
Air quality objective	25[a,b]	50[a,b]	60[c]	25[a,b]	50[a,b]	60[c]	8[a,b]	25[a,b]	50[a,b]	60[c]
	µg m^{-3}			µg m^{-3}			ppm	µg m^{-3}		
5/10/2015						56				
6/10/2015						55.7				
7/10/2015				22.9	67.1	120.9				
4/11/2015	20.4									
5/11/2015	27.3			29.6						
21/11/2015	21.2									
10/03/2016						55.9				
2/05/2016										68
5/05/2016						50.9				
19/05/2016			50							
25/05/2016										59.1
10/08/2016								20.4		
11/08/2016	55.8	59	61							
15/10/2016						62.1				
7/11/2016					48.8	93.7				
16/11/2016						50.9				
22/11/2016						56.4				
23/11/2016					41.2	73.2				
2/12/2016						60.1				
6/12/2016	35.9	46.3	58.1	25.7				28.1	44.4	66.5
7/12/2016										54.4
14/12/2016	20									
22/12/2016							0.065			

[a] NEPM (2016)

[b] Air (EPP) (2008) Queensland

[c] DEHP TSP guidelines based on MFE (2016)

4.1.2 Identification of methane events

Methane does not have an air quality objective and was measured in this study as a tracer for CSG activities and for other components present in CSG emissions. As such, the analysis of methane events undertaken here aims to explore the likely sources of methane in the study area, and relate this, where possible, to implications for air quality.

The 5 largest methane events from each of the Gas field sites from 2015-2016 have been identified and investigated as follows:

- As a first step, the largest events were identified using hourly average concentrations
- For some of these events, several smaller peaks above baseline accompanied the largest peak when there were similar wind directions at the one site, or under similar wind conditions (e.g. light and variable). These peaks were considered to be part of the same "event" when: the magnitude of the smaller peak was >10% of the largest peak above baseline for that event, and, they occurred within 12 hours of the largest peak
- Events include a baseline or near baseline value either side of the first and last peak associated with that event

As such, the identification of the 5 largest methane events from each site is semi-quantitative/approximate which is suitable for an exploratory analysis. Table 25 shows the dates and the maximum 1-hour average concentrations observed during the 5 highest methane events at Gas field sites. These values were used to identify the 5 largest methane events from each site using the protocol above. The two largest 1-hour methane concentrations were recorded at Condamine (25.4 ppm) and Miles Airport (15.4) ppm with the remaining 13 largest hourly concentrations across all three sites in the range of 3.3 – 8.5 ppm.

Table 25 Dates and maximum 1 hour average concentrations observed during 5 highest methane events at Gas field sites (ppm). These values were used to identify the 5 largest methane events from each site

	Max 1 h average CH_4 concentration (ppm)		
	Hopeland	**Miles Airport**	**Condamine**
28/03/2015	5.8		
20/05/2015	6.6		
5/10/2015	3.4		
8/03/2016			6
20/03/2016			25.4
4/05/2016	3.3		
13/05/2016			3.7
22/05/2016		5.4	
7/06/2016		6.1	
22/06/2016			5.5
1/07/2016	3.5	6.7	
7/10/2016		15.4	
3/11/2016		8.5	4.1

4.2 Protocol for investigating likely source of pollutants during events

This section describes the protocol that was used to investigate the likely sources or circumstances that led to the events identified in the previous section.

4.2.1 Exceedances of air quality objectives or concentrations> 80% of air quality objectives ($PM_{2.5}$, PM_{10} and TSP events and single ozone event)

Where several peaks in an event occurred from the same wind direction, only the source of the largest peak is investigated. However where two or more peaks contributed to event and appear to be from different sources, then these peaks are investigated and reported separately in Section 4.4.

The steps taken to investigate the likely source of events included:

1) Define the event period, including the date and time. Define the time and peak concentrations of the pollutant which exceeded, or was > 80% of the relevant air quality objective

2) Determine the predominant wind direction/s and wind speed during the peak pollutant concentrations

3) In the case of particle mass, determining whether the PM was mainly in the small or fine size fraction ($PM_{2.5}$, particles <2.5 µm) or coarse size fraction (PM in the range of 2.5 µm – 10 µm, calculated from $PM_{10} – PM_{2.5}$). Coarse particles are typically associated with airborne dust and soil, whereas fine particles are associated with smoke and secondary aerosols and fine dust.

4) Identify the other measured pollutants whose concentrations correlated with the pollutant that was the subject of the event. Pollutants were only stated as being correlated where the coefficient of determination (R^2) was moderate or greater (R^2>0.4) and the correlation was statistically significant at a 95% confidence interval.

For instance, $PM_{2.5}$, carbon monoxide (CO) and carbon dioxide (CO2) are emitted during combustion. Correlations between $PM_{2.5}$ and carbon monoxide and carbon dioxide can be used to identify sources of $PM_{2.5}$ exceedances associated with smoke from fires. Likewise, methane and carbon dioxide are emitted from cattle and correlations between these pollutants can be used to identify sources of PM_{10} and TSP peaks due to dust from cattle farming activities. The absence of a correlation between pollutants can also be used to rule out sources.

5) Calculate an average ratio of the exceeding pollutant to any other correlating pollutants during the peak concentration period and examine whether this ratio indicates a particular emission source (fires, dust, cattle, CSG combustion etc.). Correlating pollutants were plotted against one another, and the ratio was the slope of the linear relationship between the two.

Previous studies have examined the ratios of $PM_{2.5}$ to carbon monoxide ($PM_{2.5}$/CO) and carbon monoxide to carbon dioxide (CO/CO_2) in smoke (Andreae and Merlet, 2001; Akagi et al., 2011) and the ratios of methane to carbon dioxide (CH_4/CO_2) in the breath of cattle (Bai et al 2014). These published ratio data will be used to here to identify possible sources.

6) Identify possible sources of the exceeding pollutant and other correlating pollutants upwind of the measurement location, and determine the distance from the measurement location to

potential sources. For example, Geoscience Australia's Sentinel website, and NASA Worldview website (see A.5) as well as information from local fire authorities and landholders was used to provide information on the locations and occurrence of fires and smoke in the study region. Likewise, the Queensland Globe database was used to identify CSG infrastructure (GPFs, pipelines, wells) as well as other potential pollutant sources such as feedlots.

6) Investigate other relevant information, for example whether exceedances occurred at other sites that day. Exceedances at multiple sites can indicate a regional source/event.

7) Identify the likely dominant source of the pollutant during the event, recognising that there may not be sufficient information to identify a likely source for each event.

The case studies of events presented in Section 4.5 demonstrate how the protocol was applied to investigate the circumstances and sources of 3 different events.

4.2.2 Protocol for investigating methane events

The steps taken to investigate the likely source of methane events is very similar to the protocol for investigating $PM_{2.5}$, PM_{10} and TSP events and included:

1) Define the date and duration of the methane event. Methane events are defined as one or a series of peaks that occurred in the same wind direction/similar wind conditions, no more than 12 hours apart (Section 4.1.2). The average concentration over the duration of the event, as well as the maximum hourly and maximum 5 or 15 minute concentrations are also reported. Note that the highest time resolution validated data was used (either 5 or 15 minute), depending on availability.

2) Determine predominant wind direction(s) and speed during the peak methane concentration

3) Identify other pollutants whose concentrations correlated with methane concentrations. Methane and other pollutants were only stated as being correlated where the coefficient of determination (R^2) was moderate or greater (R^2>0.4) and the correlation was statistically significant at a 95% confidence interval.

4) Calculate an average ratio of methane to any other correlating pollutants during the peak concentration period and examine whether this ratio indicates a particular emission source (cattle, CSG combustion, un-combusted CSG etc). Methane was plotted against any correlating pollutants and the ratio was the slope of the linear relationship between the two.

5) Identify possible sources of methane and other correlating pollutants upwind of the measurement location, and identify the distance from the measurement location to point sources.

6) Investigate other relevant information

7) Identify the likely dominant source of methane during the event. Note that there may not be sufficient information to identify a likely source for each event.

In cases where the major methane peak did not correlate with any other pollutants (e.g. carbon dioxide which could indicate cattle, carbon monoxide which could indicate combustion), and potential CSG emissions sources were identified upwind, the source of the methane peak was attributed as likely being from intentional or unintentional release of un-combusted CSG from

CSG activities/infrastructure. While methane emissions from terrestrial seeps or legacy boreholes could be a source of the methane observed in these cases, CSG-related activities or infrastructure are considered to be a more likely source, given the high density of CSG infrastructure (wells, gathering networks, GPFs, WTF, compressor stations) in close proximity to these Gas field sites (see Table 1).

4.3 Methane events – implications for air quality

CSG in the study area is 96-98% methane (Lawson et al., 2017) and emissions of CSG may occur from several sources including from wells, pipelines, gathering networks, separators, processing facilities and storage facilities. CSG emissions occur both through intentional release (e.g. pneumatically driven gas and water separators on well heads) and unintentional release (e.g. via leaks in infrastructure). Methane does not have an air quality objective, and was included in this study as a tracer for other components of CSG which do have air quality objectives.

To understand the air quality impact of the likely CSG-related methane events, the composition of undiluted CSG can be used to estimate the concentrations of other components such as VOCs and hydrogen sulphide during the peak methane concentrations observed. This analysis assumes that the methane observed was CSG. The largest methane event observed in this study to date which was attributed to CSG (Condamine on the 18-21 March 2016) is analysed further as a case study in Section 4.5.1, including an estimate of the concentration of BTX and hydrogen sulphide during the event.

Because the gas composition data used in this analysis (reported in Lawson et al., 2017) is based on a relatively limited number of measurements from wellheads and GPFs, these data cannot be considered representative of all CSG-related sources in the study region. Future work could include a wider measurement of gas composition in the study area. However, the impact of CSG emissions on VOCs and hydrogen sulphide in the atmosphere in the study region has been assessed over a period of 16 months in the Radiello Passive Gas monitoring program (Part 2 of this report) which targeted several species of potential concern in CSG including BTX and hydrogen sulphide.

Passive Radiello sampling recommenced in October 2016 at some existing sites and 10 new sites. Data from these measurements will be available for reporting as part of the GISERA project Investigating air, water and soil impacts of hydraulic fracturing (Dunne et al., 2017).

4.4 Summary of events

This section briefly summarises the most likely source of pollutants during events summarised in Section 4.1.

A summary of the dominant sources most likely responsible for events is given below for each site. Table 26 ($PM_{2.5}$, PM_{10}, TSP and ozone) and Table 27 (methane) lists the sources most likely responsible by date and site. In Table 26 red text indicates an exceedance and black text indicates the concentration was >80% of the relevant air quality objective.

An analysis of each individual event including supporting information is provided in Section 4.4.1, including exceedance events (Table 28 – Table 30), events with concentrations > 80% of air quality objectives (Table 31 – Table 33) and methane events (Table 34 – Table 36).

A more detailed analysis of 3 case studies is provided in Section 4.5.

The most likely dominant sources identified for the observed events were:

- Regional vegetation fires which emitted smoke resulting in $PM_{2.5}$, PM_{10} and TSP events at multiple sites on the same day
- Local vegetation fires which emitted smoke resulting in $PM_{2.5}$, PM_{10} and TSP events at individual sites
- Cattle farming activities which emitted dust resulting in local PM_{10} and TSP events
- CSG operational or development activities and/or vehicle traffic resulting in local PM_{10} and TSP events
- CSG activities or infrastructure which emit un-combusted CSG

For some events, the source of the pollutant exceedance could not be determined with the available information and remains unknown. For example there were several local PM_{10} and TSP events which may have been due to dust emitted from unsealed roads from wind or vehicle traffic, or agricultural activities, but the specific source could not be identified.

Hopeland

3 x 24-hour $PM_{2.5}$ exceedance events attributed to vegetation fire

3 x 24-hour events with $PM_{2.5}$ concentration > 80% of air quality objective, attributed to vegetation fire

1 x 24-hour PM_{10} exceedance event attributed to vegetation fire

1 x 24-hour event with PM_{10} concentration >80% of air quality objective, attributed to a combination of vegetation fire and local dust

1 x 24-hour TSP exceedance of nuisance dust guidelines attributed to vegetation fire

1 x 24-hour event with TSP > 80% nuisance dust guidelines with source unknown, and 1 x 24-hour event with TSP >80% of nuisance dust guidelines attributed to a combination of vegetation fire and local dust

4 x methane events attributed to emissions of CSG from CSG activities/infrastructure, 1 event source unknown

Miles Airport

2 x 24-hour $PM_{2.5}$ exceedance events attributed to vegetation fire

1 x 24-hour event with $PM_{2.5}$ concentration > 80% of air quality objective, source unknown

1 x 24-hour PM_{10} exceedance event source unknown

2 x 24-hour event with PM_{10} concentration >80% of air quality objective, one event with source unknown and one event attributed to particles from cattle farming activities

2 x 24-hour TSP exceedance of nuisance dust guidelines attributed to particles from cattle farming activities , 1 x 24-hour TSP exceedance attributed to a contribution of particles from cattle farming activities and unknown source and 2 x 24-hour TSP exceedances with source unknown

2 x 24-hour events with TSP > 80% nuisance dust guidelines attributed to particles associated with cattle farming, 3 x 24-hour TSP events with source unknown, 1 x 24-hour TSP event attributed to combination of unknown source and particles from cattle farming activities

1 x regional ozone event with 4-hour average concentrations >80% of air quality objective, source unknown.

5 x methane events attributed to emissions of CSG from CSG activities/infrastructure

Condamine

1 x 24-hour $PM_{2.5}$ exceedance event attributed to vegetation fire

1 x 24-hour events with $PM_{2.5}$ concentration > 80% of air quality objective, attributed to vegetation fire

1 x 24-hour PM_{10} concentration > 80% of air quality objective, attributed to vegetation fire and local dust from unsealed roads and/or CSG development or operational activities

1 x 24-hour TSP exceedance of nuisance dust guidelines attributed to unsealed roads and/or CSG development or operational activities, 1 x 24-hour TSP event attributed to combination of vegetation fire and unsealed roads and/or CSG development or operational activities

2 x 24-hour events with TSP > 80% nuisance dust guidelines attributed to unsealed roads and/or CSG development or operational activities

5 x methane events attributed to emissions of CSG from CSG activities/infrastructure

Table 26 summary of the most likely sources responsible for each exceedance (red text) and >80% value (black text). $PM_{2.5}$, PM_{10} and TSP exceedances are based on 24-hour average concentration values while ozone in based on a 4 hour average value.

	Hopeland			Miles Airport				Condamine		
	$PM_{2.5}$	PM_{10}	TSP	$PM_{2.5}$	PM_{10}	TSP	O_3	$PM_{2.5}$	PM_{10}	TSP
5/10/2015						unknown				
6/10/2015						unknown				
7/10/2015				unknown	unknown	unknown				
4/11/2015	Local vegetation fire									
5/11/2015	Regional vegetation fire*			Regional vegetation fire*						
21/11/2015	Local vegetation fire									
10/03/2016						cattle farming				
2/05/2016										Unsealed roads and/or CSG development or operational activities
5/05/2016						unknown				
19/05/2016			unknown							
25/05/2016										Unsealed roads and/or CSG development or operational activities
10/08/2016								Local vegetation fire		

	Hopeland			Miles Airport				Condamine		
	$PM_{2.5}$	PM_{10}	TSP	$PM_{2.5}$	PM_{10}	TSP	O_3	$PM_{2.5}$	PM_{10}	TSP
11/08/2016	Local vegetation fire*	Local vegetation fire*	Local vegetation fire							
15/10/2016						cattle farming				
7/11/2016					unknown	unknown				
16/11/2016						unknown and cattle farming				
22/11/2016						cattle farming				
23/11/2016					cattle farming	cattle farming				
2/12/2016						Unknown and cattle farming				
6/12/2016	Regional vegetation fire*	Regional vegetation fire and local dust	Regional vegetation fire and local dust	Regional vegetation fire*				Regional vegetation fire*	Regional vegetation fire and unsealed roads/CSG activities	Regional vegetation fire and unsealed roads/CSG development and operational activities
7/12/2016										Unsealed roads and/or CSG development or operational activities
14/12/2016	Local vegetation fire									
22/12/2016							Regional (unknown)			

***these PM2.5 and PM10 exceedances would be classed as being associated with exceptional events according to NEPM protocols (NEPM 2016)**

Table 27 summary of the sources attributed to the largest 5 methane events from each of the Gas field sites in this study from 2015-2016.

Date of event	Hopeland	Miles Airport	Condamine
28/03/2015	Emissions of CSG from CSG activities/infrastructure		
20/05/2015	Emissions of CSG from CSG activities/infrastructure		
5/10/2015	unknown		
8/03/2016			Emissions of CSG from CSG activities/infrastructure
20/03/2016			Emissions of CSG from CSG activities/infrastructure
4/05/2016	Emissions of CSG from CSG activities/infrastructure		
13/05/2016			Emissions of CSG from CSG activities/infrastructure
22/05/2016		Emissions of CSG from CSG activities/infrastructure	
7/06/2016		Emissions of CSG from CSG activities/infrastructure	
22/06/2016			Emissions of CSG from CSG activities/infrastructure
1/07/2016	Emissions of CSG from CSG activities/infrastructure	Emissions of CSG from CSG activities/infrastructure	
7/10/2016		Emissions of CSG from CSG activities/infrastructure	
3/11/2016		Emissions of CSG from CSG activities/infrastructure	Emissions of CSG from CSG activities/infrastructure

4.4.1 Analysis of events with exceedances of air quality objectives

Table 28 Hopeland - $PM_{2.5}$ and PM_{10} exceedances of the Air (EPP) Objectives and TSP exceedances of the DEHP nuisance dust limit values (MFE 2016)

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra -tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
5/11/2015	$PM_{2.5}$ 27.3 µg m^{-3} (24-hr av) 15 min peak = 93.9 µg m^{-3} at 02:15	NNE - NE 3-4 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate	Combustion	$PM_{2.5}$/CO ratio indicates vegetation fire	Hotspots in previous 24 hours indicate fires about 70 km NNW of Hopeland and 100 - 200 km N – NE of Surat region.	$PM_{2.5}$ exceedance Miles Airport	Information available suggests regional vegetation fire event (more than one site impacted)
11/8/2016	$PM_{2.5}$ 55.8 µg m^{-3} (24-hr av) 5 min peak = 360.0 µg m^{-3} at 01:00 PM 10 59 µg m^{-3} (24-hr av) 5 min peak = 368.3 µg m^{-3} at 1:00 TSP 61 µg m^{-3} (24-hr av)	Light and variable winds 1-3 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate fires about 10 km SW and 50 km N of Hopeland. Landholders in area report smoke	No other exceedances	Information available suggests local vegetation fire

	5 min peak = 370.8 µg m^{-3} at 01:00							
6/12/2016	$PM_{2.5}$ 35.9 µg m^{-3} (24-hr av) 5 min peak = 271.8 µg m^{-3} at 15:15	NNE – N - NW 4-6 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate $PM_{2.5}$ and NO_x correlate CO_2 and CH_4 correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate vegetation fires about 10 km SW and 50 km N of Hopeland. Landholders in area report smoke	$PM_{2.5}$ exceedances Miles Airport and Condamine TSP exceedance Condamine PM_{10} >80% EPP objective Hopeland and Condamine TSP >80% DEHP dustlimit Hopeland See case study in Section 4.5.2	Information available suggests regional vegetation fire (more than one site impacted)

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

Table 29 Miles Airport - $PM_{2.5}$ and PM_{10} exceedances of the Air (EPP) Objectives and TSP exceedances of the DEHP nuisance dust limit values (MFE 2016)

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra-tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
7/10/2015	PM_{10} 67.1 µg m^{-3} (24-hr av) 5 min peak = 847.7 µg m^{-3} at 19:30 TSP 120.9 µg m^{-3} (24-hr av) 5 min peak = 1631.8 µg m^{-3} at 19:30	E - ENE 2-4 m s^{-1}	PM is mainly large fraction No correlations No CO_2 or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		Feedlot 2 km Agriculture CSG wells and gathering network Vehicles	$PM_{2.5}$ >80% EPP objective at Miles Airport	Could not be determined with available data
5/11/2015	$PM_{2.5}$ 29.6 µg m^{-3} (24-hr av) 5 min peak = 124.7 µg m^{-3} at 01:15	NNE 4-7 m s^{-1}	PM is mainly small fraction No correlations No CO or CH_4 data	Combustion		Hotspots in previous 24 hours indicate fires about 70 km N of Miles Airport and 100 - 200 km N – NE of Surat region.	$PM_{2.5}$ exceedance Hopeland	Information available suggests regional vegetation fire event (more than one site impacted)
15/10/2016	TSP 62.1 µg m^{-3} (24-hr av)	E - ENE 2 m s^{-1}	PM is mainly large fraction	Airborne dust and soil from unsealed roads, agriculture	CH_4/CO_2 ratio consistent with cattle	Feedlot 2km Agriculture CSG wells and gathering network	No other exceedances See case study in section 4.5.3	Information available suggests particles associated with cattle farming

	5 min peak = 1231.5 µg m^{-3} at 19:20		TSP and CH_4, CO_2 correlate	activities, CSG activities				
7/11/2016	TSP 93.7 µg m^{-3} (24-hr av) 5 min peak = 1765.5 µg m^{-3} at 19:55	ENE 2 m s^{-1}	PM is mainly large fraction No correlations No CO_2, CO, NO_x or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		Feedlot 2 km Agriculture CSG wells and gathering network	PM_{10} >80% EPP objective Miles Airport	Could not be determined with available data
23/11/2016	TSP 73.2 µg m^{-3} (24-hr av) 5 min peak = 1360.5 µg m^{-3} at 20:20	E - NE 2-3 m s^{-1}	PM is mainly large fraction TSP and CH_4, CO_2 correlate	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	CH_4/CO_2 ratio consistent with cattle.	Feedlot 2 km Agriculture CSG wells and gathering network	PM_{10} >80% EPP objective Miles Airport	Information available suggests particles associated with cattle farming
2/12/2016	TSP 60.1 µg m^{-3} (24-hr av) 1st 5 min peak = 527.9 µg m^{-3} at 21:05 2nd 5 min peak = 309.6 µg m^{-3} at 21:55 3rd 5 min peak = 248.7 µg m^{-3} at 22:55	SE - NE 2-4 m s^{-1}	PM is mainly large fraction 1st Peak: TSP and CO_2, CH_4 correlate All Peaks: CO_2 and CH_4 correlate		CH_4/CO_2 ratio consistent with cattle	Feedlot 2 km Agriculture CSG wells and gathering network	No other exceedances Three TSP peaks contributing to this event	Information available suggests particles associated with cattle farming with possible contribution from another source (unknown)

6/12/2016	$PM_{2.5}$ 25.7 µg m^{-3} (24-hr av) 5 min peak = 125.4 µg m^{-3} at 00:25	NNE – NNW 3-5 m s^{-1}	PM is mainly small fraction. $PM_{2.5}$ and CO, NO_x , CO_2, CH_4 correlate CO and NO_X, CO_2, CH_4 correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate fires about 30 - 50 km N - NE of Miles Airport	$PM_{2.5}$ exceedances Hopeland and Condamine TSP exceedance Condamine PM_{10} >80% EPP objective Hopeland and Condamine TSP >80% DEHP dust limit Hopeland See case study in Section 4.5.2	Information available suggests regional vegetation fire event (more than one site impacted)

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

Table 30 Condamine - $PM_{2.5}$ and PM_{10} exceedances of the Air (EPP) Objectives and TSP exceedances of the DEHP nuisance dust limit values (MFE 2016)

Event date	Event time (average and peak) and concentrations	Wind at time of peak concenetr-ation	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
2/5/2016	TSP 68 µg m^{-3} (24-hr av) 5 min peak = 2195.7 µg m^{-3} at 02:55	S 1 m s^{-1}	PM is mainly large fraction No correlations	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	n/a	CSG wells and gathering network and infrastructure (including GPF- 1km S/SE) unsealed roads	No other exceedances	Information available suggests TSP associated with unsealed roads and/or development or operational CSG activities to south
6/12/2016	$PM_{2.5}$ 28.1 µg m^{-3} (24-hr av) 5 min peak = 111.5 µg m^{-3} at 01:35	N - NNE 2-4 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate	Combustion	$PM_{2.5}$ and CO ratio indicates vegetation fire	Hotspots in previous 24 hours indicate fires about 40 - 60 km N - NE of Condamine.	$PM_{2.5}$ exceedances Hopeland and Miles Airport PM_{10} >80% EPP objective Hopeland and Condamine TSP >80% DEHP dust limit Hopeland Sharp peaks suggest local source See case study in section 4.5.2	Information suggests likely regional vegetation fire event (more than one site impacted) with contribution from dust event (TSP exceedance)

	TSP 66.5 µg m^{-3} (24-hr av) 5 min peak = 596.4 µg m^{-3} at 19:25	SW – SSW 1-4 m s^{-1}	PM is mainly large fraction No correlations	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		CSG wells and gathering network and infrastructure (including pond, compressor station -1.5km SW) unsealed roads	As above	Information available suggests particles associated with unsealed roads and/or CSG development or operational activities to south with contribution from fire event earlier in day

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

4.4.2 Analysis of events with concentrations >80% of air quality objectives

Table 31 Hopeland – $PM_{2.5}$ and PM_{10} greater than 80% of the Air (EPP) Objectives (>80% EPP objective) and TSP greater than 80% of the DEHP nuisance dust limit values (>80% DEHP dust limit) MFE (2016)

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra -tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
4/11/2015	$PM_{2.5}$ 20.4 µg m^{-3} (24-hr av) 15 min peak = 42.9 µg m^3 at 01:00	NE 2-4 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate fires about 80 km N of Hopeland and 100 - 200 km N – NE of Surat region.	No other exceedances	Information available suggests local vegetation fire
21/11/2015	$PM_{2.5}$ 21.2 µg m^{-3} (24-hr av) 15 min peak = 47.4 µg m^{-3} at 07:30	NE – N - NNW 1-5 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate No CO_2, CH_4 data	Combustion	$PM_{2.5}$/CO ratio indicates vegetation fire	Hotspots in previous 24 hours indicate fires about 60 km WNW of Hopeland and 90 - 150 km N – NE of Surat region.	No other exceedances	Information available suggests local vegetation fire
19/5/2016	TSP 50 µg m^{-3} (24-hr av) 15 min peak = 311.8 µg m^{-3} at 10:30	S - SW 1-2 m s^{-1}	PM is mainly large fraction No correlations No CO_2 or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		CSG wells and gathering network Agriculture	No other exceedances Similar magnitude TSP peaks occurred the following day in similar wind direction.	Could not be determined with available data

6/12/2016	PM 10 46.3 µg m^{-3} (24-hr av) 5 min peak = 280.6 µg m^{-3} at 15:15	NNE – N - NW 4-6 m s^{-1} (~15:15)	PM is mainly small fraction $PM_{10}/PM_{2.5}$ and CO correlate $PM_{10}/PM_{2.5}$ and NO_x correlate CO_2 and CH_4 correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate fires about 50 - 60 km N - NW of Hopeland. Landholders in area report smoke	$PM_{2.5}$ exceedances Hopeland, Miles Airport and Condamine TSP exceedance Condamine PM_{10} >80% EPP objective Hopeland and Condamine TSP >80% DEHP dustlimit Hopeland See case study in section 4.5.2	Information available suggests PM_{10} mainly from regional vegetation fire (more than one site impacted) with contribution from dust later in day
	TSP 58.1 µg m^{-3} (24-hr av) 1st peak 5 min = 291.5 µg m^{-3} at 15:15 2nd peak 5 min =230.5 µg m^{-3} at 18:45	SW 4-6 m s^{-1} (~18:30)	PM is mainly large fraction	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities			As above Short lived event and sharp peak suggests local source	information available suggests TSP mainly from local dust with contribution from regional vegetation fire

14/12/2016	$PM_{2.5}$ 20 µg m^{-3} (24-hr av) 5 min peak = 81.6 µg m^{-3} at 5:05	ENE - NE 2-4 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate $PM_{2.5}$ and CO_2 correlate $PM_{2.5}$ and NO_x correlate CO and CO_2 correlate	Combustion	$PM_{2.5}$/CO ratio and CO_2/CO ratio indicate vegetation fire	Hotspots in previous 24 hours indicate fires about 30 km NE of Hopeland.	No other exceedances	Information available suggests local vegetation fire

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

Table 32 Miles Airport – $PM_{2.5}$ and PM_{10} greater than 80% of the Air Quality Objective (>80% EPP objective) and TSP greater than 80% of the DEHP nuisance dust limit values (>80% DEHP dust limit), MFE (2016)

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra -tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
05/10/2015	TSP 56 µg m^{-3} (24-hr av) 5 min peak = 1056.7 µg m^{-3} at 17:45	NE - ESE 1-2 m s^{-1}	PM is mainly large fraction No correlations No CO_2 or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	n/a	Feedlots (2/4km) Agriculture CSG wells and gathering network	No other exceedances Short lived event and sharp peak (1 hr) suggests local source	Could not be determined with available data
06/10/2015	TSP 55.7 µg m^{-3} (24-hr av) 5 min peak = 447.5 µg m^{-3} at 09:00	NE 3-5 m s^{-1}	PM is mainly large fraction No correlations No CO_2 or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	n/a	Feedlot 2km Agriculture CSG wells and gathering network	No other exceedances Short lived event and sharp peak (1 hr) suggests local source	Could not be determined with available data
7/10/2015	$PM_{2.5}$ 22.9 µg m^{-3} (24-hr av) 5 min peak = 179.8 µg m^{-3} at 19:30	E - ENE 2-4 m s^{-1}	PM is mainly large fraction $PM_{2.5}$ and NO_x correlate No CO_2 or CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		Feedlot 2km Agriculture CSG wells and gathering network	PM_{10} exceedance Miles Airport TSP exceedance Miles Airport	Could not be determined with available data
10/3/2016	TSP 55.9 µg m^{-3}	E 2-4 m s^{-1}	PM is mainly large fraction	Airborne dust and soil from unsealed roads,	CH_4/CO_2 ratio consistent with cattle	Feedlot 2km Agriculture	No other exceedances	Information available suggests particles

	(24-hr av) 5 min peak = 1014.1 µg m^{-3} at 19:15		TSP and CH_4, correlate	agriculture activities, CSG activities		CSG wells and gathering network		associated with cattle farming
5/5/2016	TSP 50.9 µg m^{-3} (24-hr av) 5 min peak = 676.1 µg m^{-3} at 18:10	S - SE 1-2 m s^{-1}	PM is mainly large fraction No correlations	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	n/a	Feedlot 4km Agriculture CSG wells and gathering network	No other exceedances Short lived event and sharp peak (1 hr) suggests local source	Could not be determined with available data
7/11/2016	PM_{10} 48.8 µg m^{-3} (24-hr av) 5 min peak = 882.9 µg m^{-3} at 19:55	ENE 2 m s^{-1}	PM is mainly large fraction No correlations No CO, NO_x, CO_2, CH_4 data	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		Feedlot 2km Agriculture CSG wells and gathering network	TSP exceedance Miles Airport	Could not be determined with available data
16/11/2016	TSP 50.9 µg m^{-3} (24-hr av) 1st 5 min peak = 558.7 µg m^{-3} at 19:45 2nd 5 min peak = 153.7 µg m^{-3} at 23:05	1st peak SSE 1-2 m s^{-1} 2nd peak ENE 1-2 m s^{-1} (gust to 7 m s^{-1})	PM is mainly large fraction 1st Peak No correlations 2nd peak TSP and CO_2, CH_4 correlate	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	2nd peak: CH_4/CO_2 ratio consistent with cattle	Feedlots (2/4 km) Agriculture CSG wells and gathering network	No other exceedances Two TSP peaks contributing to this event	Information available suggests particles associated with cattle farming (second peak), as well as an additional unknown source.
22/11/2016	TSP 56.4 µg m^{-3}	NE - E - SE 2-4 m s^{-1}	PM is mainly large fraction	Airborne dust and soil from unsealed roads,	CH_4/CO_2 ratio consistent with cattle	Feedlots (2/4 km) Agriculture	No other exceedances	Information available suggests particles

	(24-hr av) 5 min peak = 1037.6 µg m^{-3} at 19:50		TSP and CO_2, CH_4 correlate	agriculture activities, CSG activities		CSG wells and gathering network		associated with cattle farming
23/11/2016	PM_{10} 41.2 µg m^{-3} (24-hr av) 5 min peak = 738.6 µg m^{-3} at 20:20	E – NE 2 m s^{-1}	PM is mainly large fraction No correlations PM_{10} and CH_4 correlate	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	CH_4/CO_2 ratio consistent with cattle	Feedlot 2km Agriculture CSG wells and gathering network	TSP exceedance Miles Airport	Information available suggests associated with cattle farming
22/12/2016	O_3 0.065 ppm at 15:00 and 14:00 (4-hr av)	During day ENE – ESE 2-6 m s^{-1}, early morning NE 3-9 m s^{-1}	No correlations	Fires Other sources of VOCs and NO_x		No fires/hotspots	No other exceedances Previous night, early morning ozone higher than typical concentrations at Miles Airport, Hopeland, Condamine and Burncluith sites (no O_3 data at Tara Region), this led to higher than average concentration peaks during the following day.	Could not be determined with available data but likely regional event

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

Table 33 Condamine – $PM_{2.5}$ and PM_{10} greater than 80% of the Air Quality Objective (>80% EPP objective) and TSP greater than 80% of the DEHP nuisance dust limit values (>80% DEHP dustlimit), MFE (2016)

Event date	Event time (average and	Wind at time of	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source

	peak) and concentrations	**peak concentra -tion**						
25/5/2016	TSP 59.1 µg m^{-3} (24-hr av) 5 min peak = 504.0 µg m^{-3} at 20:40	ENE 1-2 m s^{-1}	PM is mainly large fraction TSP and CH_4 correlate	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		CSG wells and gathering network Unsealed roads	No other exceedances	Information available suggests particles associated with unsealed roads and/or CSG development or operational activities
10/8/2016	$PM_{2.5}$ 20.4 µg m^{-3} (24-hr av) 5 min peak = 213.4 µg m^{-3} at 02:15	NE 3-4 m s^{-1}	PM is mainly small fraction PM and CO correlate No CO_2 data	Combustion	$PM_{2.5}$ and CO ratio indicates vegetation fire NO_x/CO and NO_x/CH_4 ratios do not indicate gas fired compressors or generators (Talinga emission data, Lawson et al., 2017)	GPFs 10 km to NE and 13 km to ENE	No other exceedances	Information suggests likely due to local vegetation fire
6/12/2016	PM_{10} 44.4 µg m^{-3} (24-hr av) 1st peak 5 min peak 121 µg m^{-3} at 01:50 2nd peak	N - NNE 2-4 m s^{-1}	PM is mainly small fraction $PM_{2.5}$ and CO correlate	Combustion Airborne dust and soil from unsealed roads, agriculture activities, CSG activities	$PM_{2.5}$ and CO ratio indicates vegetation fire	Hotspots in previous 24 hours indicate fires about 40 - 60 km N - NE of Condamine.	$PM_{2.5}$ exceedances Hopeland, Miles Airport and Condamine TSP exceedance Condamine PM_{10} >80% EPP objective Hopeland	Information available suggests particles associated with unsealed roads and/or CSG development or operational activities to south (peak concentration) and also the regional vegetation fire event (see $PM_{2.5}$ exceedance)

	5 min peak = 239.1 µg m^{-3} at 19:25	SW – SSW 1-4 m s^{-1}	PM is mainly large fraction			CSG wells and gathering network CSG infrastructure including compressor station 1.5km SW) unsealed roads	TSP >80% DEHP dust limit Hopeland See case study in section 4.5.2	
7/12/2016	TSP 54.4 µg m^{-3} (24-hr av) 5 min peak = 1273.6 µg m^{-3} at 14:00	SW 2-4 m s^{-1}	PM is mainly large fraction No correlations	Airborne dust and soil from unsealed roads, agriculture activities, CSG activities		CSG wells and gathering network CSG infrastructure (including pond and compressor station -1.5km SW) unsealed roads	No other exceedances 6 x 0.5 hr peaks contributing	Information available suggests TSP near-exceedance associated with unsealed roads and/or CSG development or operational activities to south)

For PM events, the PM species ($PM_{2.5}$, PM_{10}, TSP) were always correlated with one another, and so PM correlations are not explicitly stated

4.4.3 Analysis of methane events

Table 34 Hopeland methane events

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra -tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
28/03/2015	14:15-19:15 Average 3.9 ppm 15:45 Peak=9.3 ppm (15 min data) 16:00 5.8 ppm (1 hr av)	Light and variable N - W 0-2 m s^{-1}	No correlations No PM data	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
20/05/2015	23:00 19/5/2015 – 04:30 20/5/2015 Average 4.2 ppm 00:45 Peak=12.9 ppm (15 min data) 01:00 6.6 ppm (1 hr av)	Light and variable SE 1-2 m s^{-1}	CH_4 and NO_x correlate	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network GPF 3 km to SE	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure

05/10/2015	21:30 4/10/2015 – 07:30 5/10/2015 Average 2.6 ppm 01:30 Peak=4.0 ppm (15 min data) 02:00 3.4 ppm (1 hr av)	Light and variable SE 0-2 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion However CH_4 and CO_2 do correlate more broadly overnight.	CSG wells and gathering network GPF 3 km to SE	CH_4 increases overnight for several consecutive nights between 0:00 – 6:00 in light SE winds. Suggests CH_4 trapped in boundary layer, source unknown.	Could not be determined with available data
4/5/2016	20:15 3/5/2016 – 08:00 4/5/2016 Average 2.2 ppm 06:00 Peak=3.5 ppm (15 min data) 06:00 3.3 ppm (1 hr av)	Light and variable SW 0-2 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
1/07/2016	00:40 – 08:45 Average 2.7 ppm 04:25 Peak=6.4 ppm (5 min data) 06:00 3.5 ppm (1 hr av)	WNW 1-2 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network Gas infrastructure (~4 km)	CH_4 event Miles Airport, peak at 20:10	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure

Table 35 Miles Airport methane Events

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra-tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
22/5/2016	1st two peaks 18:15-20:05 Average 4.9 ppm 2nd two peaks 22:05-00:15 Average 4.1 ppm 18:40 Peak=14.1 ppm (5 min data) 19:00 5.4 ppm (1 hr av)	NE 1-3 m s^{-1}	1st two peaks No correlations 2nd two peaks CH_4 and NO_x correlate	CSG activities Cattle Dam/reservoir	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	Feedlot 2km Agriculture CSG wells and gathering network	Similar pattern at 21:00 on the 23/5 with NE winds.	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
7/6/2016	06:30- 8:05 6.2 ppm 06:55 Peak=11.3 ppm (5 min data) 08:00 6.1 ppm (1 hr av)	WNW 1-3 m s^{-1}	No correlations	CSG activities Cattle Dam/reservoir	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network Gas infrastructure (GPF, WTF) about 2 km to WNW and NNW	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure

1/7/2016	20:00-21:40 Average 5.6 ppm 20:10 Peak=22.9 ppm (5 min data) 21:00 6.7 ppm (1 hr av)	SSW 2-3 m s^{-1}	No correlations	CSG activities Cattle Dam/reservoir	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network	CH_4 event Hopeland peak at 04:25 NO_x and CH_4 peaks coincide but values do not correlate	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
7/10/2016	20:35 6/10/16 – 03:35 7/10/16 Average 6.9 ppm 01:10 Peak=26.6 ppm (5 min data) 02:00 15.4 ppm (1 hr av)	SW 0-2 m s^{-1}	No correlations	CSG activities Cattle Dam/reservoir	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
3/11/2016	19:25 – 22:55 Average 6.7 ppm 22:40 Peak=18.2 ppm (5 min) 22:00 8.5 ppm (1 hr av)	ENE 1-3 m s^{-1}	No correlations	CSG activities cattle Dam/reservoir	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	Feedlot -2km Agriculture CSG wells and gathering network	CH_4 event Condamine, peak at 23:20 (2/11/2016)	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure

Table 36 Condamine methane Events

Event date	Event time (average and peak) and concentrations	Wind at time of peak concentra -tion	Species correlated	Possible sources in study area	Emission ratio interpretation	Sources identified upwind	Other info	Likely source
8/3/2016	02:05 – 02:45 Average 7.4 ppm 02:20 Peak=21.1 ppm (5 min data) 03:00 6 ppm (1 hr av)	Light and variable S 0-1 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network GPF 1km S/SE, compressor station 1.5 km SW Agriculture	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
20/3/2016	18:30 18/3/2016 – 00:35 21/3/2016 Average 7.0 ppm 19:35 Peak=79.2 ppm (5 min data) 21:00 25.4 ppm (1 hr av)	SW 0-2 m s^{-1} when CH_4 elevated	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network Gas infrastructure 1.5 km to SW Agriculture	Industry identified source as leak in CSG infrastructure about 150m to SW see case study in section 4.5.1	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure

13/5/2016	17:55 13/5/2016 – 07:50 14/5/2016 Average 2.2 ppm 22:30 Peak=4.6 ppm (5 min data) 23:00 3.7 ppm (1 hr av)	Light and variable SSW – SE - ENE 0-2 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network Gas infrastructure 1.5 km to SW GPF 1km to S/SE Agriculture	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
22/6/2016	21:15 21/6/2016 – 03:10 22/6/2016 Average 3.9 ppm 23:00 21/6/2016 Peak=8.7 ppm (5 min data) 00:00 22/6/16 5.5 ppm (1 hr av)	Light and variable NE 0-2 m s^{-1}	No correlations	CSG activities cattle	No correlation of CH_4 with CO_2 or CO indicates unlikely to be cattle or combustion	CSG wells and gathering network GPFs 10 km to NE and 13 km to ENE Agriculture	n/a	Information available suggests emissions of uncombusted CSG from CSG activities/infrastructure
3/11/2016	22:00 2/11/2016 –	SE	No correlations	CSG activities	No correlation of CH_4 with CO_2	GPF 1 km to S/SE	CH_4 event Miles Airport, peak at 23:40	Information available suggests emissions of

	01:30 3/11/2016 Average 2.9 ppm 23:20 2/11/2016 Peak=6.9 ppm (5 min data) 00:00 3/11/2016 4.1 ppm (1 hr av)	1-2 m s^{-1}	No CO or PM data	cattle	indicates unlikely to be cattle or combustion			uncombusted CSG from CSG activities/infrastructure

4.5 Case studies of events

The purpose of this section is to show in more detail 3 events where different pollution sources impacted air quality. Two of these events led to exceedances of air quality objectives or guidelines of $PM_{2.5}$ and TSP. This section also demonstrates the process that was used to investigate air quality exceedances or events in this study.

Section 4.5.1 discusses a CSG industry-related methane event at Condamine station, Section 4.5.2 discusses a regional smoke event which led to PM exceedances at all 3 Gas field sites and Section 4.5.3 discusses an exceedance of the nuisance dust guideline for TSP at Miles Airport.

4.5.1 Condamine methane event March 2016

Summary of event

- The methane event was observed at the Condamine Air quality station over 3 days from 18 March 2016 – 21 March 2016
- The largest ambient concentration of methane in this study up until December 2016 was observed in this event. The highest concentrations of methane were 79 ppm (maximum 5 minute average concentration) with a maximum hourly average concentration of 25 ppm.
- There are no air quality objectives for methane
- Winds during this period were predominantly from the SW, with a lesser frequency from the NE. The largest methane concentrations were observed in SW wind direction (see Figure 12)
- Highest methane concentrations were observed primarily in low wind speeds at night (Figure 13). This is likely because there is less vertical and horizontal mixing at night in calm conditions so less dilution of the methane plume
- There were no other pollutants that correlated with methane during the event
- Possible sources of methane to the SW of the station include CSG infrastructure and agriculture as well as legacy bores and seeps

Origin Energy advised that the emission source was due to a failure of an auto-low point drain injection point approximately 150 m to the SW of the Condamine ambient air station. This point is designed to move water from the gas gathering line into the adjacent water gathering line. The leak occurred because the automatic low point drain remained in the open position after operation, resulting in a gas release. Origin advised that auto-low point drains were not used widely across Origin's Assets and they have been removed from service. Origin advised that this issue was rectified immediately upon inspect by manually closing the drain and the gas release was reported to the DNRM Petroleum and Gas Inspectorate.

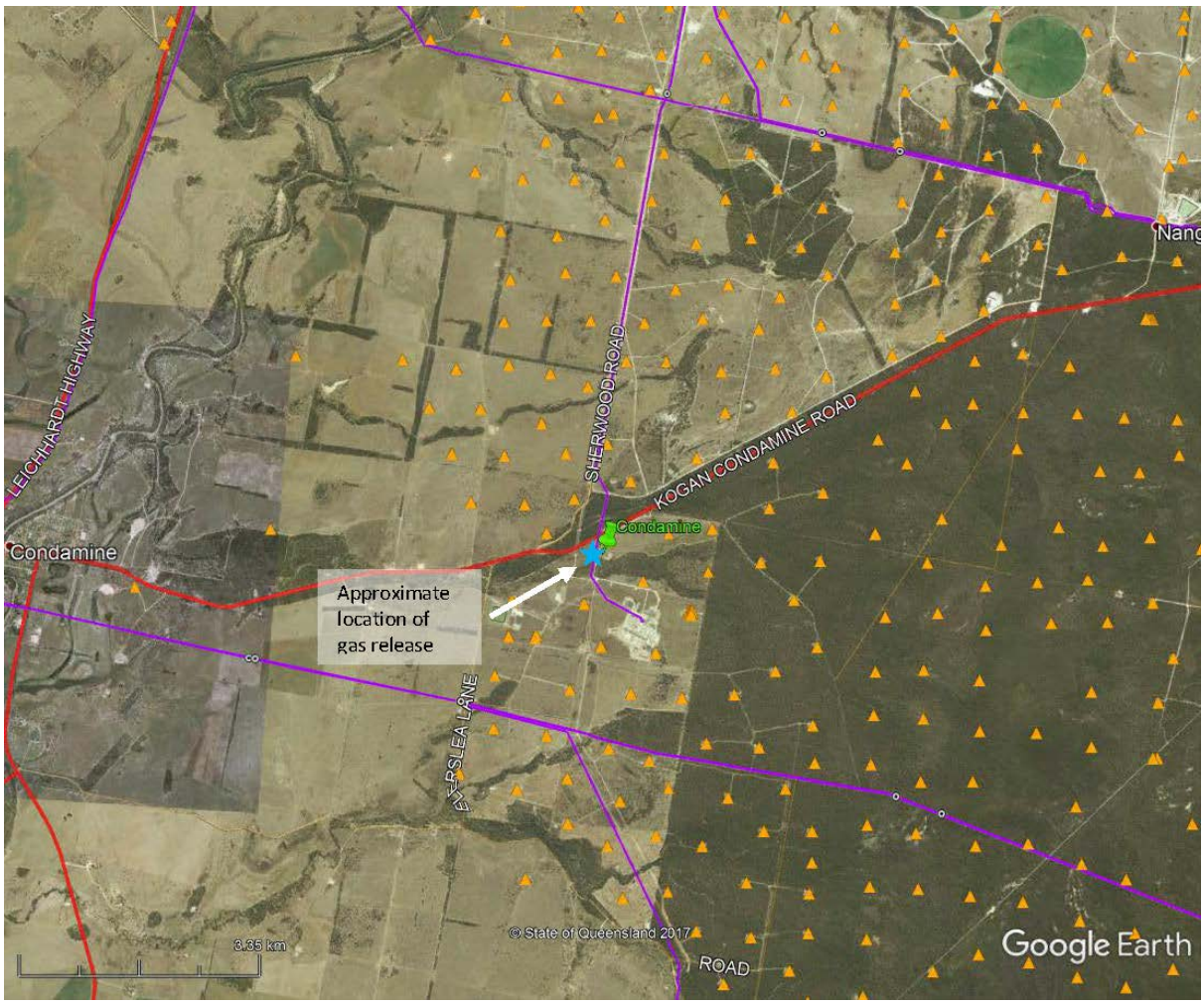

Figure 11 The location of Condamine measurement site (green pin). The red lines are major roads, purple lines are petroleum (gas) pipelines, and the orange triangles are wells. Blue star indicates the approximate location of the infrastructure fault as identified by Origin Energy

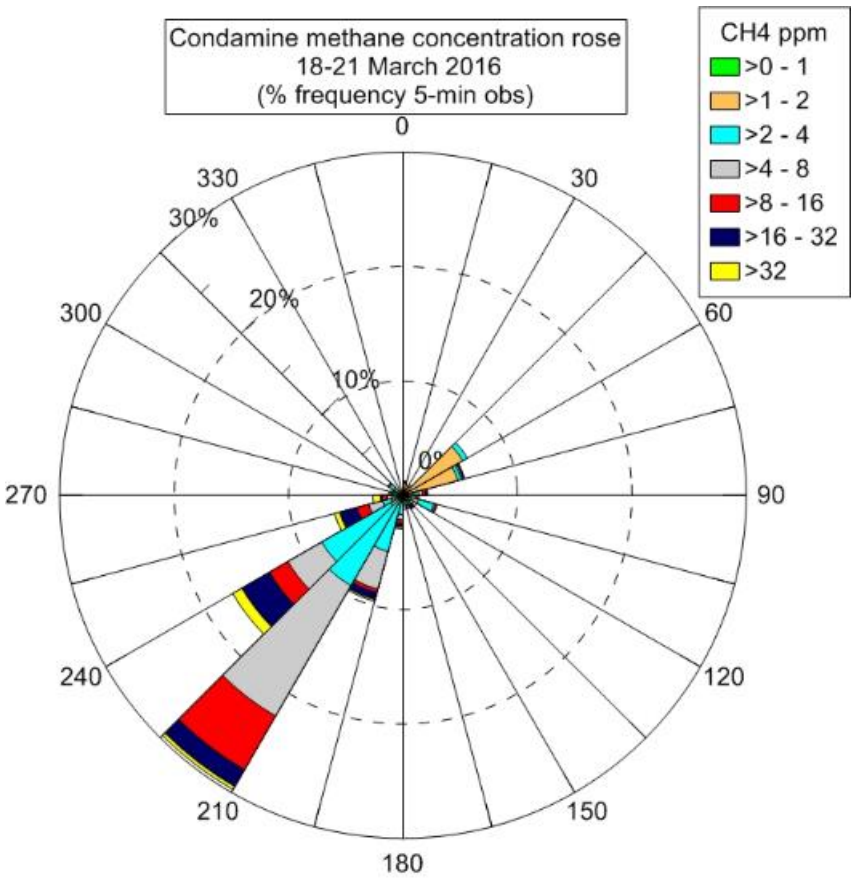

Figure 12 Pollution rose for methane during the Condamine event from the 18-21 March 2016 showing higher methane concentrations associated with winds from the SW. The concentration of methane as a function of wind direction is shown. The scale in the top right hand corner shows methane concentrations according to colour-note that the scale is exponential $f_{(x)}=2^x$.

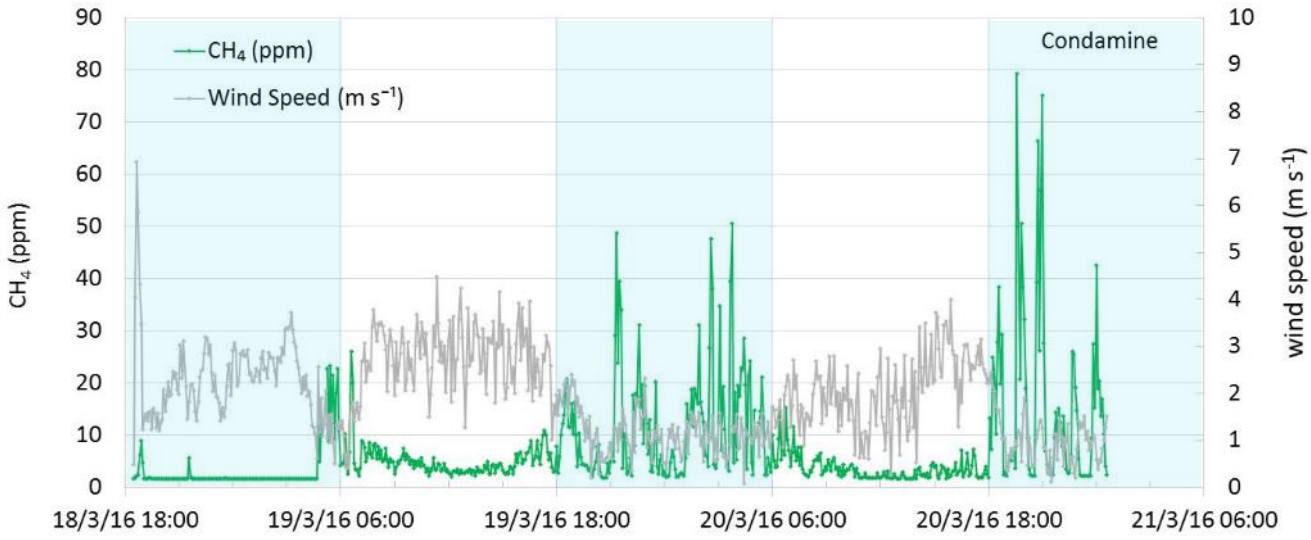

Figure 13 Time series of methane and wind speed during the Condamine event (5 minute average data shown) showing higher methane concentrations associated with low wind speeds. Blue shading is night time. Y axis on left is methane (ppm) and on right is wind speed (m s^{-1})

Implications for air quality

As previously stated methane does not have an air quality objective, and is included in this study as a tracer for other species from CSG-related sources which do have air quality objectives. The maximum 5-minute average methane concentration observed, 79 ppm, corresponds to an approximate 1/12,000 dilution of pure CSG which is 96-98% methane (Lawson et al., 2017). This dilution factor can be used to calculate the expected concentration of other components in the CSG. The measured concentration of other components in the CSG range from 0.012% (ethane) to 0.0002% (i- butane), corresponding to 120 ppm (147,000 µg m^{-3}) to 2 ppm (4745 µg m^{-3}). No other VOCs (including BTX) were detected above the detection limit of 0.0001% (1 ppm) (Lawson et al., 2017). As such, during this event, the maximum calculated concentration of other components in the CSG once diluted are ~ 7 ppb ethane, < 0.1 ppb BTX and < 0.1 ppb hydrogen sulphide. These concentrations are well below the NEPM/EPP annual air quality objectives of 3 ppb for benzene, 100 ppb for toluene and also well below the 24-hour EPP standard for H_2S of 110 ppb and 24 hour toluene objective of 1000 ppb. As such, while the methane concentrations during this event were significantly elevated above background concentrations, the low levels of these other gases in the CSG is expected to have led to very low ambient concentrations, well below air quality objectives, once the CSG was diluted in ambient air. The Radiello sampling program for this study finished in January 2016 (see Part 2 of this report) so there were no Radiello VOC or hydrogen sulphide samplers deployed at Condamine station during this event.

4.5.2 Hopeland, Miles Airport and Condamine Regional smoke event, 6th December 2016

Hopeland air quality station

Summary of event

$PM_{2.5}$ Exceedance: 35.9 µg m^{-3} (24-hour), Peak=271.8 at 15:15, winds NNE-N-NW 4-6 m s^{-1}

PM 10 > 80% of air quality objective at 46.3 µg m^{-3} (24-hour), Peak=280.6 at 15:15 (5 min data), winds NNE-N-NW 4-6 m s^{-1}

TSP > 80% of nuisance dust guideline at 58.1 µg m^{-3} (24-hour), Peak=291.5 µg m^{-3} at 15:15 (5 min data), winds NNE-N-NW 4-6 m s^{-1}

- The approximate location of the Hopeland air quality station is shown in Figure 14. The station is on a private property and the approximate location is shown for privacy reasons.
- The time series of $PM_{2.5}$ and carbon monoxide concentrations are shown in Figure 15. $PM_{2.5}$ and CO concentrations are correlated and show similar behaviour on the 6th December.
- The times series of $PM_{2.5}$, PM_{10} and TSP is shown in Figure 16. There are 2 PM peaks contributing to the elevated PM concentrations on this day. The first is at 15:15 and has very similar levels of $PM_{2.5}$, PM_{10} and TSP. This shows that the particles are mainly in the small fraction, or $PM_{2.5}$ fraction during this peak. This first PM peak corresponds with the maximum carbon monoxide concentration (Figure 15).
- The second peak at 18:45 shows relatively smaller amounts of $PM_{2.5}$ and larger amounts of PM_{10} and TSP. This shows that the particles for this second peak are in the larger or coarse size fraction. The second PM peak corresponds with a smaller carbon monoxide peak.
- Figure 17 shows pollution roses for Hopeland for $PM_{2.5}$ and for the coarse fraction (PM_{10}-$PM_{2.5}$). These plots show the 5-minute average concentration of PM as a function of wind direction from midday to midnight on 6th December.
- Figure 17 shows that the highest concentrations of $PM_{2.5}$ (> 150 µg m^{-3}) came from the NW (corresponding to the first peak in the time series), while the highest concentrations of the coarse PM (75 – 100 µg m^{-3}) came from the SW, corresponding to the second peak in the time series.

The first peak has been identified as smoke from vegetation fires for the following reasons:

- Landholders nearby reported smoke
- Figure 18 shows satellite images of fires on the 5th and 6th December which are 50 - 60 km N – NW of Hopeland, the direction of the wind during the first peak.
- The particles are predominantly fine fraction ($PM_{2.5}$) which is typical of smoke
- CO and $PM_{2.5}$ concentrations correlated (Figure 26), and the ratio of $PM_{2.5}$/CO is typical of smoke

- CO and CO_2 are correlated and the ratios are typical of smoke

The second peak has been identified as a local dust event for the following reasons:

- The PM is mainly larger fraction (PM_{10} and TSP) which is typical of dust or soil
- The highest concentrations came from a different wind direction to the smoke (SW) indicating a different source
- Peaks are sharp and short-lived indicating a local source

However there may still be smoke in the air during this event as indicated by the PM and CO concentrations showing similar patterns and correlating during the entire day.

As such, smoke from vegetation fires is the main likely cause of the $PM_{2.5}$ exceedance at Hopeland on the 6th Dec 2016. A combination of smoke from vegetation fires, and a local dust event later in the day was the likely cause of the 24-hour PM_{10} and TSP concentrations exceeding 80% of the air quality objective and nuisance dust guideline for TSP. The source of the dust event (whether related to agriculture, CSG or other activities) is unknown.

Figure 14 Approximate location of Hopeland air quality station shown by blue circle. Station is on a private property and approximate location is shown for privacy reasons. The red lines are major roads, purple lines are petroleum (gas) pipelines, and the orange triangles are wells.

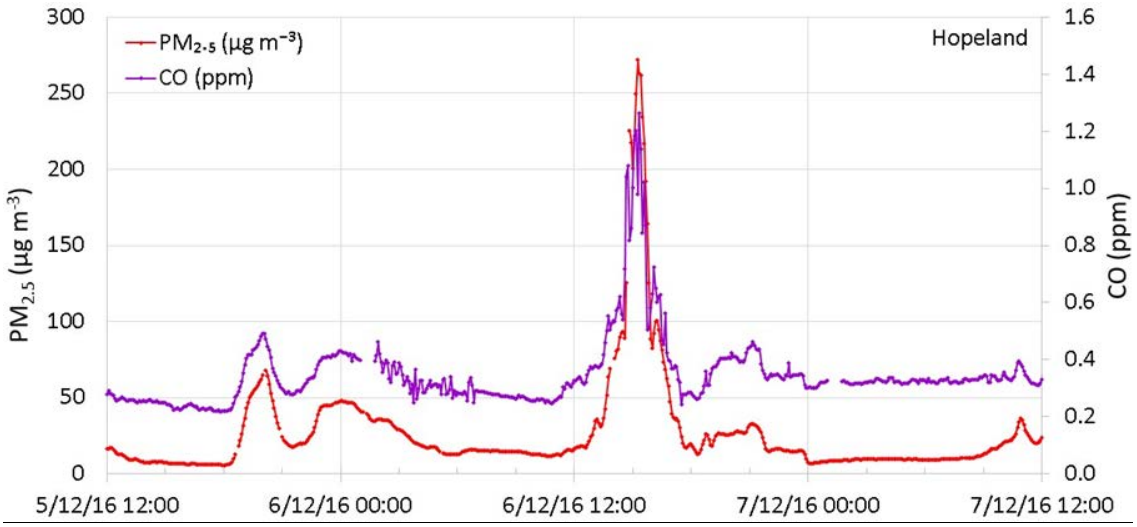

Figure 15 Time series of CO and $PM_{2.5}$ during the 6th Dec event at Hopeland

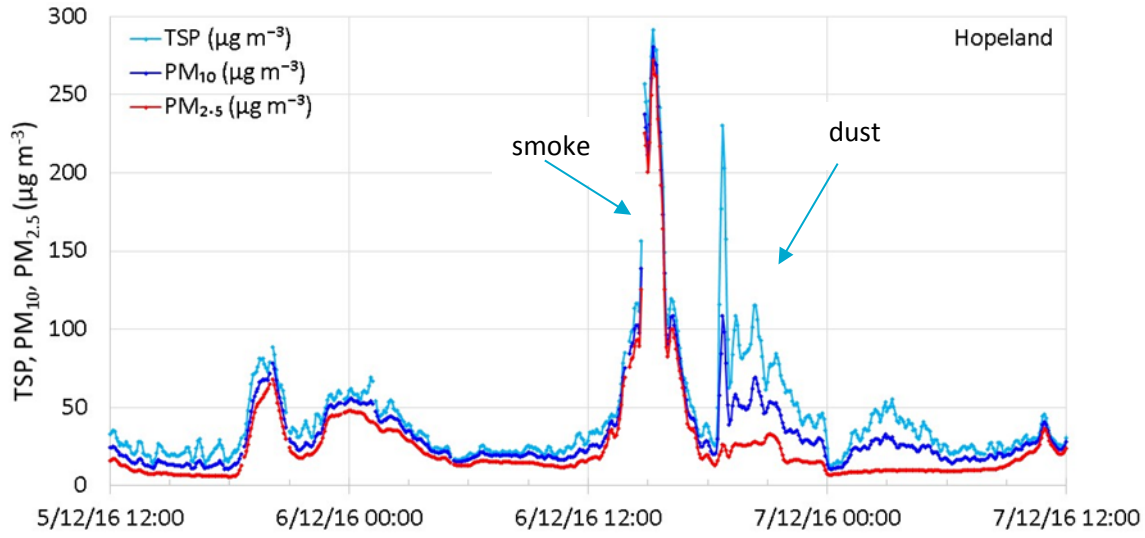

Figure 16 Time series of $PM_{2.5}$, PM_{10} and TSP during the 6th Dec event at Hopeland

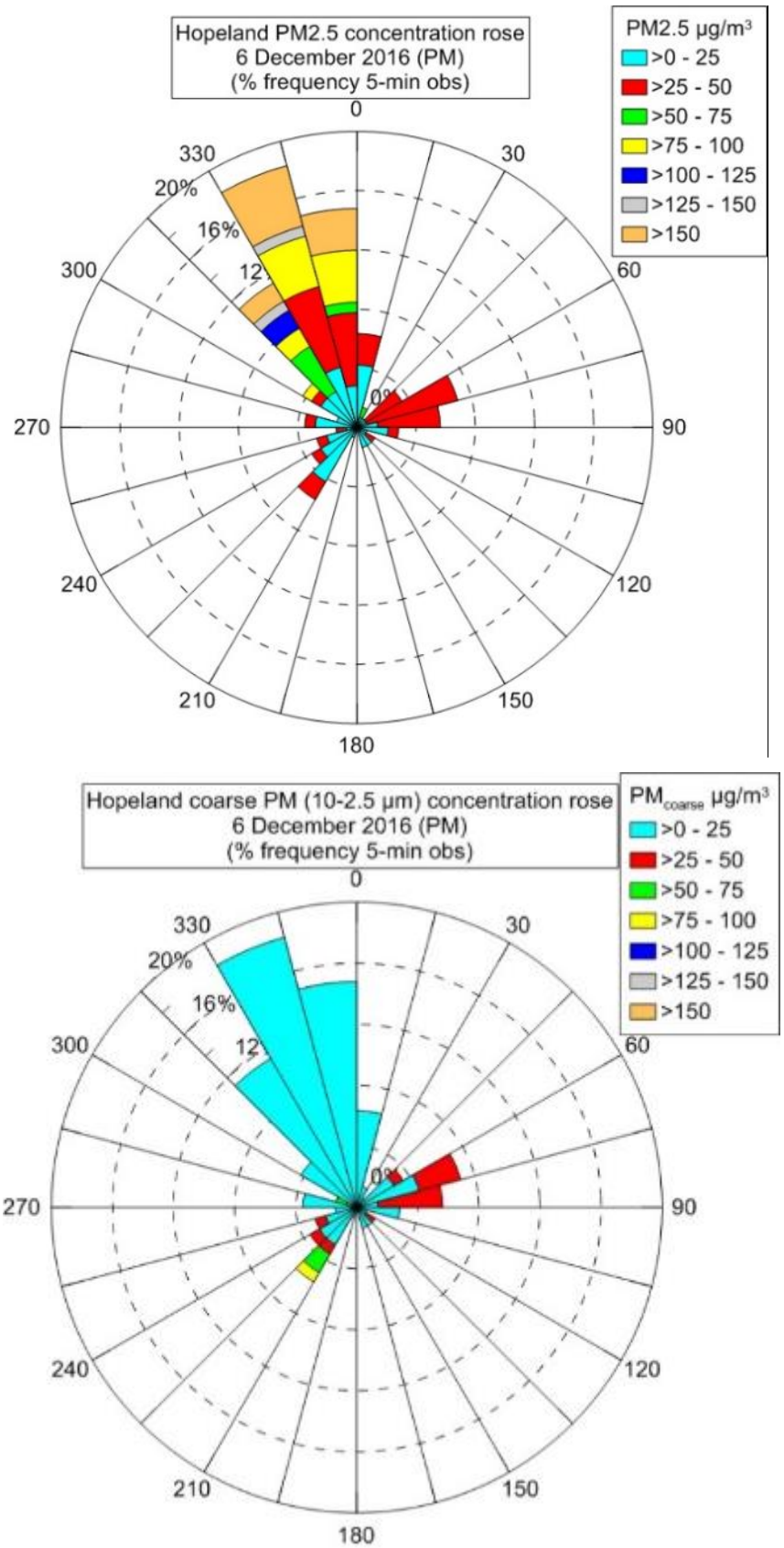

Figure 17 Pollution roses of (top) $PM_{2.5}$ at Hopeland in afternoon from 12:00-12:59 on 6th Dec showing higher $PM_{2.5}$ concentrations associated with winds from the NW; and (bottom) pollution rose of coarse particles (PM_{10}-$PM_{2.5}$) in afternoon from 12:00 –23:59 on 6th Dec.

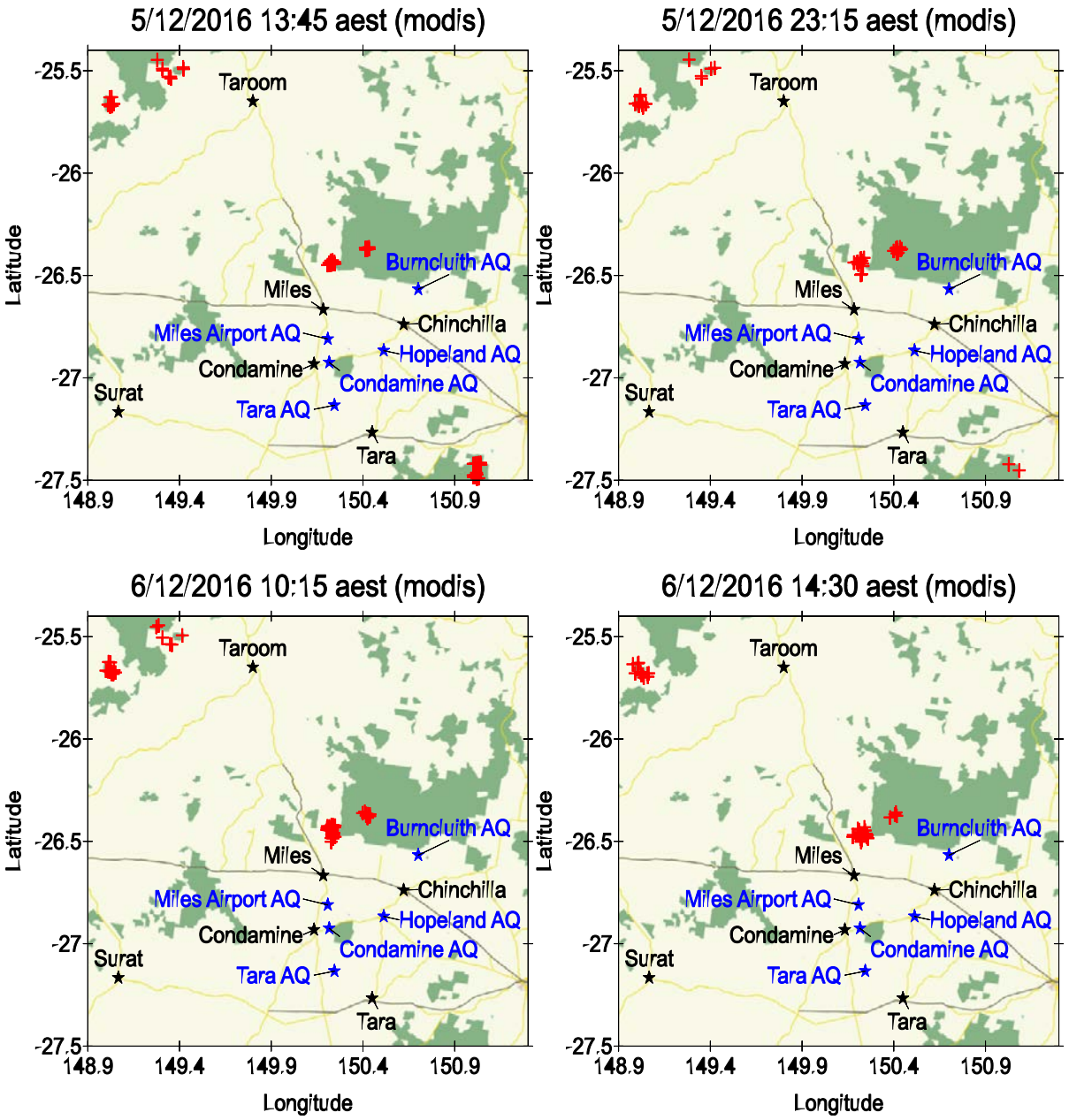

Figure 18 Hotspot fire data for the study region for the 5th and 6th December (fire products from MODIS, downloaded using FIRMS, see A.5)

Miles Airport air quality station

Summary of event

$PM_{2.5}$ Exceedance 25.7 µg m^{-3} (24 hour), Peak=125.4 µg m^{-3} at 00:25 (5 min data), winds NNE / NNW 3-5 ms^{-1}

- The location of the Miles Airport is site shown in Figure 19 (green pin).
- A time series of $PM_{2.5}$ and carbon monoxide is shown in Figure 20. $PM_{2.5}$ and carbon monoxide concentrations are correlated and show similar behaviour on the 6th December
- A times series of $PM_{2.5}$, PM_{10} and TSP is shown in Figure 21. The largest concentration of PM is observed at 00:25 on the 6th December and has very similar levels of $PM_{2.5}$, PM_{10} and TSP. This shows that most particle mass is in the small size fraction, or $PM_{2.5}$ fraction. The PM peak concentration occurs at the same time as the maximum carbon monoxide peak concentration (Figure 20).
- Figure 22 shows a pollution rose for $PM_{2.5}$ for Miles Airport. This plot shows the concentration of $PM_{2.5}$ as a function of wind direction in the morning from 0:00 -12:00 on 6th December. This shows that the highest concentrations of $PM_{2.5}$ came from the N/NE.

This peak has been identified as smoke for the following reasons:

- Figure 18 shows hotspot satellite images of fires on the 5th and 6th December which are 30 – 50 km N / NE of Miles Airport. This is the direction of the wind during the highest PM concentrations.
- The particles are predominantly small fraction which is typical of smoke.
- Carbon monoxide and $PM_{2.5}$ concentrations are correlated (Figure 26), and the ratio of $PM_{2.5}$/CO is typical of smoke from other studies
- The ratio of carbon monoxide and carbon dioxide is typical of smoke from vegetation fires

It is likely that smoke persisted in the air for the rest of the day suggested by similar behaviour of $PM_{2.5}$ and carbon monoxide concentrations

As such, the likely cause of the $PM_{2.5}$ exceedance at Miles Airport on the 6th December 2016 was smoke from vegetation fires.

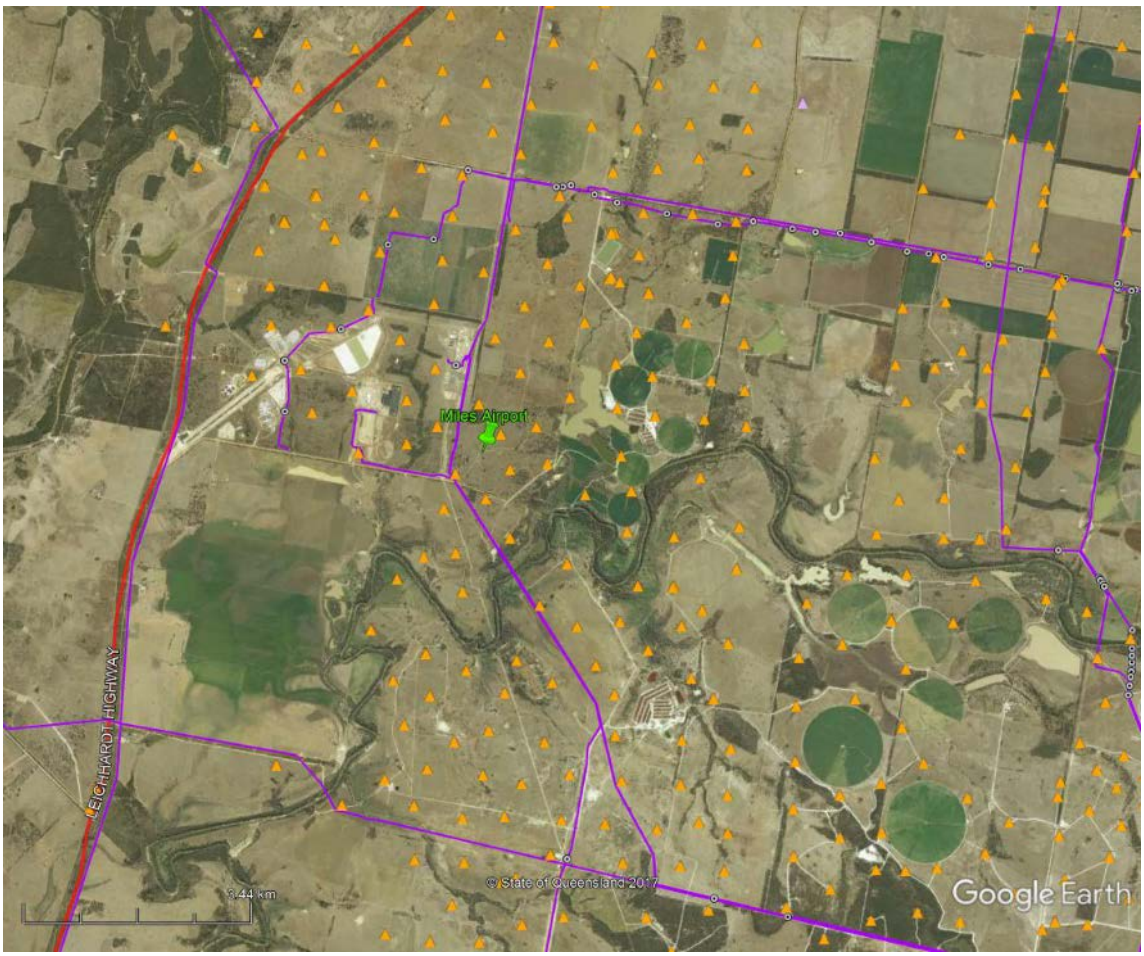

Figure 19 The Miles Airport measurement location (green pin), red lines are major roads, purple lines are petroleum (gas) pipelines, orange triangles are CSG wells.

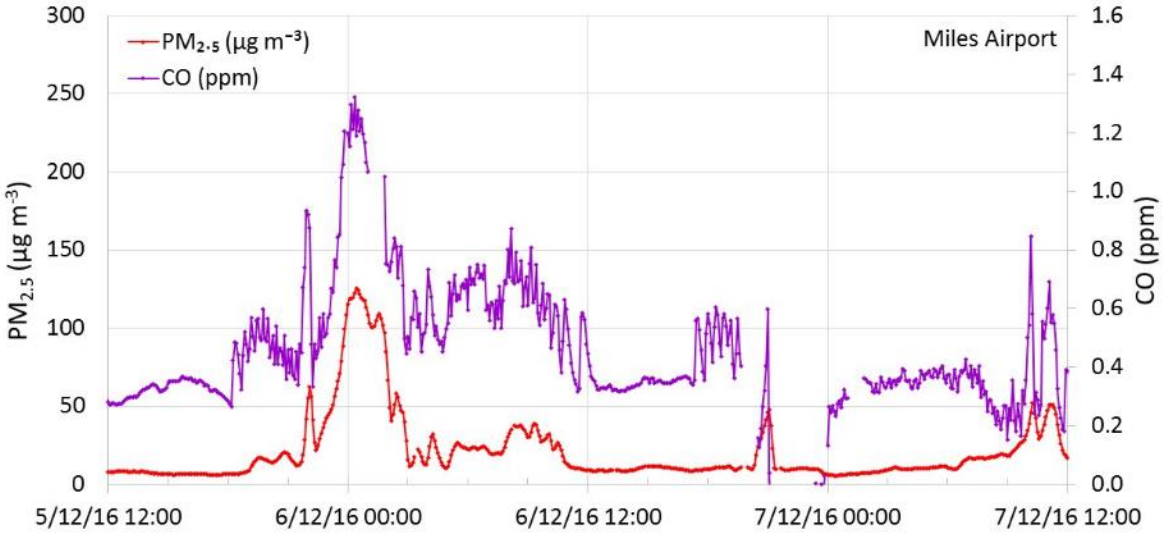

Figure 20 Time series of CO and $PM_{2.5}$ at Miles Airport during event on 6th Dec 2016

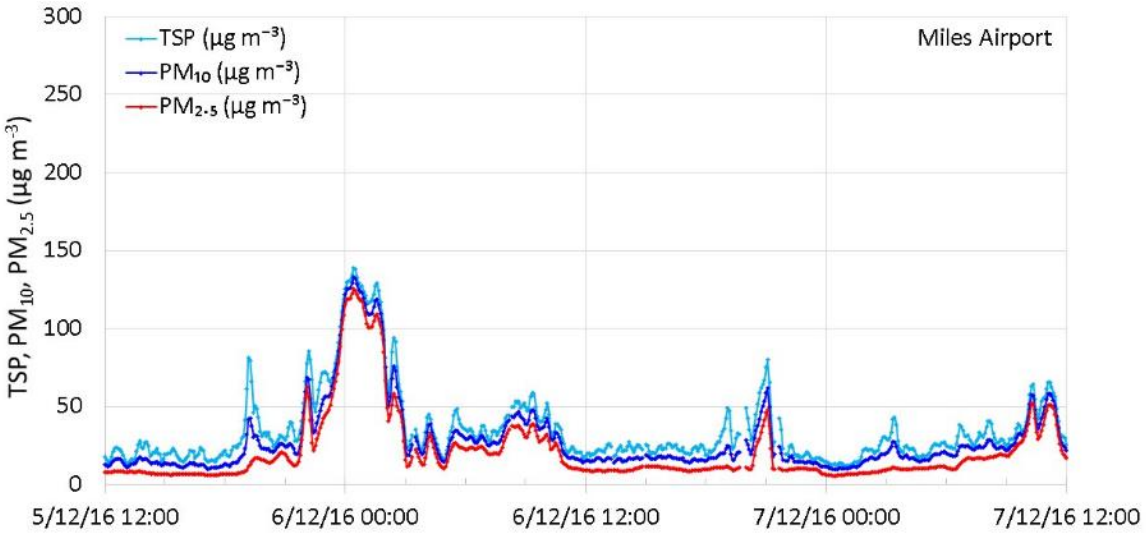

Figure 21 Time series of $PM_{2.5}$, PM_{10} and TSP during event at Miles Airport on 6th Dec 2016

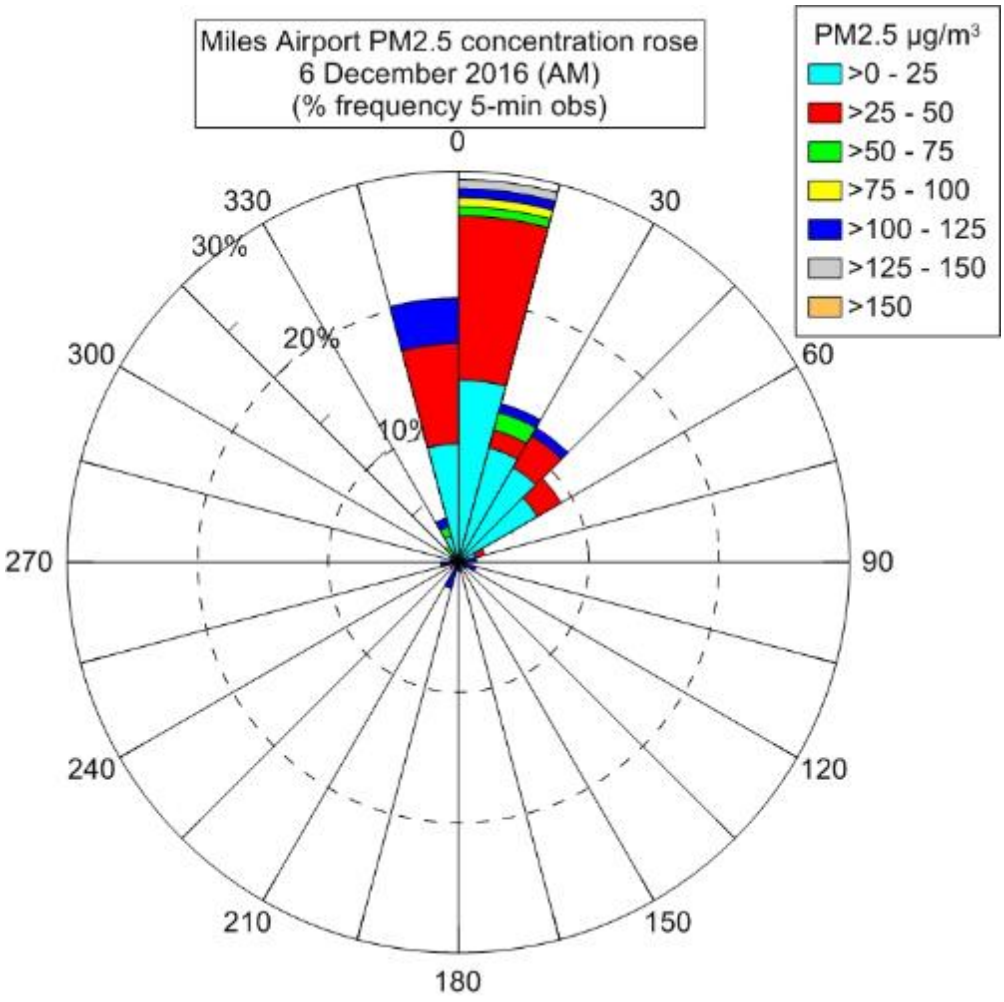

Figure 22 Pollution rose of $PM_{2.5}$ during morning of event at Miles Airport which shows $PM_{2.5}$ concentration as a function of wind direction from 0:00-12:00 on the 6th December 2016

Condamine air quality station

Summary of event

$PM_{2.5}$ exceedance 28.1 µg m^{-3} (24 hour), Peak=111.5 µg m^{-3} at 01:35 (5 min data), winds N-NNE, 2-4 ms^{-1}

TSP exceedance of nuisance dust guideline - 66.5 µg m^{-3} (24 hour), Peak=596.4 µg m^{-3} at 19:25 (5 min data), winds SW - SSW 1-4 ms^{-1}

PM_{10} >80% of air quality objective, 44.4 µg m^{-3} (24 hour) Peak=239.1 µg m^{-3} at 19:25 (5 min data), winds SW - SSW 1-4 ms^{-1}

- The location of the Condamine site is shown in Figure 11 (green pin).
- A time series of $PM_{2.5}$ and carbon monoxide concentration is shown in Figure 23. $PM_{2.5}$ and carbon monoxide concentrations are correlated and show similar behaviour until 4pm on the 6th December.
- A times series of $PM_{2.5}$, PM_{10} and TSP are shown in Figure 24.
- The largest $PM_{2.5}$ concentration occurs at 01:35 and has very similar levels of $PM_{2.5}$, PM_{10} and TSP. This shows that the particle mass is mainly from the small size fraction, or $PM_{2.5}$ fraction. This PM peak occurs at the same time as the maximum carbon monoxide peak (Figure 23).
- The largest PM_{10} and TSP peaks occur at around 19:00 and show the particle mass is made up of a small concentration of $PM_{2.5}$ and larger concentrations of PM_{10} and TSP. The particle mass during these later peaks are mainly in the larger or coarse size fraction (Figure 24).
- Figure 25 shows pollution roses for Condamine $PM_{2.5}$ for AM (morning) and PM (afternoon) and pollution roses for the coarse fraction (PM_{10}-$PM_{2.5}$) for morning and afternoon. These plots show the concentration of PM as a function of wind direction
- Figure 25 shows that the highest concentrations of $PM_{2.5}$ came from the N and NW (corresponding to the first peak in the time series) in the morning, with lower concentrations in the afternoon. The highest concentrations of the coarse PM came from the SW direction in the afternoon, with lower concentrations in the morning.

The $PM_{2.5}$ peak at 01:35 has been identified as smoke from vegetation fires for the following reasons:

- Figure 18 shows satellite images of fires on the 5th and 6th December which are 40 - 60 km N - NE of Condamine, the direction of the wind during the first peak (N/NNE)
- The particles are predominantly fine fraction ($PM_{2.5}$) which is typical of smoke
- CO and $PM_{2.5}$ concentrations are correlated, and the ratio of $PM_{2.5}$/CO is typical of smoke from vegetation fires from other studies
- The ratio of CO and CO_2 is typical of smoke from vegetation fires

The later peaks of PM_{10} and TSP have been identified as being a local dust event for the following reasons:

- The PM is mainly larger fraction (PM_{10} and TSP) which is typical of dust or soil, whereas smoke is mainly $PM_{2.5}$
- Highest concentrations came from a different wind direction to the smoke event (SW)
- Multiple peaks are sharp and short-lived indicating a local source

However there may still be smoke in the air during this event as indicated by the PM and carbon monoxide concentrations showing similar behaviour until 16:00.

As such, smoke from vegetation fires is the main likely cause of the $PM_{2.5}$ exceedance at Condamine on the 6th December 2016. A combination of smoke, and a local dust event later in the day was the likely cause of the 24-hour TSP exceedance of the nuisance dust guideline, and PM_{10} exceeding 80% of the air quality objective. The source of the dust event was likely associated with both unsealed roads and/or CSG development or operational activities to the SW.

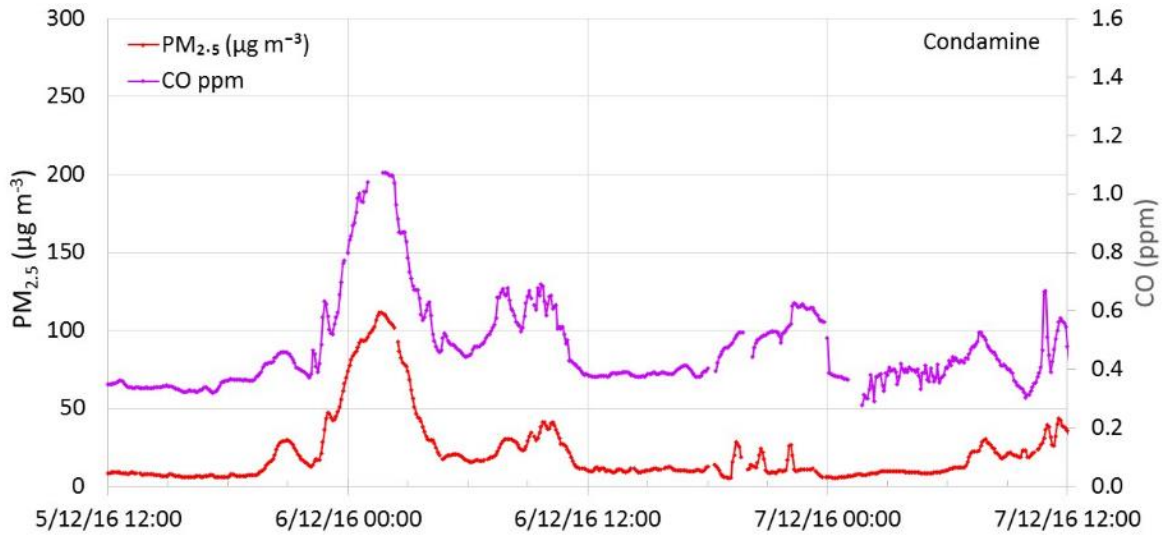

Figure 23 Time series of CO and $PM_{2.5}$ at Condamine air quality station

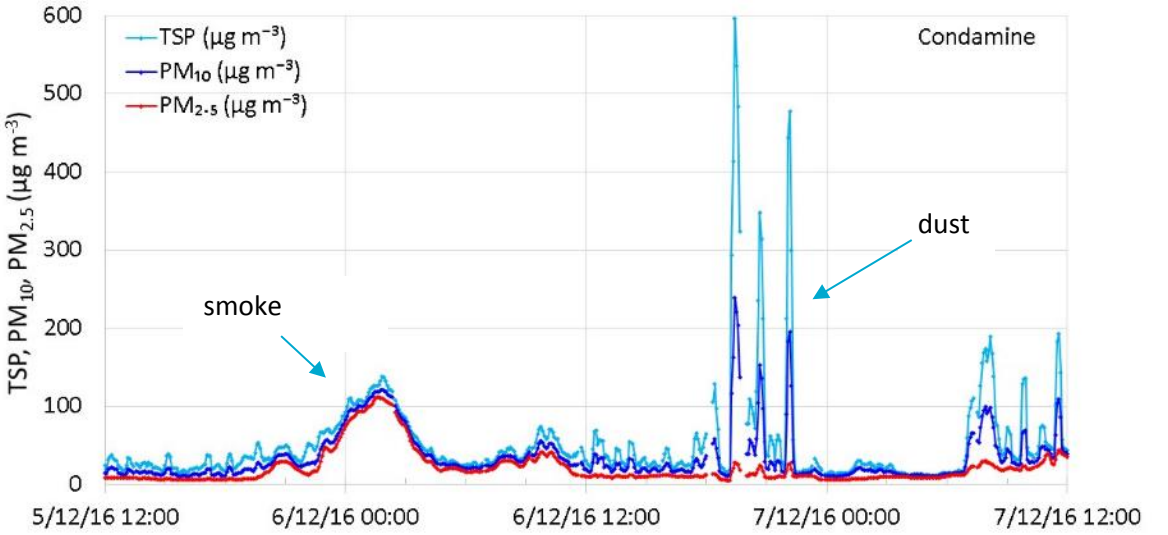

Figure 24 Time series of $PM_{2.5}$, PM_{10} and TSP at Condamine air quality station

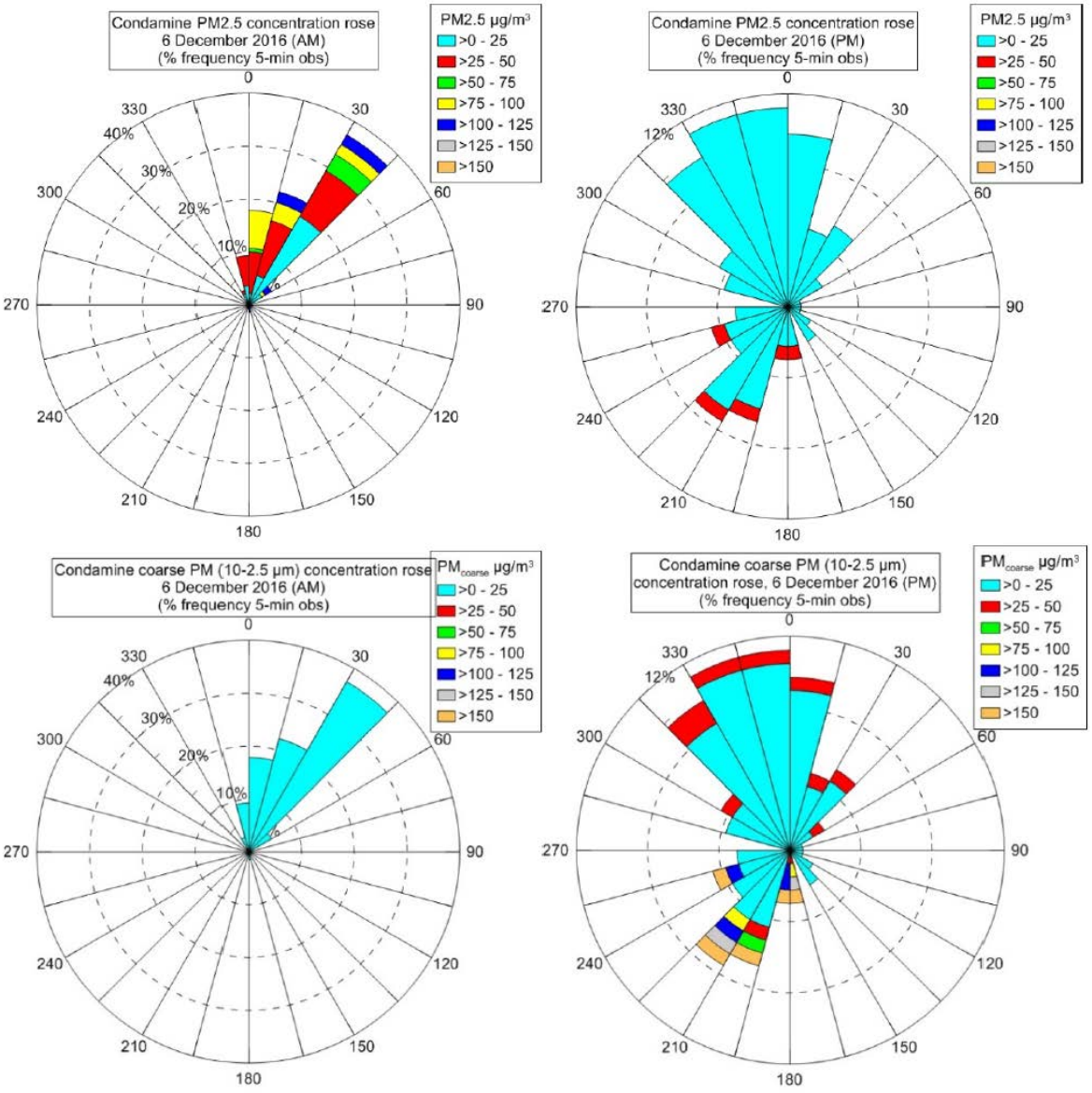

Figure 25 Pollution roses for Condamine Air quality station (top) $PM_{2.5}$ morning (top left) and afternoon (top right) and bottom, coarse particles morning (bottom left) and afternoon (bottom right)

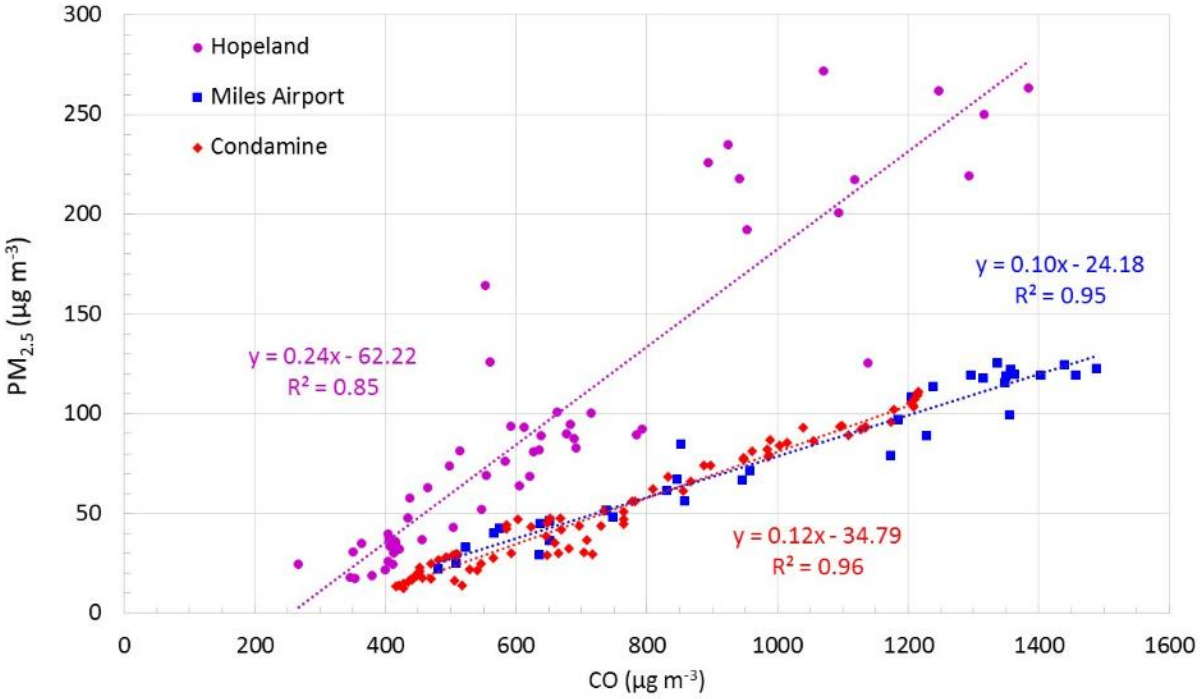

Figure 26 $PM_{2.5}$ versus carbon monoxide concentrations for Hopeland (purple), Miles Airport (blue) and Condamine (red) during peak $PM_{2.5}$ concentrations on the 6th December 2016

Regional smoke events

Analysis above shows that vegetation fires impacted all 3 sites on the 6th December. The wind directions during the peak $PM_{2.5}$ concentrations suggest that the fires to the N of the air monitoring sites (in the Barakula State forest) were likely responsible for the exceedances observed at all 3 sites. This is an example of a regional fire event, where an emission source(s) can impact the pollutant concentrations in an area over hundreds of kilometres. This event also shows how multiple sources (for example fires and dust at both Hopeland and Condamine) can increase pollutant concentrations at a site over 24 hours in different wind directions. In such cases there is no single cause of an air quality objective exceedance, but rather the exceedance is the cumulative result of pollutants emitted from several different sources.

The Tara Region station was not operational during this event due to power issues. There were no exceedances at Burncluith on the 6th December, however there was also evidence of smoke in the evening in the carbon monoxide measurements, though concentrations were well below air quality objectives. There are no $PM_{2.5}$, PM_{10} or TSP measurements at Burncluith.

There was also an increase in ozone concentrations during the smoke event at several sites, consistent with the formation of ozone in smoke plumes. Concentrations of ozone at all sites were less than 80% of the air quality objective and as such ozone is not presented here.

4.5.3 Miles Airport TSP event, 15th October 2016

Summary of event

TSP exceeded the nuisance dust guideline, 62.1 µg m^{-3} (24 hour average). Peak=1231.5 µg m^{-3} at 19:20 (5 min average). Winds E - ENE 2 ms^{-1}

- Figure 19 shows location of Miles Airport station (green pin)
- Time series of particles ($PM_{2.5}$, PM_{10} and TSP) are shown in Figure 27. During the PM peak at 19:20 the particle mass is made up of a small concentration of $PM_{2.5}$ and larger concentrations of PM_{10} and TSP. The particle mass is therefore mainly in the larger or coarse size fraction.
- Time series of TSP with methane and carbon dioxide are shown in Figure 28 and Figure 29. These show that the TSP corresponds with a peak in both carbon dioxide and methane concentrations. There are also additional methane and carbon dioxide peaks that occur after the TSP peak which are accompanied by only small concentrations of TSP.
- A pollution rose (Figure 30) shows the concentration of TSP as a function of wind direction. The rose shows that the highest concentration of coarse particles came from the E/ENE wind direction.

The source of the TSP peak at 19:20 on the 15th October 2016 has been identified as likely being from dust associated with cattle farming (most likely from movement of cattle) for the following reasons:

- The PM is mainly larger fraction (PM_{10} and TSP) which is typical of dust or soil
- Methane and carbon dioxide peaks occur at the same time as TSP (are correlated with TSP) suggesting a common source.
- Methane is emitted from the breath of cattle along with carbon dioxide. Methane and carbon dioxide are correlated (Figure 31) and the ratio (0.03) is within the range of ratios reported from cattle (Bai et al. 2014). The ratio is also similar to that observed in ambient air attributed to cattle in the GISERA Regional methane flux project (Etheridge et al., 2017)
- There are agricultural areas and feedlots to the ENE of the Miles Airport station (the wind direction of the peak TSP concentration)

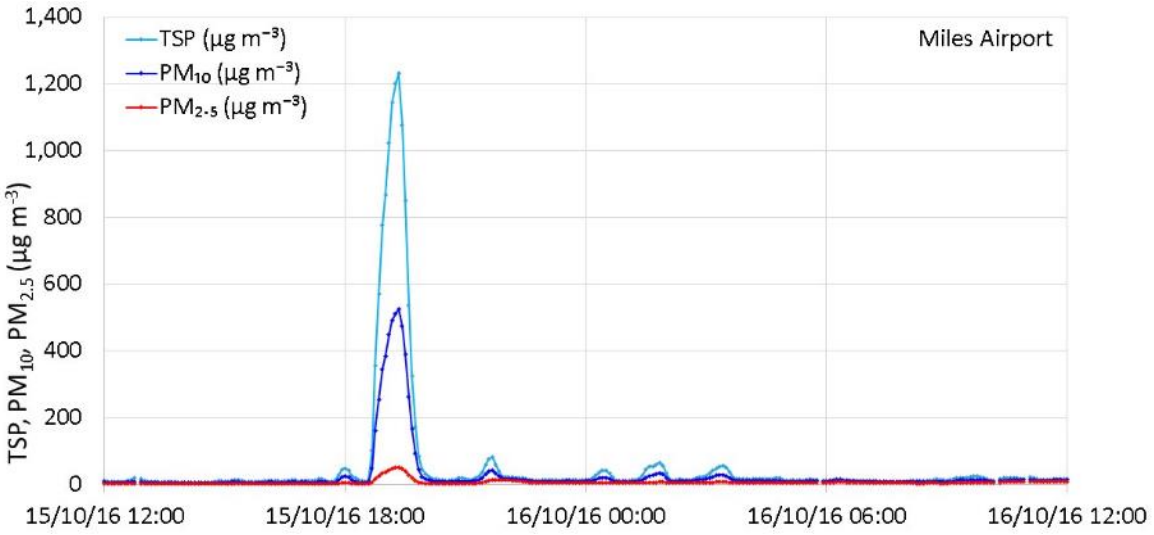

Figure 27 Time series of $PM_{2.5}$, PM_{10} and TSP during event

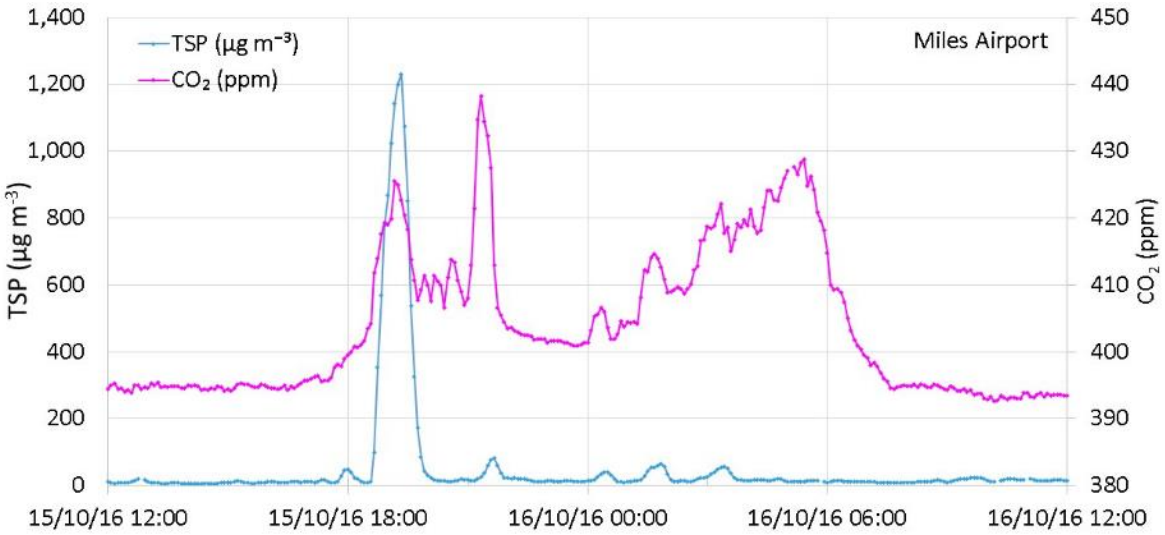

Figure 28 Time series of CO_2 and TSP during event

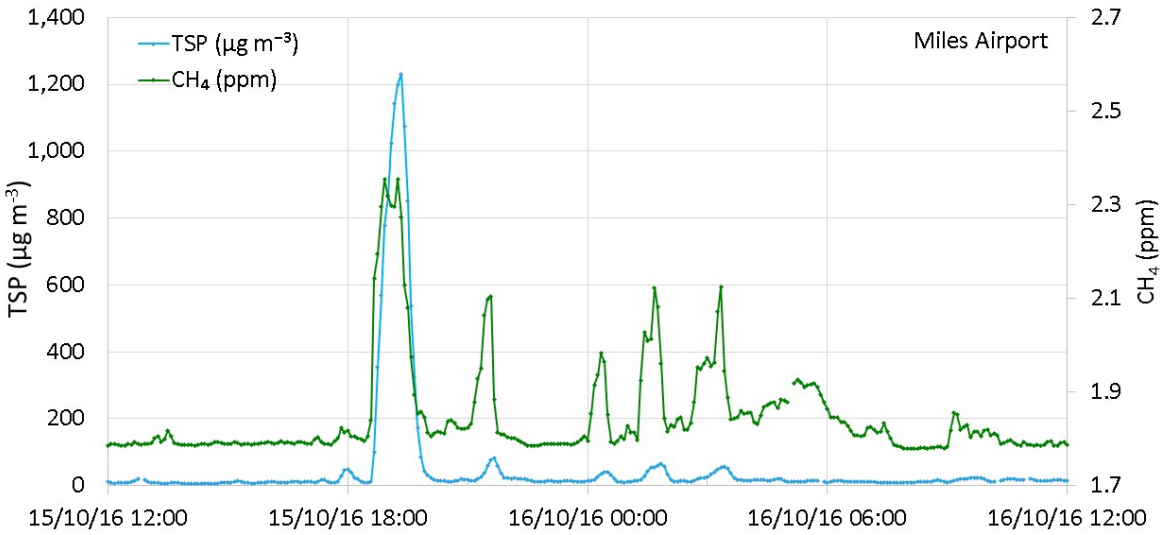

Figure 29 Time series of TSP and CH_4 during event

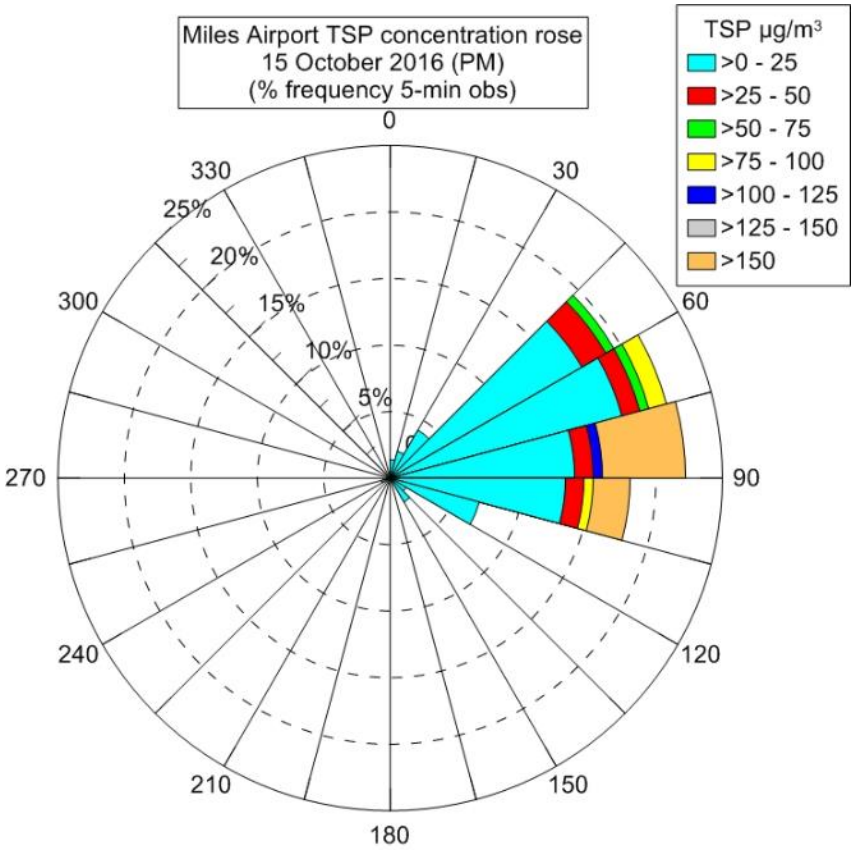

Figure 30 Pollution rose of TSP during event

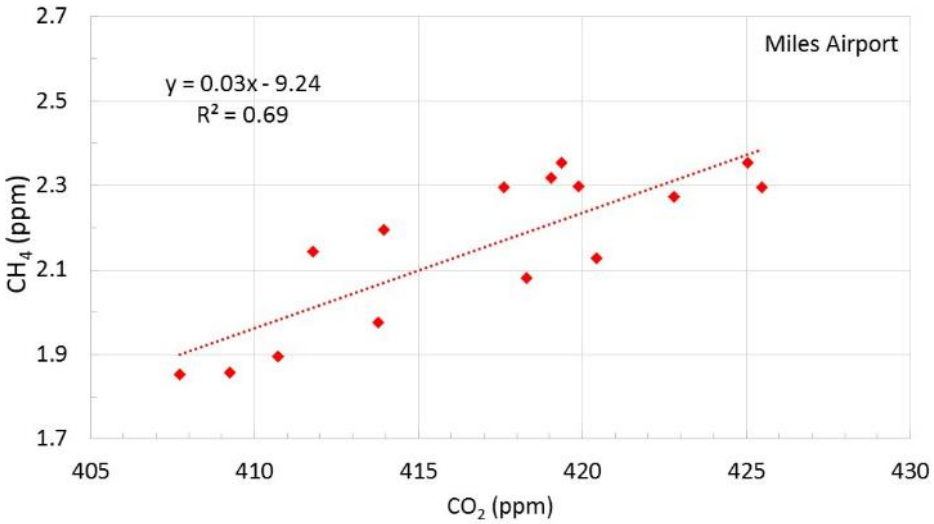

Figure 31 methane vs CO_2 during TSP peak. Slope is ratio of 0.03 indicating cattle

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National Environment Protection (Ambient Air Quality) Measure (NEPM) (2016) https://www.legislation.gov.au/Details/F2016C00215

Hotspotdata: LANCE FIRMS operated by the NASA/GSFC/Earth Science Data and Information System (ESDIS) - https://firms2.modaps.eosdis.nasa.gov/download/

Sentinel Hotspots data - https://sentinel.ga.gov.au/#/ © Commonwealth of Australia (Geoscience Australia) 2018

Part II Passive sampler network and CSIRO measurements

5 Introduction

This section reports measurements collected via a network of passive Radiello samplers, including VOCs, aldehdyes and hydrogen sulphide. VOC passive samplers were deployed at 10 sampling sites in the study area from September 2014- January 2016 and aldehyde and hydrogen sulphide passive samplers were deployed for 7 months from June 2015 – January 2016. The passive sampler technique allows measurement 54 individual gases, including 4 of the 5 gases listed in the Air Toxics NEPM (benzene, toluene and xylenes and formaldehyde), and several additional VOCs and inorganic gases, including hydrogen sulphide and chlorinated gases, included in the NPI. This section also reports on independent VOC and aldehyde measurements made by CSIRO alongside the passive Radiello samplers for a two week period at the Hopeland Gas field site from 24 June – 8 July 2015.

5.1 Potential sources of VOCs, aldehydes and inorganic gases in study area

5.1.1 CSG related emission sources

A review of CSG emission sources in the study area identified that the CSG industry is a source of several VOCs, aldehydes and hydrogen sulphide (Lawson et al., 2017).

Unprocessed coal seam gas is 96 - 98 % methane with the remainder mostly comprised of nitrogen and carbon dioxide. A review of CSG related emission sources (Lawson et al., 2017) shows that CSG contains trace (~0.01%) levels of VOCs including ethane and propane, with lower levels of VOCs and inorganic gases identified in the NEPM and EPP such as benzene, toluene, xylenes and hydrogen sulphide (< 1 ppm or < 0.0001%). However because emissions of CSG may occur from several sources including during well construction, production, transport and storage phases via venting and emissions from wells, pipelines, separators, compressors, and storage facilities, it is important to understand the contribution that the CSG industry may make to the regional emissions of VOC and hydrogen sulphide.

Measurements of emissions from gas fired compressors and engines at Talinga GPF shows that gas combustion is a source of a wide range of VOCs including aldehydes and BTX (Lawson et al., 2017). These VOCs may also be emitted from other CSG-related sources not characterised in Lawson et al. (2017) – for example emissions from gas flaring, use of diesel generators and engines, mobile sources such as motor vehicles, and well drilling and hydraulic fracturing. Depending on the location of the activities, pollutants associated with these activities may potentially be captured by the passive sampler measurements.

5.1.2 Other emission sources

There are a wide variety of natural and man-made (anthropogenic) sources of VOCs and hydrogen sulphide in the study area including but not limited to motor vehicles, domestic and commercial sources, domestic wood heaters, bushfires and prescribed burning, other industry, vegetation and agriculture. For further details see Lawson et al., (2017).

5.2 Overview of Radiello samplers

Radiello passive samplers are a portable sampler that can be deployed without the need for power or major infrastructure. Radiello passive samplers were used in this study because they provide measurement of a wide range of individual VOCs and aldehydes as well as hydrogen sulphide, over a larger spatial area than covered by the 5 ambient air quality stations. The Radiello passive samplers have a diffusive surface, which gases pass through at a known rate, and an absorbing cartridge which traps the gases until the sample is analysed. In this study three different cartridge types were employed: one capable of measuring VOCs including BTX (benzene, toluene, xylenes); another capable of measuring aldehydes (a class of oxygenated VOCs); and one capable of measuring hydrogen sulphide. Each Radiello sampler was exposed to air for approximately two weeks, providing an average concentration of gases over the two week deployment. After exposure the absorbing cartridges are packed in a sealed container and sent to a laboratory where the gases are extracted and the mass on each cartridge determined. Using the exposure time, and experimentally determined sampling rate for each gas, the concentrations of gases that were present in the air during sampling are calculated. In this study the Radiello samplers were deployed and analysed by environmental consultants SGS Leeder (Lawson et al., 2017). SGS is a NATA-accredited laboratory which 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.

In this study 45 species are reported from the VOC sampler while 8 species are reported from the aldehyde sampler and one species from the hydrogen sulphide sampler. The Radiello samplers can theoretically also measure dodecane (VOC sampler) and acrolein (aldehyde sampler), however results for these gases are not reported in this study as they provide only an approximation of the concentration of dodecane and acrolein (e.g. results are semi quantitative). Further details are provided in Appendix B.2.4. Sum of m and p xylene and o xylene are reported separately from the Radiello samplers, but in this study are reported together as sum of xylenes in order to be directly comparable to the EPP/NEPM air quality objectives for total xylenes. Information about Radiello field and site duplicates, and field blanks is provided in B.2.

Figure 32 Radiello samplers deployed in the field

5.3 Section overview

Passive sampler results (Section 6)

Results from the Radiello Passive sampler monitoring program are provided in Section 6. A summary of the VOCs, aldehydes and hydrogen sulphide measured is given as well as the occurrence (detection frequency) of each of the gases, and their concentrations in ambient air. Concentrations are compared against guideline values designed to protect human health and the environment, and against concentrations measured in other locations within Australia.

Independent VOC and aldehyde measurements by CSIRO (Section 7)

CSIRO undertook independent measurements of VOCs and aldehydes at Hopeland ambient air monitoring station for two weeks in June-July 2015. 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 concentrations at Hopeland using a different sampling and analysis method to the Radiello Passive method. The results of the CSIRO VOC and aldehyde measurements, and passive sampler method comparison is presented in Section 7.

A list of gases measured via the Radiello samplers, deployment details and quality assurance details are provided in Appendix B as well method descriptions for both SGS Leeder and CSIRO.

6 Radiello Passive sampler network results

6.1 Passive sampler monitoring locations

In this study, Radiello passive samplers were deployed at 10 sites in the study area from September 2014 – January 2016. The Radiello passive 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 air quality station sites (Burncluith and Tara Region) and in the Chinchilla township.

The 10 passive sampler sites are summarised in Table 37. This table lists the proximity of the sites to wells and other potential emission sources. The locations of the 10 passive sampler sites as of January 2016 are shown in Figure 33.

The Gas field passive sampler sites were located within 500 m of Condabri North GPF (Miles/Condabri North passive site), within 1 km of Condabri South GPF (Condamine passive site), within 1.5 km of Condabri Central GPF (Miles Airport passive site), 3 km from Talinga GPF (Rockwood passive site) and within 4 km of Orana GPF (Hopeland passive site). The Greenswamp passive sampler site was located within 50 m of a Condamine River gas seep. All of the Gas field sites with the exception of Greenswamp had between 12- 31 gas wells within a 2 km radius.

In contrast at the Regional passive sampler sites there were few emission sources nearby. At the Chinchilla township site the main likely emission sources was motor vehicles and domestic commercial sources associated with the town.

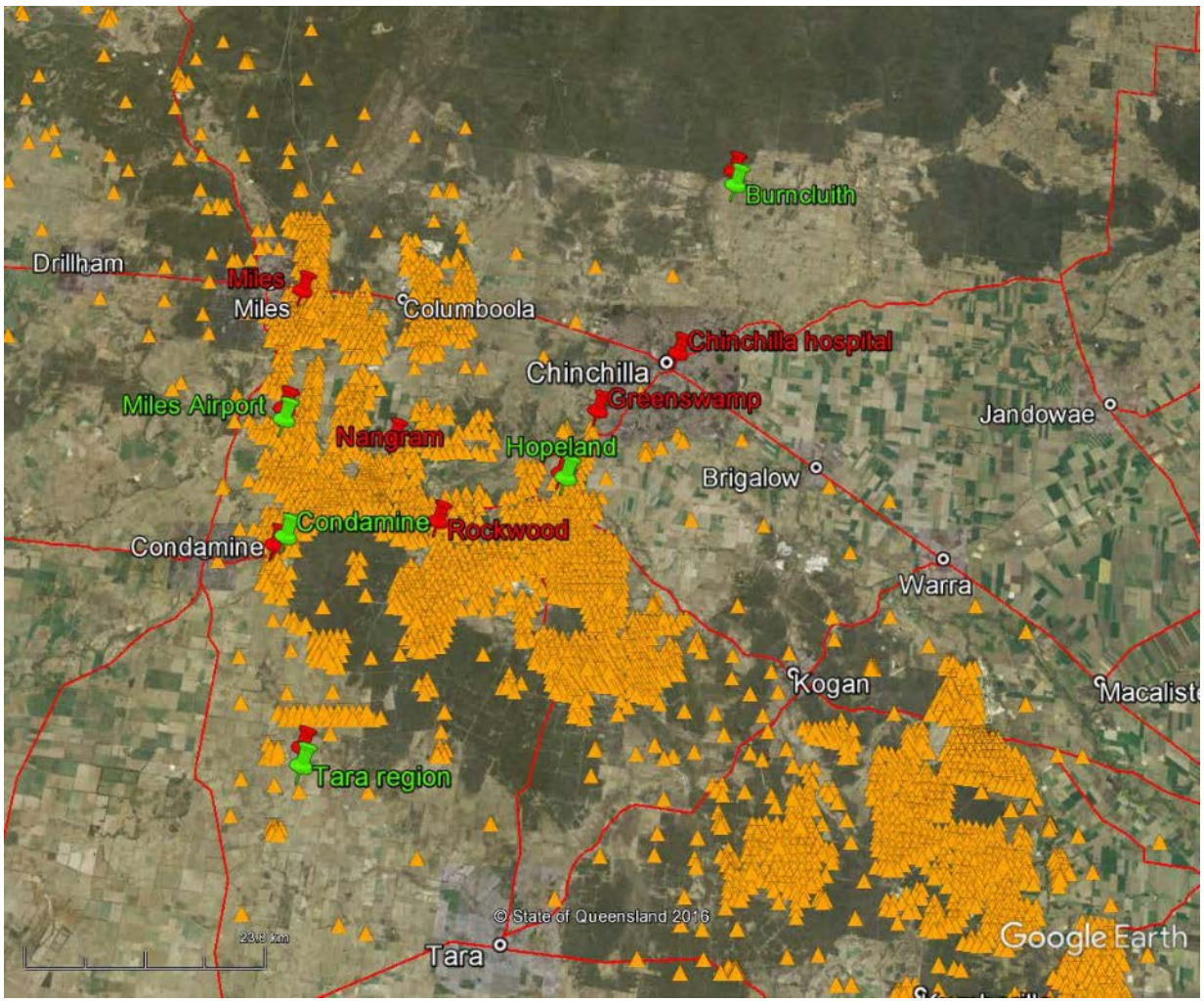

Figure 33. Location of passive sampler sites (red pins) and ambient air monitoring stations (green pins). Township names in white text. Orange triangles represent individual wellheads. Source: Study Design Report, Lawson et al 2017

Table 37 Air quality station and Radiello passive sampler monitoring locations including category (Gas field, Regional or Chinchilla), nearby gas infrastructure and other potential emission sources

Locations	Air Quality Station	Passive Radiello	Gas wells ≤ 2 km as of March 2016	Other sources
Gas field sites				
Hopeland	Y	Y	15	GPF <4 km
Miles Airport	Y	Y	12*	GPF 1.5 km Airport Feedlot
Condamine	Y	Y	25	GPF 1 km Township 7 km Road 300 m
Miles (Condabri North)	N	Y	31	GPF 500 m Township 3 km
Nangram/Monreagh	N	Y	17	n/a
Rockwood /Talinga	N	Y	27	GPF 3 km
Greenswamp	N	Y	0	Road 700 m
Regional sites				
Tara Region	Y	Y	1	n/a
Burncluith	Y	Y	0	Dwelling
Chinchilla				
Chinchilla	N	Y	0	Vehicles Domestic and commercial sources

***refers to location near sensitive receptor**

6.2 Role of measurement service providers and CSIRO/QA QC – data management

SGS Leeder were 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.

6.3 Reporting methodology

In this Section, the gases measured via the Passive sampler network will be reported in the following way:

- Detection limits (lowest measurable concentration) are discussed for each VOC and hydrogen sulphide, including how frequently each gas was detected in the samplers
- The measured concentrations of each VOC are compared to air quality objectives
- Where a VOC was detected >80% of time at one site or more, the potential sources are discussed, and ambient concentrations are compared to other regions in Australia

6.3.1 Air Quality Objectives used in this study

Ambient air objectives for VOCs have been developed by a number of regulatory bodies to protect human health and the environment. A major aim in the design of the GISERA study of Ambient Air Quality in the Surat Basin (Lawson et al., 2017) was to compare the concentration of air pollutants measured in the Surat Basin to air quality objectives.

A hierarchy of air quality objective was established for comparison to the average VOC concentrations measured using the Radiello method. If an air quality objective / value was not available from the first tier, the next tier was used.

Tier 1: **National Environment Protection (Air Toxics) Measure (Air Toxics - NEPM), 2011**. The desired environmental outcome of this Measure is to facilitate management of air toxics in ambient air that will allow for the equivalent protection of human health and well being. The pollutants to which the NEPM measure applies are benzene, toluene, xylenes, formaldehyde and benzo(a)pyrene. Benzo(a) pyrene was not selected for measurement in this study (for pollutant selection criteria see Lawson et al., 2017).

Tier 2: **Queensland Environmental Protection (Air) Policy (EPP), 2008**. The air quality objectives in the EPP (2008) are prescribed to protect the health and wellbeing of humans, the health and biodiversity of ecosystems, agriculture and the aesthetic environment.

The EPP (2008) includes all VOCs prescribed in the NEPM along with hydrogen sulphide and 6 other VOCs (1,2 dichloroethane,1,3-butadiene,dichloromethane, styrene, tetrachloroethylene, vinyl chloride monomer) which, with the exception of 1,3 butadiene and vinyl chloride monomer, are measurable by the Radiello passive samplers employed in this study.

Australian Federal or State ambient air objectives were not available for many of the VOCs measured in this study. In the absence of Australian objectives international objectives that covered the range of VOCs measured in this study were used:

Tier 3: **Texas Commission on Environmental Quality Air Monitoring Comparison Values (AMCV) and Effects Screening Levels (ESLs)**. The AMCV and ESL values are “chemical specific air concentrations set to protect human health and welfare. Where AMCV values were not available for a specific compound the appropriate ESL was used. For details on the difference between AMCVs and ESLs the reader is referred to TCEQ (2010) (https://www.tceq.texas.gov/toxicology/amcv/about). Only the “long term” values, which are

based on annual data concerning chronic health and vegetation effects were used for comparison with the Radiello data in this study.

Each Radiello sampler was exposed to the air an average of 14 days and the concentrations reported here are an integrated average for the sampling period.

Air quality objectives relevant to this study have averaging periods of 24 hours, 1 week or one year (annual), and there are no air quality objectives for 14 day averaging periods. Given the 14 day averaging times used in the sampling procedure in this study it is appropriate to compare the reported concentrations with long–term air quality objectives such as annual averages, rather than shorter averaging periods (e.g. 24-hr). This is a conservative measure, as air quality objectives for the same substance are higher in shorter averaging periods (e.g. 24-hour) than longer averaging periods (e.g. annual) for the same pollutant.

For instance, the EPP (2008) and NEPM (2011) prescribe only 24-hour average maximum air quality objective values for formaldehyde and hydrogen sulphide (EPP only). Consequently, the measurements of formaldehyde and hydrogen sulphide from the two weekly integrated samples taken in this study should not be assessed against the short term NEPM / EPP objectives. In lieu of long term federal or state air quality objectives for these pollutants the WA Department of Health recommended 90 day exposure limit for H_2S of 0.014 ppm, and the annual Texas AMCV for formaldehyde of 8.9ppm were used.

In the next sections the detection limits and measured concentrations of the VOCs are compared with the air quality objectives described above.

6.4 Results -Detection limits and frequency of detection

All techniques that measure atmospheric pollutants have a lower limit beneath which the concentration of a pollutant cannot be reliably measured. As such the detection limit is the lowest measurable concentration of a pollutant for a particular measurement technique. Detection limits were determined for each gas measured with the Radiello samplers and are reported in B.3.

Fifty four gases are reported by the Radiello sampling techniques employed in this study (45 gases via VOC sampler, 8 gases via aldehyde sampler and 1 gas via hydrogen sulphide sampler). Of these 54 gases 31 were measured above the detection limit in one or more of the Radiello samples. The gases, and the percentage of samples in which the gases were detected above the detection limit are listed by site type (Regional, Gas-field, Chinchilla) in Table 38 below. Conversely there were 23 gases which were not measured above the detection limit in any of the samples.

At the Regional sites 19 of the 54 targeted gases were detected, at the Gas field sites 21 of the targeted gases were detected while at the Chinchilla township site 29 of the targeted gases were detected.

Summary statistics for VOCs detected in at least 10% of samples from one site or more are provided in B.3

Table 38 The percentage (%) of samples in which gases were detected above the detection limit (DL) at the Regional, Gas field and Chinchilla sites during this study.

	Samples > DL (%)		
	Regional sites	Gas-field sites	Chinchilla
Alkanes and cyclo-alkanes			
2-methyl pentane	5	6	72
3-methyl pentane	2	0	53
n-Hexane	8	13	64
n-Heptane	0	0	36
n-Octane	0	0	8
Iso-octane	0	0	42
n-Nonane	0	0	11
n-Decane	23	15	56
n-Undecane	23	20	47
Methyl cyclopentane	0	0	44
Cyclohexane	0	0	58
Methylcyclohexane	0	0	19
Aromatics			
Benzene	30	27	92
Toluene	37	29	100
Ethylbenzene	0	0	50
Sum Xylenes	0	1	94
1,2,4-Trimethylbenzene	2	2	44
Chlorinated			
Carbon tetrachloride	100	100	100
Trichloromethane	22	4	33
Aldehydes			
Formaldehyde	96	100	100
Acetaldehyde	88	86	92
Propanaldehyde	64	66	77
Butanaldehyde	32	34	23
Pentanaldehyde	16	14	8
Hexanaldehyde	48	47	38
Benzaldehyde	0	1	0
Other oxygenated VOCs			
Methyl ethyl ketone	7	3	25
Cyclohexanone	8	13	11
Ethyl acetate	15	17	22
Butanol	0	0	3
2-Butoxyethanol	0	0.4	0

	Regional sites	Gas field s sites	Chinchilla
Gases not detected in any sample			
Aromatics			
n-propylbenzene	0	0	0
Iso-propylbenzene	0	0	0
Naphthalene	0	0	0
Styrene	0	0	0
Chlorinated			
1,1,1-trichloroethane	0	0	0
Trichloroethylene	0	0	0
Tetrachloroethylene	0	0	0
1,2-dichloroethane	0	0	0
1,2-dichloropropane	0	0	0
Chlorobenzene	0	0	0
1,4-dichlorobenzene	0	0	0
Bromochloromethane	0	0	0
Aldehydes			
Glutaraldehyde	0	0	0
Other oxygenated VOCs			
Butyl acetate	0	0	0
1-methoxy-2-propyl acetate	0	0	0
Methyl methacrylate	0	0	0
Methyl isobutyl ketone	0	0	0
Isobutanol	0	0	0
2-ethyl-1-hexanol	0	0	0
1-methoxy-2-propanol	0	0	0
Ethyl-tert-butyl ether	0	0	0
Methyl-tert-butyl ether	0	0	0
Other gases			
Hydrogen Sulphide	0	0	0

6.5 Comparison with air quality objectives

Table 39 shows the average and maximum concentrations of the 31 VOCs detected in the Radiello samples from the Regional, Gas field and Chinchilla sites (see Table 38) compared with the air quality objectives described previously (Section 6.3.1). Table 40 includes the gases measured which were always below detection limit, with the maximum detection limit compared to air quality objectives. There were no exceedances of annual air quality objectives for the 54 target gases during the period September 2014 – January 2016. In all cases the maximum concentrations observed were well below air quality objectives. For aldehydes and hydrogen sulphide there was less than one year of data to compare to annual air quality objectives, but for assessment purposes, given the concentrations observed were well below air quality objectives it would be reasonable to assume the annual objective would be met.

Table 39 Concentrations for all gases where there was at least one measurement above the detection limit (DL) at one or more sites. The average concentration is given in ppb with the maximum value following (in brackets).

	CAS No.	Regional sites	Gas field sites	Chinchilla	Annual Ambient air objective	
Gases >detection limit		**Avg (max) ppb**			**ppb**	**Source**
Alkanes and cyclo-alkanes						
2-methyl pentane	107-83-5	0.021 (0.051)	0.023 (0.125)	0.088 (0.267)	99	Texas AMCV
3-Methylpentane	96-14-0	0.020 (0.034)[d]	<DL (0.048)	0.034 (0.098)	100	Texas AMCV
n-Hexane	110-54-3	0.034 (0.213)	0.036 (0.253)	0.063 (0.247)	190	Texas AMCV
n-Heptane	142-82-5	<DL (0.037)	<DL (0.049)	0.027 (0.057)	2200	Texas AMCV
n-Octane	111-65-9	<DL (0.034)	<DL (0.047)	0.020 (0.039)	380	Texas AMCV
Iso-octane	540-84-1	<DL (0.034)	<DL (0.045)	0.024 (0.088)	75	Texas ESL
n-Nonane	111-84-2	<DL (0.034)	<DL (0.046)	0.020 (0.041)	280	Texas AMCV
n-Decane	124-18-5	0.022 (0.076)	0.023 (0.122)	0.025 (0.056)	175	Texas AMCV
n-Undecane	1120-21-4	0.036 (0.188)	0.035 (0.122)	0.039 (0.086)	55	Texas AMCV
Methylcyclopentane	96-37-7	<DL (0.035)	<DL (0.049)	0.029 (0.074)	75	Texas AMCV
Cyclohexane	110-82-7	<DL (0.047)	<DL (0.064)	0.051 (0.160)	100	Texas AMCV
Methylcyclohexane	108-87-2	<DL (0.032)	<DL (0.045)	0.021 (0.037)	400	Texas AMCV
Aromatic hydrocarbons						
Benzene	71-43-2	0.024 (0.053)	0.023 (0.078)	0.060 (0.200)	3 1.4	NEPM/EPP Texas AMCV
Toluene	108-88-33	0.020 (0.035)	0.019 (0.042)	0.146 (0.389)	100 1100	NEPM/EPP Texas AMCV
Ethylbenzene	100-41-4	0.016 (0.030)	0.017 (0.039)	0.021 (0.046)	440	Texas AMCV
Sum Xylenes	179601-23-1[a] 95-47-6[b]	0.034 (0.058)	0.034 (0.081)	0.080 (0.215)	200 140	NEPM/EPP Texas AMCV
1,2,4-Trimethylbenzene	95-63-6	0.020 (0.041)	0.021 (0.049)	0.026 (0.066)	37	Texas AMCV

	CAS No.	Regional sites	Gas field sites	Chinchilla	Annual Ambient air objective	
Gases> detection limit		**Average (max) ppb**			**ppb**	**Source**
Chlorinated gases						
Carbon tetrachloride	56-23-5	0.081 (0.117)	0.079 (0.132)	0.072 (0.106)	2	Texas AMCV
Trichloromethane	67-66-3	0.018 (0.055)	0.014 (0.033)	0.015 (0.027)	2	Texas ESL
Aldehydes and Ketones (Oxygenated VOCs)						
Formaldehyde	50-00-0	0.659 (1.385)*	0.675 (1.874)*	0.652 (1.018)*	40 8.9	NEPM/EPP Texas AMCV
Acetaldehyde	75-07-0	0.153 (0.500)*	0.164 (0.511)*	0.164 (0.528)*	25	Texas AMCV
Propanaldehyde	123-38-6	0.101 (0.244)*	0.098 (0.244)*	0.094 (0.166)*	55	Texas AMCV
Butanaldehyde	123-72-8	0.175 (0.407)*	0.171 (0.373)*	0.157 (0.193)*	34	Texas AMCV
Pentanaldehyde	110-62-3	0.051 (0.077)	0.051 (0.091)*	0.051 (0.065)*	50	Texas AMCV
Hexanaldehyde	66-25-1	0.083 (0.164)*	0.080 (0.186)*	0.103 (0.242)*	200	Texas AMCV
Benzaldehyde	100-52-7	<DL (0.014)*	<DL (0.018)*	0.012 (0.014)*	2.1	Texas AMCV
Methyl ethyl ketone	78-93-3	0.022 (0.037)	0.021 (0.051)	0.023 (0.041)	3000	Texas AMCV
Cyclohexanone	108-94-1	0.019 (0.057)	0.021 (0.145)	0.020 (0.060)	20	Texas ESL
Other oxygenated VOCs						
Ethyl acetate	141-78-6	0.019 (0.047)	0.022 (0.214)	0.021 (0.058)	400	Texas AMCV
Butanol	35296-72-1	<DL (0.040)	<DL (0.053)	0.024 (0.091)	20	Texas ESL
2-Butoxyethanol	111-76-2	<DL (0.031)	0.019 (0.085)[d]	<DL (0.035)	780	Texas ESL

"< DL" indicates all samples were below detection limit for that species; value in brackets is max DL.

[a] CAS No. for m/p-xylenes; [b] CAS No. for o-xylene;

[d] Only 1 sample > DL

***average and maximum concentration based on 7 months of data**

Table 40 The gases measured in the Radiello samples in this study that were always below the detection limit (DL) at all of the sites

Compound	CAS No.	Max DL (ppb)	Ambient Air Guideline (ppb)	Averaging period	Source
Compounds always < DL					
n-propylbenzene	103-65-1	0.04	51	annual	Texas AMCV
Isopropylbenzene	98-82-8	0.04	51	annual	Texas AMCV
Naphthalene	91-20-3	0.09	9.5	annual	Texas AMCV
Styrene	100-42-5	0.04	60 110	1 week annual	EPP Texas AMCV
1,1,1-trichloroethane	71-55-6	0.03	930	annual	Texas AMCV
Trichloroethylene	79-01-6	0.03	10	annual	Texas ESL
Tetrachloroethylene	127-18-4	0.03	3.6 3.8	1 year annual	EPP Texas AMCV
1,2-dichloroethane	107-06-2	0.04	170 0.72	24h annual	EPP Texas AMCV
1,2-dichloropropane	78-87-5	0.04	10	annual	Texas AMCV
Chlorobenzene	108-90-7	0.04	10	annual	Texas AMCV
1,4-dichlorobenzene	106-46-7	0.04	27	annual	Texas ESL
Bromochloromethane	74-97-5	0.03	200	annual	Texas ESL
Butyl acetate	123-86-4	0.04	990	annual	Texas AMCV
1-methoxy-2-propyl acetate	108-65-6	0.04	50	annual	Texas ESL
Methyl methacrylate	80-62-6	0.04	50	annual	Texas ESL
Methyl isobutyl ketone	108-10-1	0.04	20	annual	Texas AMCV
Glutaraldehyde	111-30-8	0.02	0.05	annual	Texas ESL
Isobutanol	78-83-1	0.05	50	annual	Texas ESL
2-ethyl-1-hexanol	104-76-7	0.05	30	annual	Texas ESL
1-methoxy-2-propanol	107-98-2	0.06	100	annual	Texas ESL
Ethyl-tert-butyl ether	637-92-3	0.05	5	annual	Texas ESL
Methyl-tert-butyl ether	1634-04-4	0.05	50	annual	Texas AMCV
Hydrogen Sulphide	7783-06-4	0.82	110	24 h	EPP

6.5.1 **NEPM Air Toxics - Benzene, Toluene, Xylenes (BTX) and Formaldehyde**

Table 39 shows that the average and maximum concentrations of benzene, toluene, xylenes and formaldehyde measured by the Radiello passive samplers at all sites. Time series of the fortnightly concentrations are presented in Figure 34 - Figure 37 with the air quality objectives are shown on the plots with a dotted line.

The average and maximum concentrations of benzene, toluene and xylenes measured by the Radiello passive samplers at all sites were tens to hundreds of times lower than the relevant objectives in the National Environment Protection (Air Toxics) Measure (Air Toxics - NEPM), 2011 and Queensland Environmental Protection (Air) Policy (EPP), 2008. While the average of all 16 months of data is shown, the concentration average for the 12 months of 2015 is very similar to the average of the 16 months of data.

The EPP (2008) and NEPM (2011) prescribe a 24-hour average maximum value of 40 ppb for formaldehyde. The measurements of formaldehyde from two weekly integrated samples cannot be directly compared against the short term NEPM and EPP objectives. As such the 7-monthly average value for formaldehyde was instead compared to the annual Texas AMCV value of 8.9 ppb (Figure 37). While a 7-monthly average value cannot be directly compared to a guideline value based on a 12-month averaging period, for assessment purposes, if the 7-monthly value is less than the 12-monthly value it can reasonably be assumed that the long term guideline would be met. The 7 month average concentration of formaldehyde measured at all sites ranged from 0.52 – 0.81 ppb which is over ten times lower than the Texas AMCV annual guideline value.

24-hr average formaldehyde measurements were obtained via an active measurement technique for one 2 week period at the Hopeland site in June - July 2015 (see Section 7). The 24-hour concentrations of formaldehyde measured at Hopeland using this technique were on average 0.48 ppb (range of 0.40 – 0.57 ppb), well below the 24h NEPM objective of 40 ppb.

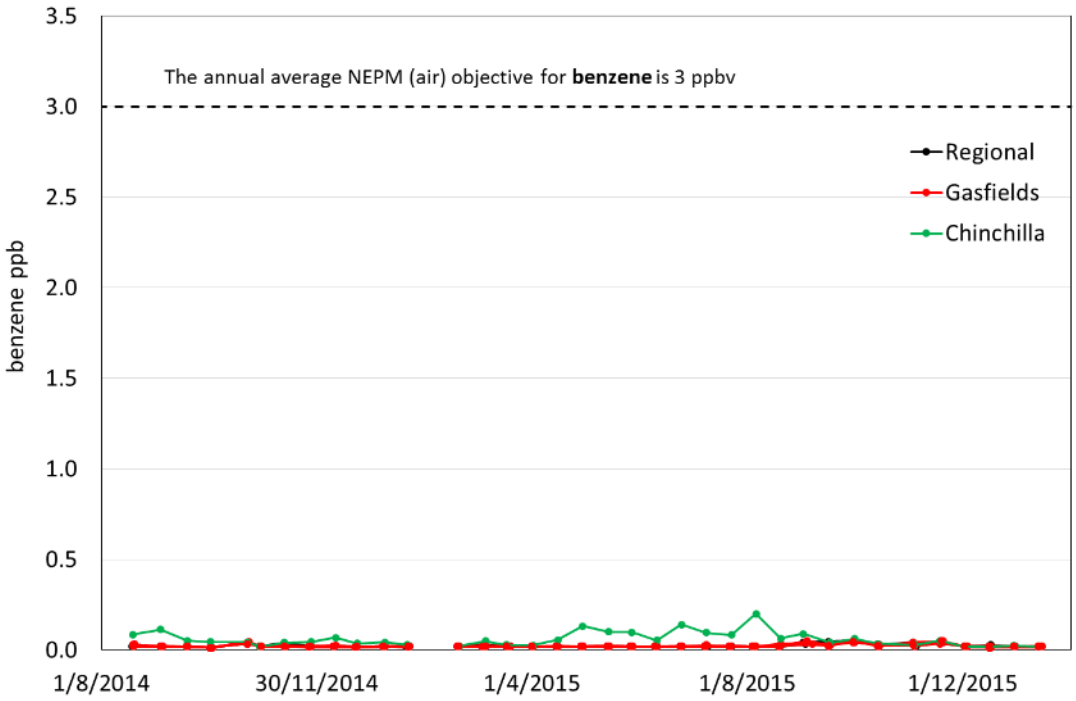

Figure 34 Time series of benzene measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The annual average Air (EPP) and NEPM (air) objective is shown by the dotted line

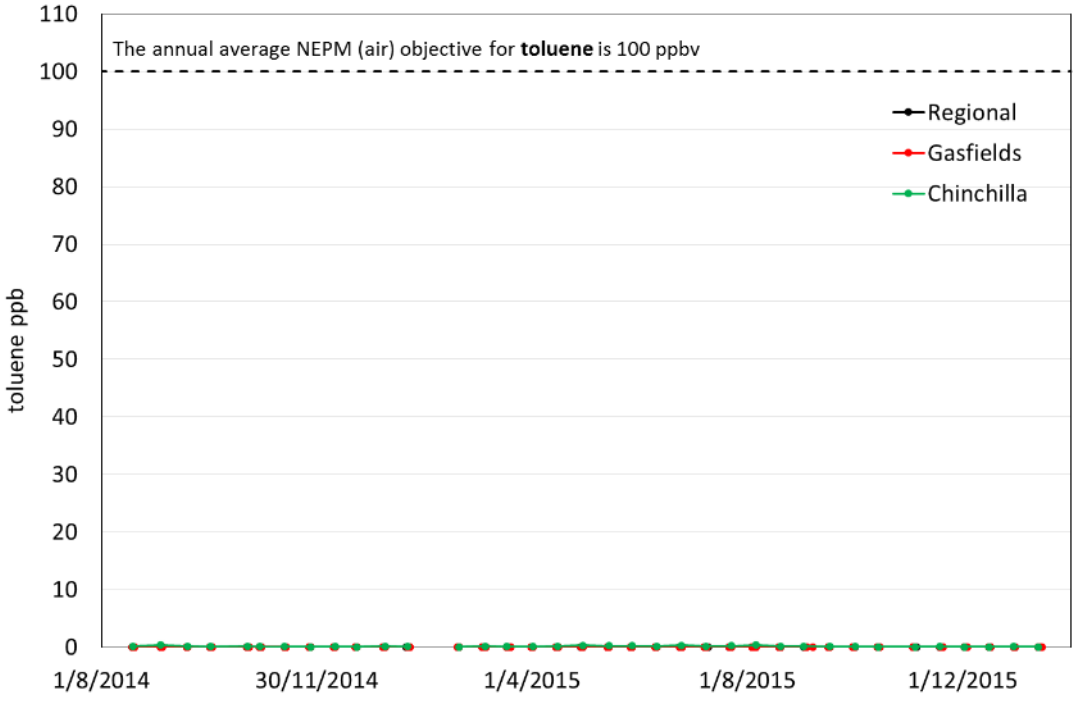

Figure 35 Time series of toluene measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The annual average NEPM (air) objective is shown by the dotted line

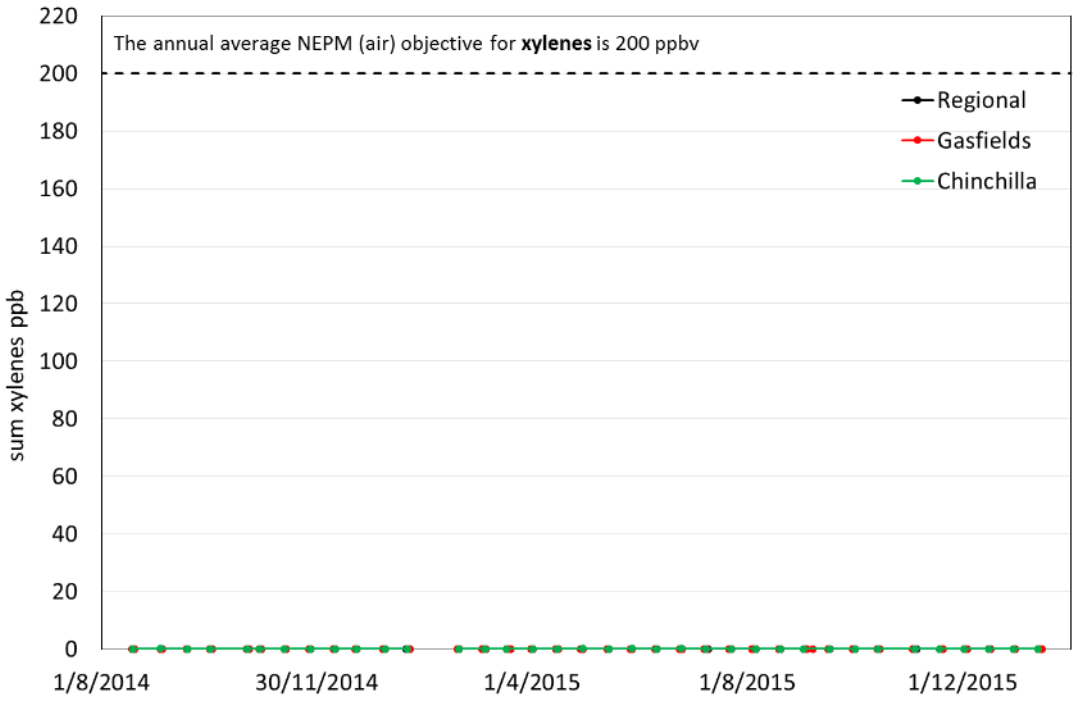

Figure 36 Time series of sum of xylenes measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The annual average NEPM (air) objective is shown by the dotted line

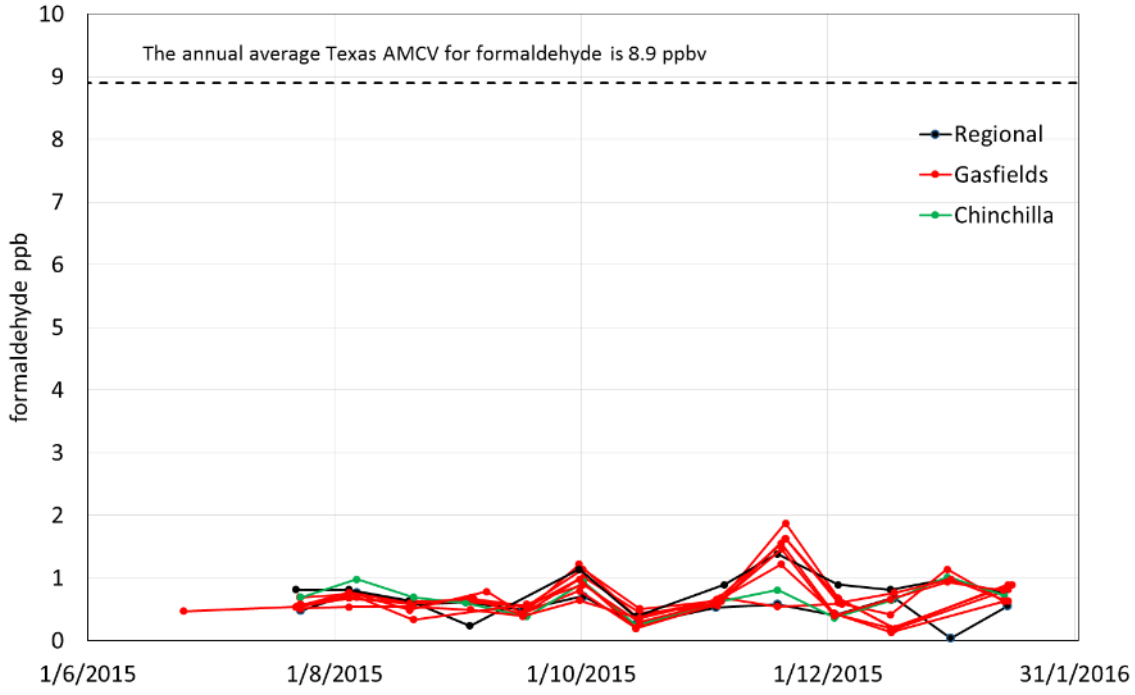

Figure 37 Time series of formaldehyde measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The annual average Texas AMCV objective is shown by the dotted line.

6.5.2 Comparison of other gases measured with air quality objectives

Maximum concentrations of 27 other gases (excluding benzene, toluene, xylenes and formaldehyde) measured above the detection limit using the Radiello samplers did not exceed the ambient air objectives consulted.

Twenty two VOCs as well as hydrogen sulphide were always below the detection limit at all sites in this study. For these gases the maximum detection limits were tens to hundreds of times lower than the relevant ambient air quality objectives. This indicates that the Radiello technique is suitably sensitive for the purpose of comparing measured concentrations of these gases with air quality objectives in this study.

Glutaraldehyde was also always below the detection limit at all sites, however the maximum detection limit (0.02 ppb) was only 2.5 times lower than the Texas air quality objective (0.05 ppb). While this indicates air quality objectives were not exceeded, the closeness of the detection limit to the air quality objective indicates that passive Radiello measurement technique is not an optimal technique for measuring and comparing glutaraldehyde to the Texas air quality objective.

To summarise, of the 54 gases targeted, 31 were measured above detection limit and concentrations were well below relevant air quality objectives, 23 gases were always below their detection limit. For 22 gases the maximum detection limits were well below air quality objectives

6.6 Discussion of frequently detected gases and comparison to elsewhere in Australia

Here we further investigate gases which were persistently detected in the air at the Surat Basin sites over the 16 month sampling period. Gases are discussed here if they were detected in more than 80% of the Radiello samples at one or more of the 3 site categories (Gas field, Regional or Chinchilla sites).

Gases that meet this requirement are benzene, toluene, xylenes, carbon tetrachloride, formaldehyde and acetaldehyde. Four of these frequently detected gases (benzene, toluene, xylenes and formaldehyde) are covered by the Air Toxics NEPM. Five of these gases (benzene, toluene, xylenes, formaldehyde and acetaldehyde) are included in Australia's NPI.

In this Section, these 6 gases are plotted as time series showing data points from all 10 sites with concentrations colour coded as Regional (black), Gas field (red) and Chinchilla (green) categories (Figure 38- Figure 43). Note that these figures contain the same data as shown in Figure 34 - Figure 37 but have a different concentration scale so that differences between individual sites can be seen. Table 41 presents average concentrations of these 6 gases from the Regional, Gas field and Chinchilla categories from this study with measurements made by CSIRO at other locations in Australia and measurements made by the Queensland Department of Science, Information Technology and Innovation (DSITI) elsewhere in Queensland. Other sites used for comparison include urban areas (Brisbane and Melbourne), urban fringe (Sydney outskirts; Bringelly, NSW), a rural town (Ovens, Victoria) and a rural site in north-west Tasmania (Cape Grim).

Table 41 Average concentrations of frequently detected gases at Regional, Gas field and Chinchilla sites, and concentrations at urban and rural sites in Australia

		Benzene ppb	Toluene ppb	Xylenes ppb	Carbon tetrachloride ppb	Formaldehyde ppb	Acetaldehyde ppb	Reference
Surat Basin								
Regional	Rural	0.02	0.02	0.03	0.08	0.66	0.15	This study
Gas-Field	Rural	0.02	0.02	0.03	0.08	0.67	0.16	
Chinchilla	Rural town	0.06	0.15	0.08	0.07	0.65	0.16	
Other Locations								
Brisbane Qld 2015[a]	urban	0.9	4.5	6.6	*nm*	*nr*	*nm*	DSITI (2016)
Melbourne VIC[b] 2008 – 2010	urban	0.25	1.04	0.64	0.08[c]	1.14	0.39	Cheng et al (2016) Fraser et al (2014)
Bringelly NSW[d] 2007	urban fringe	0.11	0.45	0.20	*nm*	2.11	0.30	CSIRO (2009)
Ovens VIC[be] 2006 - 2007	Rural town	0.07	0.10	0.02	*nm*	*nm*	nm	Meyer et al (2008)
Cape Grim Tas[f] 2006	Rural/coastal	0.01	0.01	0.02	0.08	0.54	0.05	Lawson et al (2015) AGAGE (2017)

[a] Annual average based on 2015 daily 24 h average concentrations at Springwood.

[b] Average based on weekly integrated measurements

[c] approximate value Melbourne 2010

[d] Average based on daily 7- hour daytime samples 20/1/07 – 27/2/07.

[e] Excludes data from periods impacted by wildfires

[f] average background concentration. Benzene, toluene, xylenes, formaldehyde and acetaldehyde measurements are from an easterly wind direction (not marine baseline)

***nr:* not reported as only maximum 24 h concentrations for each month are available for this site**

***nm:* not measured**

6.6.1 Benzene, toluene, xylenes (BTX)

Benzene, toluene and xylenes (BTX) are a class of VOCs which are emitted from many man-made sources (e.g. vehicles, industry), as well as some other sources such as wildfires. They are discussed here together as they typically are co-emitted from the same sources. Benzene was detected in 30%, 27% and 92 % of Regional, Gas field and Chinchilla samples, respectively. Toluene was detected in 37%, 29% and 100 % of Regional, Gas field and Chinchilla samples respectively and xylenes detected in 0%, 1% and 94% of Regional, Gas field and Chinchilla samples respectively (Table 38). As such benzene, toluene and xylenes were all measured above the detection limit more frequently in the township of Chinchilla than in the Regional sites and gas-field sites. Chinchilla also had higher average concentrations and maximum concentrations of BTX than the Regional and Gas field sites (Table 39). The summary statistics for BTX concentrations measured at each of the 10 individual sites are provided in Appendix B.3.

The time series plots of benzene, toluene and xylenes (Figure 38- Figure 40 below) shows that concentrations were higher at Chinchilla (green line) throughout most of the sampling period, with most of the Chinchilla measurements well above the detection limit (dotted line). In contrast, many of the measurements at the Regional and Gas field sites were below the detection limit. Field blank concentrations shown in the time series were always below the detection limit for BTX, indicating the samples were not influenced by artefacts from the sampling and analysis process (see B.2.6).

Note that the detection limit in the plots are an average detection limit and provide an indication of the typical detection limit for that VOC during the entire study. In practice the detection limits varied each sampling round/fortnight. For the percentage of samples > detection limit for each VOC please refer to Table 38 which takes into account the variation in the detection limit each fortnight.

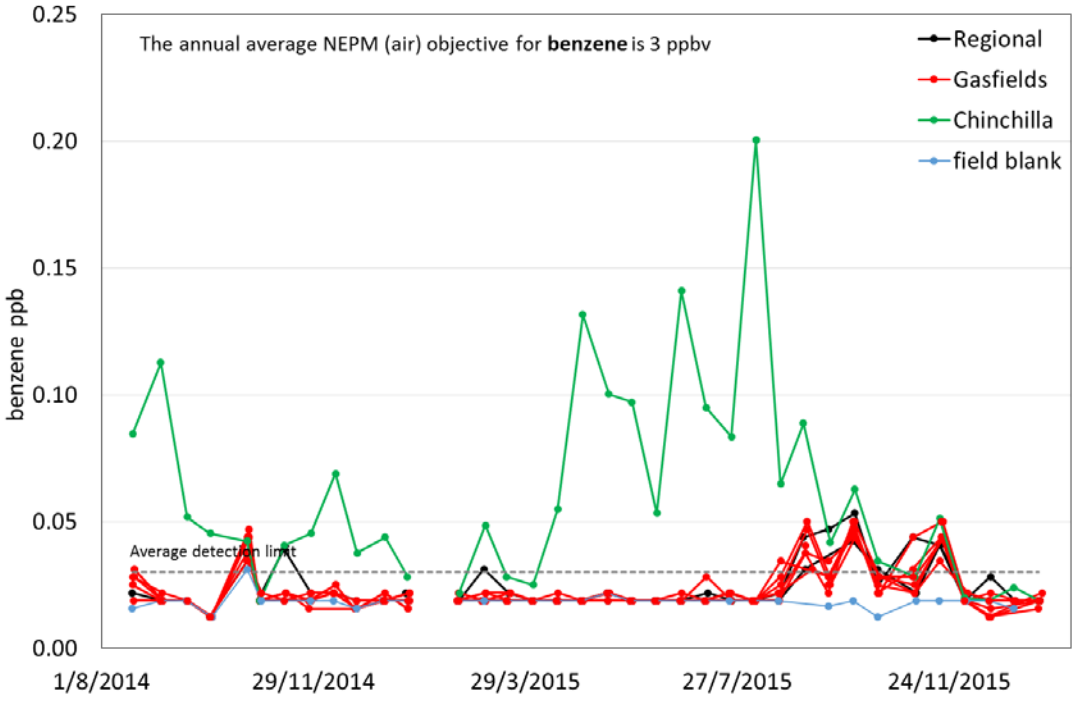

Figure 38 Benzene concentrations measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The average detection limit for benzene is shown with a dotted line. Note that this contains the same data as Figure 34, but with a smaller concentration scale so that detail can be seen.

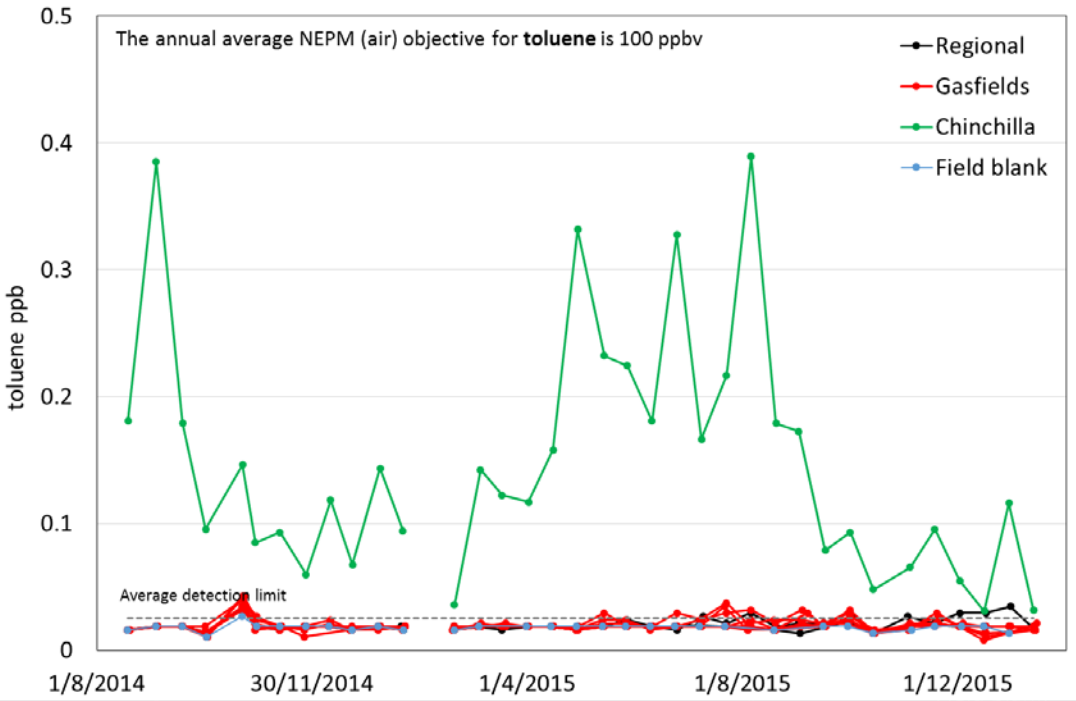

Figure 39 Toluene concentrations measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The average detection limit for toluene is shown with a dotted line. Note that this contains the same data as Figure 35, but with a smaller concentration scale so that detail can be seen.

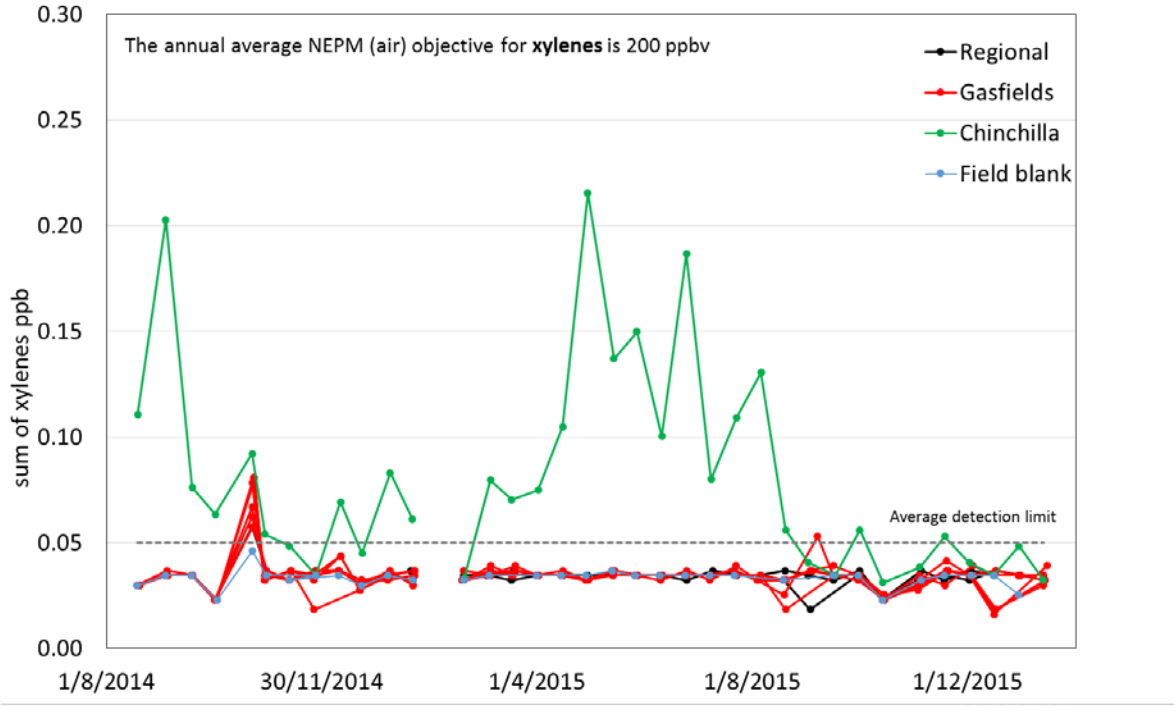

Figure 40 Xylene concentrations measured using Radiello samplers at the Regional, Gas field and Chinchilla site. The average detection limit for xylenes is shown with a dotted line. Field blanks are shown by the light blue marker. Note that this contains the same data as Figure 36 but with a smaller concentration scale so that differences between sites can be seen.

The BTX concentrations measured in the Regional, Gas field and Chinchilla sites in this study were lower than typical ambient concentrations reported for suburban areas in Brisbane (DSITI, 2015, 2016) and Melbourne (Cheng et al., 2016) and an urban fringe area in Sydney (CSIRO, 2009). The Chinchilla concentrations were close to those observed for a rural town in Victoria (Meyer et al, 2008) (Table 41). The BTX concentrations measured in Chinchilla were higher than measured in a rural/coastal site in Tasmania, while the Regional and Gas field sites were slightly higher than the rural/coastal site.

The Chinchilla site is within the township, 1 km from the central business district and 200 m from the Warrego highway. Ratios of benzene/toluene can be used as 'emission signatures' to indicate the likely source of the BTX measured in Chinchilla. Motor vehicles are a major source of benzene, toluene and xylene in Australia (NPI 2016) with contributions also from fuel burning (wood smoke) particularly for benzene, and domestic commercial sources for toluene. The emission ratio of benzene/toluene in towns which have a large influence from woodsmoke is typically >0.5, while in urban environments dominated by motor vehicles and domestic commercial sources the ratio is usually <0.5 (CSIRO, 2014). The higher benzene/toluene ratio in woodsmoke impacted environments is because in woodsmoke emissions benzene is emitted in a higher concentration than toluene, while in motor vehicle emissions toluene is emitted in a higher concentration than benzene (NPI 2016).The benzene/toluene ratio at Chinchilla is 0.37 which is similar to other Australian urban and rural environments, and lower than in towns impacted significantly by woodsmoke (CSIRO, 2014). The source of benzene, toluene and xylenes at the Chinchilla site is

likely due predominantly to motor vehicles, as well as domestic and commercial sources within the town. Emission ratios could not reliably be calculated for the Gas fields and Regional sites due to low numbers of samples where both benzene and toluene was above the detection limit.

Several of the Gas field sites were situated between 0.5 km – 4 km from GPFs and all sites had between 12-31 gas wells within a 2 km radius, with the exception of the Greenswamp site which was 50 m from a Condamine River gas seep (Table 37). A review of emission sources from CSG infrastructure (Lawson et al., 2017) found that BTX is present in gas combustion emissions, including gas-fired engines and compressors, and is also emitted from motor vehicles and generators. Emissions and venting of CSG was identified as a possible further CSG-related source, however BTX concentrations in CSG were found to be lower than 1 ppm (measurement detection limit) (Lawson et al., 2017). While the CSG industry is a known source of several of these gases including BTX, formaldehyde and acetaldehyde, levels of VOCs and aldehydes in ambient air in the vicinity of populated areas in this study were well below air quality objectives and were comparable to rural/regional concentrations elsewhere in Australia. BTX concentrations at the Regional sites are similar to the Gas fields sites.

As shown in Table 39, the levels of BTX measured at Regional sites, Gas field sites and Chinchilla are well below air quality objectives.

6.6.2 Carbon tetrachloride

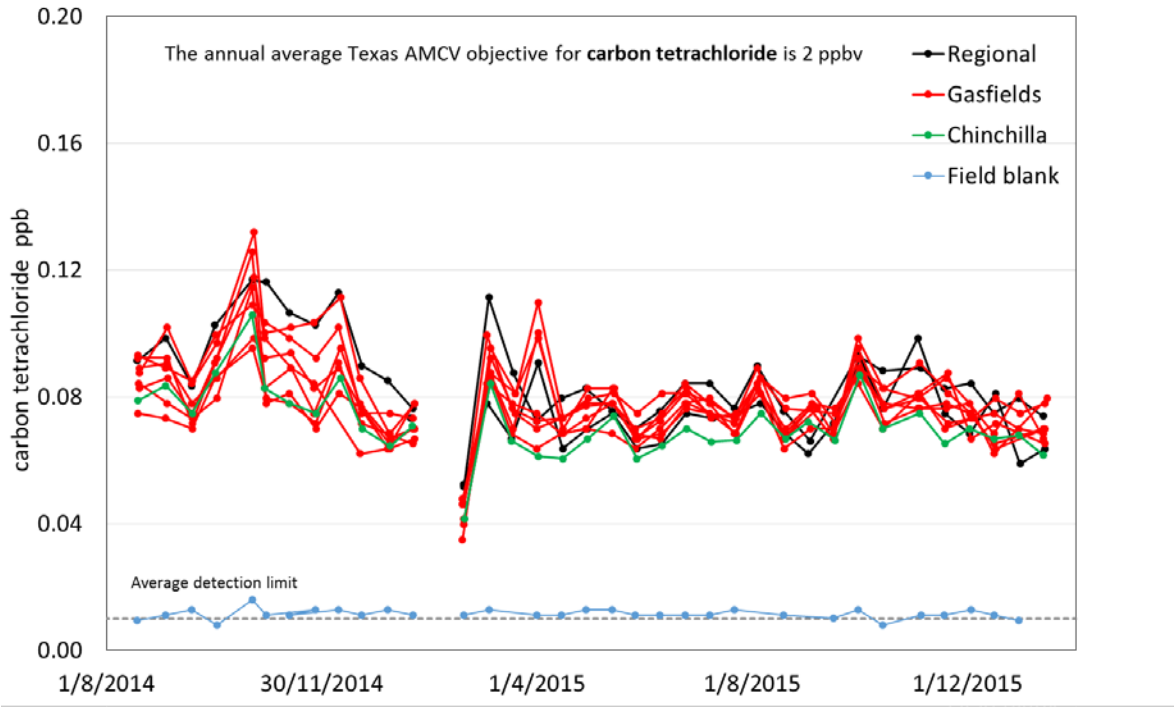

Figure 41 Carbon tetrachloride measured using Radiello samplers at the Regional (black), Gas field (red) and Chinchilla (green) sites. The average detection limit for carbon tetrachloride is shown by a dotted line, field blanks are shown by a light blue marker.

Carbon tetrachloride is an ozone depleting gas and greenhouse gas. Carbon tetrachloride was detected in all samples in the Gas field, Regional and Chinchilla sites. Figure 41 shows a time series plot of carbon tetrachloride concentrations in the samples from all sites. Field blank concentrations were always below the detection limit for each sampling round. The concentrations at all sites throughout the 16 month sampling period are consistently above the detection limit with concentrations ranging from 0.03 – 0.13 ppb.

The Montreal protocol in 1989 led to the phasing out of carbon tetrachloride globally, with carbon tetrachloride no longer used in the developed world, including Australia, since 1996, and no longer used worldwide by any country since 2010 (Fraser et al., 2014).

Prior to phasing out, carbon tetrachloride was used as a solvent, refrigerant, grain fumigant and a fire retardant, and as a feedstock chemical for synthetic chlorofluorocarbons (CFCs), perchloroethylene (CCl_2CCl_2) and recently some hydrofluorocarbons (HFCs) (Fraser et al., 2014).

However, carbon tetrachloride is long lived in the atmosphere with an average lifetime of 26 years, which means that carbon tetrachloride emitted decades ago is still present in the atmosphere globally, though levels are declining each year. Table 41 shows the average concentrations at Regional (0.08 ppb), Gas field (0.08 ppb) and Chinchilla (0.07 ppb) sites are similar to available measurements from Melbourne and at the rural site in NW Tasmania. As such, the concentrations of carbon tetrachloride measured in this study are at background levels typical of other parts of Australia and do not indicate the presence of a local source. As shown in Table 39, the levels of carbon tetrachloride measured at Regional sites, Gas field sites and Chinchilla is well below air quality objectives.

6.6.3 Formaldehyde and acetaldehyde

Formaldehyde and acetaldehyde are aldehydes, which is a class of VOC. Formaldehyde was detected in 96% of Regional samples, and 100% of the Gas field and Chinchilla samples while acetaldehyde was detected in 88% of Regional samples, 86% of Gas field samples and 92% of Chinchilla samples (Table 38). As such, both formaldehyde and acetaldehyde detection frequencies were consistent across the 3 categories. Concentrations were also consistent across the Regional, Gas field and Chinchilla sites with 7-monthly average values of 0.66, 0.67 and 0.65 ppb respectively for formaldehyde, and averages of 0.15, 0.16 and 0.16 ppb respectively for acetaldehyde (Table 41). The summary statistics for formaldehyde and acetaldehyde concentrations measured at each site are provided in B.3.

Time series of formaldehyde and acetaldehyde are presented in Figure 42 and Figure 43 and shows some variability in the concentration measured between sites over time. Field blank concentrations for formaldehyde were slightly above the detection limit 21% of the time indicating the samples had occasional minor influence from artefacts from the sampling and analysis process. These artefact levels were not subtracted from the samples due to the low frequency of detects on blanks, and low blank concentrations relative to the ambient concentrations. Field blank concentrations for acetaldehyde were above the detection limit for 14% of the time. These artefacts were not subtracted from the samples due to the low frequency of detects on blanks, however for two sample periods in September and October blank levels may have contributed to ambient concentrations by 0.1-0.2 ppb.

Domestic solid fuel burning and motor vehicles are listed as the main emission sources of formaldehyde and acetaldehyde Australia wide (NPI 2017). In the study area, combustion of gas in engines, compressors and flares as well as fuel burning is a source of formaldehyde and to a lesser degree acetaldehyde. However unlike BTX, formaldehyde and acetaldehyde are also produced continuously in the atmosphere as products from photochemical reactions of VOCs (both man-made and natural), and oxidation of methane in the case of formaldehyde. As such there is a certain background concentration of formaldehyde and acetaldehyde present in the atmosphere even if there are no nearby direct emissions – however direct emissions will increase the concentrations above background levels.

Formaldehyde was measured at concentrations of 0.54 – 2.11 ppb at the Australian comparison sites, with the lowest concentration at the rural Tasmanian site, and the highest concentrations at the urban and urban fringe sites in Melbourne and Sydney (Table 41). The formaldehyde concentrations measured in the Regional, Gas field and Chinchilla sites in this study were roughly one half to one third of the concentrations reported for suburban sites in Melbourne (CSIRO 2009) and a suburban fringe site in Sydney (Cheng et al., 2016), and are comparable to, though slightly higher than the Rural Tasmanian coastal site (Lawson et al., 2015).

For acetaldehyde, the Regional, Gas field and Chinchilla sites in this study were roughly one half of the concentrations reported for suburban sites in Melbourne (CSIRO 2009) and a suburban fringe site in Sydney (Cheng et al., 2016), and are higher than the Rural Tasmanian coastal site (Lawson et al., 2015) (Table 41).

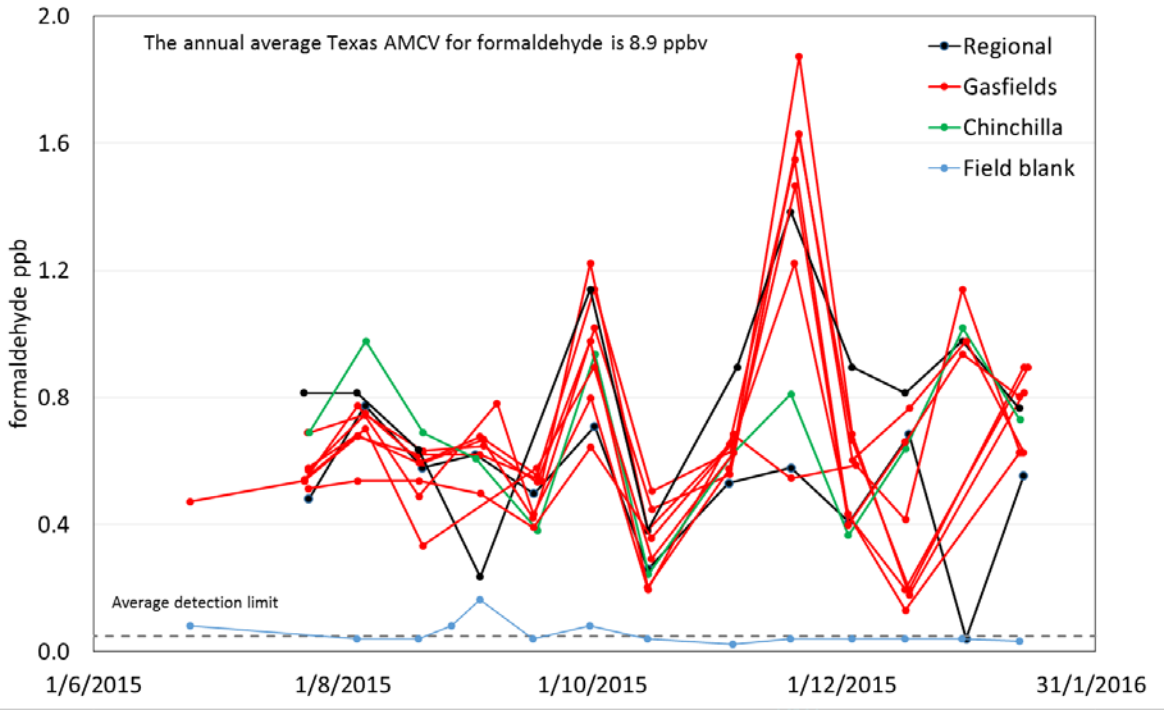

Figure 42 Formaldehyde measured using Radiello samplers at the Regional (black markers), Gas field (red markers) and Chinchilla (green marker) sites. The average detection limit for formaldehyde is shown by a blue dotted line, field blanks are light blue markers.

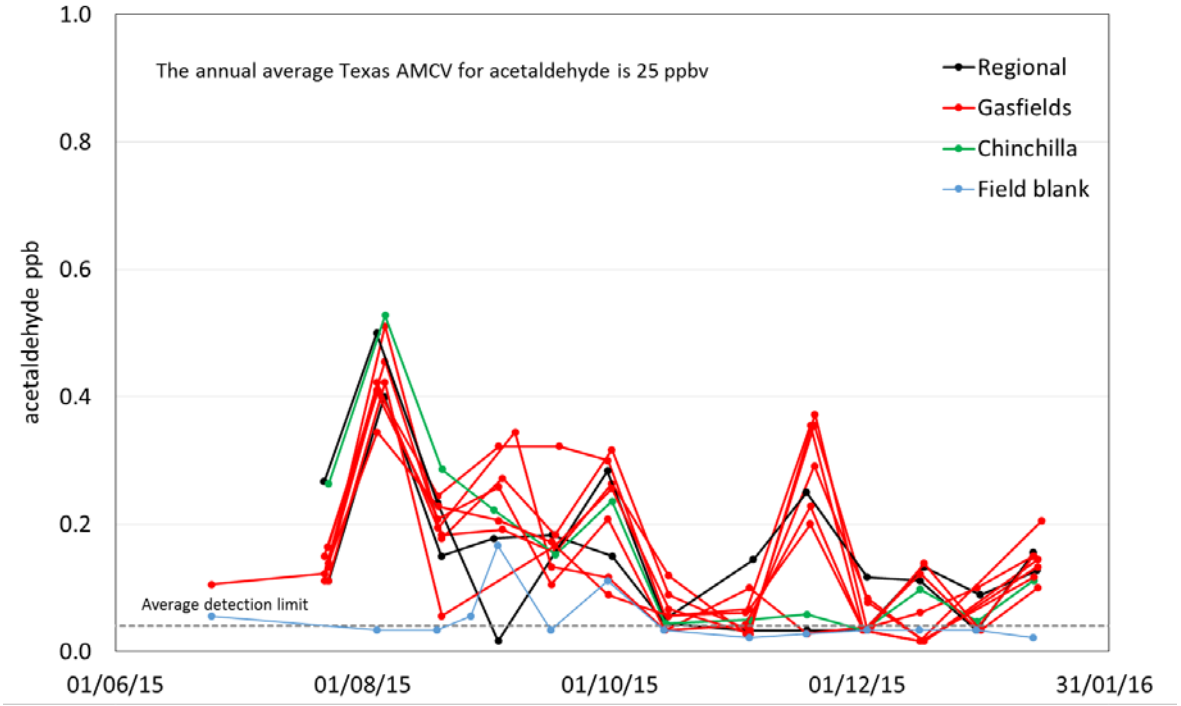

Figure 43 Acetaldehyde measured using Radiello samplers at the Regional (black markers), Gas field (red markers) and Chinchilla (green marker) sites. The average detection limit for acetaldehyde is shown by a blue dotted line, field blanks are light blue markers.

6.7 Summary and Conclusion of VOC monitoring network results

This section reported measurements collected via a network of passive Radiello samplers. VOC passive samplers were deployed at 10 sampling sites in the study area from September 2014-January 2016 and aldehyde and hydrogen sulphide passive samplers were deployed for 7 months from June 2015 – January 2016.

Of the 54 targeted gases able to be measured by the Radiello samplers 31 were measured above the detection limit in one or more of the Radiello samples. Conversely, 23 gases which were not measured above the detection limit in any of the samples, including hydrogen sulphide.

At the Regional sites 18 of the 54 targeted gases were detected, at the Gas field sites 21 of the targeted gases were detected while at the Chinchilla township site 29 of the targeted gases were detected.

Concentrations at Gas field, Regional and Chinchilla sites were compared with air quality objectives. There were no exceedances of air quality objectives for the 54 target gases and concentrations at all sites were consistently well below relevant air quality objectives. For aldehydes and hydrogen sulphide there was less than one year of data to compare to annual air quality objectives, but for assessment purposes, given the concentrations observed were well below air quality objectives it would be reasonable to assume the objective would be met.

Gases most frequently detected (present in ≥80% of the samples from Gas field, Regional and/or Chinchilla sites) were BTX, carbon tetrachloride, formaldehyde and acetaldehyde. BTX was detected more frequently at the Chinchilla site, while carbon tetrachloride, formaldehyde and acetaldehyde were detected evenly across all site categories.

Concentrations of frequently detected gases were compared to available data from other Australian sites. BTX levels in Chinchilla were similar to a rural town in Victoria, while Regional and Gas field sites were lower than Chinchilla and most comparable to a rural/coastal site in Tasmania. The benzene/toluene ratio at Chinchilla of 0.37 which is similar to other Australian urban and rural environments, and lower than in towns impacted significantly by woodsmoke (CSIRO, 2014). The source of benzene, toluene and xylenes at the Chinchilla site is likely predominantly motor vehicles, as well as domestic and commercial sources within the town.

Concentrations of carbon tetrachloride at Gas field, Regional and Chinchilla sites in this study are similar to background levels measured in rural Tasmania and Melbourne and do not indicate the presence of a local source. Formaldehyde concentrations at Chinchilla, Regional and Gas field sites are comparable to a rural/coastal site in Tasmania, while acetaldehyde concentrations at all categories are higher than rural Tasmania and roughly half the concentration observed in Melbourne and Sydney sites.

Overall, levels of VOCs and aldehydes in the study region were well below air quality objectives and were comparable to rural/regional concentrations elsewhere in Australia.

While the CSG industry is a known source of several of these gases including BTX, formaldehyde and acetaldehyde (Lawson et al., 2017), levels of VOCs and aldehydes in the study region were well below air quality objectives and were comparable to rural/regional concentrations elsewhere in Australia.

6.8 References

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7 CSIRO measurements and method comparison: VOCs and aldehydes

CSIRO undertook measurements of VOCs and aldehydes at Hopeland ambient air monitoring station for two weeks in June-July 2015. This allowed an independent check of VOC and aldehyde levels at the Hopeland site using a different sampling and analysis method to the Radiello Passive method. This also allows comparison of the different methods used by SGS Leeder and CSIRO.

This Section provides a brief description of methods and comparison of results between the two techniques. Further information about the methods is provided in Appendix B1 and B2.

7.1 Methods

The method comparison was undertaken from 24th June to 8th July 2015 at the Hopeland ambient air monitoring station.

7.1.1 Passive Radiello samplers – VOC and aldehyde

Two VOC Passive Radiello samplers and one aldehyde sampler were exposed to air for two weeks at the Hopeland ambient air station. Radiello samplers were affixed to a pole at a height of 2 m above ground 15 m to the east of the ambient air station. After two weeks the samplers were sealed and sent to laboratories for analysis. The VOC samplers were sent to two different laboratories - one VOC sampler was analysed by SGS Leeder laboratory in Mitcham Victoria, while the second VOC sampler was analysed by Eurofins laboratory in California, USA. The Eurofins analysis provides an independent check of the analytical measurement technique so that results obtained from the two different laboratories (SGS Leeder and Eurofins) can be compared. The aldehyde sampler was sent to SGS Leeder laboratory in Mitcham Victoria. Details about the methods are provided in B.2.

7.1.2 CSIRO VOC and aldehyde measurements

CSIRO collected 12-hour VOC and aldehyde samples twice per day over the two week sample period. Samples were collected using pumps which drew air through the VOC sampling tubes (adsorbent tubes) and aldehyde cartridges (2,4-DNPH) using CSIRO's custom built sampling automated Sequencer. The Sequencer drew air from the sampling manifold down the air quality station sample inlet. A total of 28 VOC tube samples and aldehyde cartridges were collected (2 per day for 14 days), with each sample providing an integrated concentration over the 12 hours of sampling. The 28 samplers covered the period that the Radiello Passive samplers were exposed. Tubes and cartridges were capped and sent back to CSIRO Aspendale for analysis. CSIRO's VOC analytical method is based on USEPA Compendium method TO-17 while CSIRO's aldehyde analytical method is based on USEPA method TO-11. Further details can be found in B.2 in this report.

7.2 Results and discussion

7.2.1 Air quality and meteorology during method comparison period

Table 42 shows the concentrations and data capture rate of carbon monoxide, nitrogen dioxide methane and TVOCs at the Hopeland station during the period of the method comparison. These average and max concentrations are typical of the concentrations observed at Hopeland throughout 2015, indicating that this period is broadly representative of the wider measurement period (see Section 2 and Section 3). Ozone and PM instruments were not yet installed at the time of the method comparison. Figure 44 shows BTX, carbon tetrachloride, formaldehyde and acetaldehyde at Hopeland, with the period corresponding to the CSIRO measurements/method comparison study highlighted blue. This also shows that the VOC and aldehyde concentrations during the method comparison were broadly consistent with the wider measurement period. Note that the aldehyde monitoring program began at Hopeland at the time of the method comparison, so there is no formaldehyde or acetaldehyde data prior for comparison.

Table 42 concentrations and data capture of carbon monoxide, nitrogen dioxide and methane at the Hopeland station during the VOC method comparison period

	Concentration (1 hour unless otherwise specified)	**data capture**
Carbon monoxide	0.2 ppm (max) 0.1 ppm (average)	96%
Nitrogen dioxide	0.006 ppm (max) 0.002 ppm (average)	96%
methane	2.4 ppm (max) 1.8 ppm (average)	100%
TVOC/NMHC	< 1 ppmC	70%

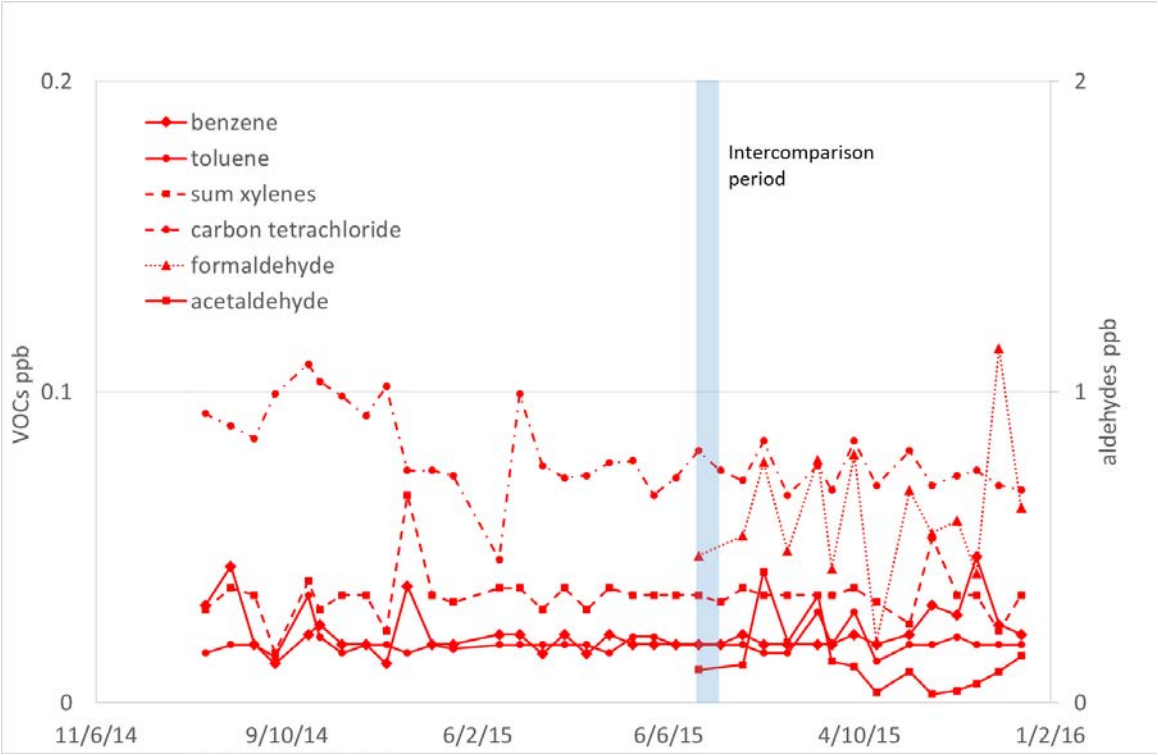

Figure 44. Concentrations of BTX, carbon tetrachloride, formaldehyde and acetaldehyde at Hopeland, with the VOC method comparison study period highlighted in blue

Figure 45 shows a wind rose plot of hourly wind speed and direction during the method comparison study. The winds were mainly from the south, particularly SE and SSW with speeds typically of 2-4 m s^{-1}. These wind conditions were typical of the average June and July wind conditions at Hopeland in 2015 and 2016, however wind speed was somewhat lower during the study period compared to the average wind speed range at Hopeland in 2015-2016 (see A.3.1).

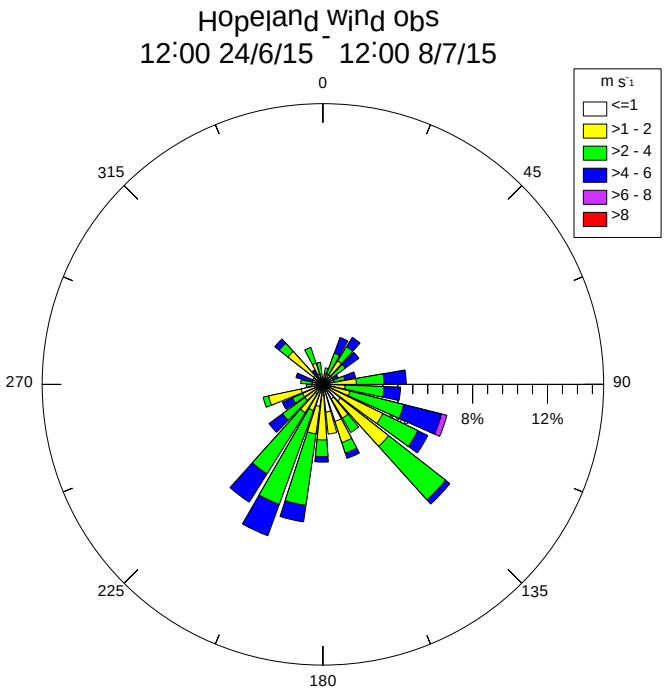

Figure 45 Wind speed and direction during two weeks of method comparison in June and July 2015

7.2.2 Comparison of Radiello Passive measurements with CSIRO measurements

The concentration data obtained from CSIRO's VOC and aldehyde samples was averaged to compare with

a) the 2 week integrated results for the Radiello Passive VOC and aldehyde methods analysed by SGS Leeder, and

b) the 2 week integrated results for the Radiello Passive VOC analysed by Eurofins laboratory California. Note that SGS Leeder provided all the analytical results for the Radiello Passive monitoring program and the analysis of duplicate Hopeland samples by Eurofins was undertaken as a quality control measure. Results are presented in Table 43 and Table 44. CSIRO concentration values less than the detection limit were given a value equal to the detection limit, and so the 2-weekly average concentration can be considered as an upper estimate of the VOC concentrations measured.

In general the CSIRO measurements had lower detection limits than the Radiello Passive measurement for most VOCs. This suggests that VOCs could be measured at lower concentrations in the air using the CSIRO technique compared to the Radiello technique. As a result the CSIRO measurements were able to detect a higher number of VOCs and aldehydes in the air than the Radiello Passive technique. It should be noted however that the Radiello passive technique does have sufficient sensitivity to compare VOCs and aldehydes with relevant air quality objectives, as discussed in Section 6. All VOCs and aldehydes measured using both the Radiello Passive samplers and CSIRO adsorbent tubes during the method comparison were below air quality objectives.

VOC comparison

Table 43 shows the average 2-weekly VOC concentration of individual VOCs using the VOC Radiello sampler analysed by SGS Leeder, using the VOC Radiello duplicate sampler analysed by Eurofins California and using VOC adsorbent tubes deployed and analysed by CSIRO.

Both the Radiello Passive measurements and CSIRO tube measurements show low levels of VOCs, with most VOCs targeted below the measurement detection limit.

For the SGS Leeder Radiello Passive samples, 3 VOCs were measured above the detection limit, for the Eurofins Radiello Passive sampler duplicate, 1 VOC was measured above the detection limit, while for the CSIRO adsorbent tubes 10 VOCs were measured above the detection limit.

Carbon tetrachloride and n-hexane

Carbon tetrachloride and n-hexane were the only VOCs that were detected by both the Passive Radiello technique and the CSIRO adsorbent tube technique. Carbon tetrachloride was detected in Radiello samplers analysed by SGS Leeder and Eurofins and the CSIRO tubes, while n-hexane was detected in the Radiello sampler analysed by SGS Leeder and CSIRO tubes.

The carbon tetrachloride CSIRO and SGS Leeder concentrations agree within 15%, with a lower concentration reported by Eurofins laboratory. A more in depth comparison of the SGS Leeder and Eurofins results is in Appendix B.2.2. The concentration measured at Hopeland by both Radiello (SGS Leeder) and CSIRO is consistent with concentrations measured throughout study and consistent with background levels in Australia (see Table 41).

The reported n-hexane CSIRO concentration is about 6 times lower than the SGS Radiello concentration – however the n-hexane concentration in both cases was very low (thousands times lower than Texas Air Quality objective) and approaching analytical detection limits.

Comparison of BTX

In both Radiello Passive samplers BTX was below the detection limit and so results cannot be directly compared with the CSIRO measurements. However CSIRO BTX results are discussed here as BTX is included in the frequently detected gases as part of the wider passive gas monitoring network (Section 6). The CSIRO-measured concentrations of benzene and toluene in Hopeland samples were similar to the 16-month average Regional and Gas field concentrations in this study and were also similar to concentrations reported from rural Tasmania (Table 41). The average xylenes concentration was below the detection limit in the CSIRO samples consistent with the low detection frequency (0 – 1%) for all gas field and regional sites reported in the Radiello results previously (Table 38).

Table 43 Concentrations of gases measured using VOC Radiello sampler analysed by SGS Leeder, VOC Radiello duplicate sampler analysed by Eurofins California and average concentrations measured by CSIRO using adsorbent tube samplers. Radiello passive samplers were exposed for 2 weeks. CSIRO concentrations are calculated from 26 individual samples. All measurements reported at 25°C and 1 atmosphere pressure.

		Hopeland Radiello SGS analysis		Hopeland Radiello Duplicate Eurofins analysis		Hopelands adsorbent tubes CSIRO analysis	
Sample date		**24-Jun to 8-Jul-2015**		**24-Jun to 8-Jul-2015**		**24-Jun to 8-Jul-2015**	
VOC	**CAS No.**	**Detection limit (ppb)**	**Concentration (ppb)**	**Detection limit (ppb)**	**Concentration (ppb)**	**Detection limit (ppb)**	**Average Concentration (± std dev) (ppb)**
			n= 1		n= 1		n= 26
Benzene	71-43-2	0.02	<0.02	0.08	<0.08	0.001	0.021 ± 0.007
Bromochloromethane	74-97-5	0.01	<0.01	nm	nm	nm	nm
Butanol	35296-72-1	0.02	<0.02	nm	nm	0.010	<0.010
2-butoxyethanol	111-76-2	0.02	<0.02	nm	nm	0.006*	<0.006
Butyl acetate	123-86-4	0.02	<0.02	nm	nm	0.006*	<0.006
Carbon tetrachloride	56-23-5	0	0.08	0	0.05	0.005	0.09 ± 0.02
Chlorobenzene	108-90-7	0.02	<0.02	0.02	<0.02	0.007	<0.007
Cyclohexane	110-82-7	0.03	<0.03	0.03	<0.03	0.009	<0.009
Cyclohexanone	108-94-1	0.02	<0.02	nm	nm	0.007*	<0.007
n-decane	124-18-5	0.02	<0.02	nm	nm	0.004	0.005 ± 0.001
1,4-Dichlorobenzene	106-46-7	0.02	<0.02	0.02	<0.02	0.005	<0.005
1,2-Dichloroethane	107-06-2	0.01	<0.01	0.01	<0.01	nm	nm
1,2-Dichloropropane	78-87-5	0.02	<0.02	nm	nm	nm	nm
Ethyl acetate	141-78-6	0.02	<0.02	0.07	<0.07	0.008	<0.008
Ethylbenzene	100-41-4	0.02	<0.02	0.02	<0.02	0.003	0.003 ± 0.001
2-ethylhexanol	104-76-7	0.02	<0.02	nm	nm	0.004*	<0.004
Ethyl-tert-butyl ether	637-92-3	0.02	<0.02	nm	nm	nm	nm
n-Heptane	142-82-5	0.02	<0.02	0.02	<0.02	0.007	<0.007
n-Hexane	110-54-3	0	0.03	0.02	<0.02	0.003	0.005 ± 0.002
Isobutanol	78-83-1	0.02	<0.02	nm	nm	0.010*	<0.010
Isooctane	540-84-1	0.02	<0.02	nm	nm	0.002	<0.002
Isopropylbenzene	98-82-8	0.02	<0.02	nm	nm	0.006	<0.006
1-Methoxy-2-propanol	107-98-2	0.02	<0.02	nm	nm	nm	nm
1-Methoxy-2-propyl acetate	108-65-6	0.01	<0.01	nm	nm	nm	nm
Methyl methacrylate	80-62-6	0.02	<0.02	nm	nm	0.007*	<0.007
Methylcyclohexane	108-87-2	0.02	<0.02	nm	nm	0.007	<0.007
Methylcyclopentane	96-37-7	0.02	<0.02	nm	nm	0.009	<0.009
Methylethylketone	78-93-3	0.02	<0.02	0.02	<0.02	0.007	0.02 ± 0.009
Methylisobutylketone	108-10-1	0.02	<0.02	0.04	<0.04	0.007	<0.007

		Hopeland Radiello SGS analysis		Hopeland Radiello Duplicate Eurofins analysis		Hopelands adsorbent tubes CSIRO analysis	
		24-Jun to 8-Jul-2015		24-Jun to 8-Jul-2015		24-Jun to 8-Jul-2015	
VOC	**CAS No.**	**Detection limit (ppb)**	**Concentration (ppb)**	**Detection limit (ppb)**	**Concentration (ppb)**	**Detection limit (ppb)**	**Average Concentration (± std dev) (ppb)**
2-Methylpentane	107-83-5	0.02	<0.02	nm	nm	0.009	<0.009
3-Methylpentane	96-14-0	0.02	<0.02	nm	nm	0.009	<0.009
Methyl-ter-butyl ether	1634-04-4	0.02	<0.02	0.02	<0.02	nm	nm
Naphthalene	91-20-3	0.04	<0.04	0.04	<0.04	0.006*	0.006 ± 0.003
N-Nonane	111-84-2	0.02	<0.02	nm	nm	0.002	<0.002
N-Octane	111-65-9	0.02	<0.02	nm	nm	0.006	<0.006
n-Propylbenzene	103-65-1	0.02	<0.02	0.02	<0.02	0.006	<0.006
Styrene	100-42-5	0.02	<0.02	0.02	<0.02	0.001	0.001 ± 0.0007
Tetrachloroethylene	127-18-4	0.01	<0.01	0.01	<0.01	0.004	<0.004
Toluene	108-88-3	0.02	<0.02	0.02	<0.02	0.011	0.02 ± 0.01
1,1,1-Trichloroethane	71-55-6	0.01	<0.01	0.01	<0.01	nm	nm
Trichloroethylene	79-01-6	0.01	<0.01	0.01	<0.01	0.006	<0.006
Trichloromethane	67-66-3	0	0.01	0.01	<0.01	nm	nm
124-Trimethylbenzene	95-63-6	0.02	<0.02	nm	nm	0.004	0.006 ± 0.01
N-Undecane	1120-21-4	0.03	<0.03	nm	nm	0.003	<0.003
Sum xylenes	108-38-3 / 106-42-3/95-47-6	0.04	<0.04	0.04	<0.04	0.01	<0.01

*these VOCs did not have gas standards run during the analysis of samples from this study but were detected previously in other CSIRO studies using the same sampling and analytical method

nm = not measured

n refers to the number of samples

Dodecane not reported (see Appendix B.2.4)

Comparison of aldehyde samplers

Table 44 shows the average 2 weekly aldehyde concentrations measured using the Radiello aldehyde sampler analysed by SGS Leeder, and DNPH sample tubes deployed and analysed by CSIRO.

Both the Radiello Passive measurements and CSIRO tube measurements show low levels of aldehydes. For the SGS Leeder Radiello Passive samples, 2 aldehydes were measured above the detection limit, while for the CSIRO tubes 7 aldehydes were measured above the detection limit.

Formaldehyde and acetaldehyde

Formaldehyde and acetaldehyde were measured above detection limit in both Radiello and CSIRO samplers. Measurements show very good agreement between techniques with agreement within 5% for formaldehyde and 10% for acetaldehyde. Figure 46 shows the CSIRO 24-hour average formaldehyde concentrations plotted over the two weeks, the CSIRO average 2-week

concentration calculated from these samples, and the average Radiello concentration. The 24-hour concentrations shows how the concentration of formaldehyde changed during the two week period.

Formaldehyde and acetaldehyde were identified as frequently detected gases in Section 6. The concentrations at Hopeland during the method comparison were comparable to, though somewhat lower than, the Gas fields average value, and most similar to the Tasmanian rural concentrations (Table 41).

Table 44 Concentrations of gases measured using Radiello aldehyde sampler analysed by SGS Leeder and average concentrations measured by CSIRO using DNPH sample tubes. Radiello passive sampler was exposed for 2 weeks. CSIRO concentrations are calculated from 28 individual samples.

Sample Description		SGS Hopelands 656QC		Hopelands CSIRO tube VOCs	
Sample date		24-Jun-2015 to 8-Jul-2015 n= 1		24-Jun-2015 to 8-Jul-2015 n=28	
VOC	CAS No.	Detection limit (ppb)	Concentration (ppb)	Detection limit (ppb)	Average Concentration ± std dev (ppb)
Formaldehyde	50-00-0	0.00	0.47	0.032	0.48 ± 0.13
Acetaldehyde	75-07-0	0.00	0.11	0.045	0.10 ± 0.05
Propanaldehyde	123-38-6	0.07	<0.07	0.002	0.02 ± 0.01
Butanaldehyde	123-72-8	0.15	<0.15	0.002	0.003 ± 0.003
Pentanaldehyde	110-62-3	0.05	<0.05	0.001	0.003 ± 0.003
Hexanaldehyde	66-25-1	0.07	<0.07	0.004	0.007 ± 0.003
Benzaldehyde	100-52-7	0.01	<0.01	0.002	0.004 ± 0.002
Glutaraldehyde	111-30-8	0.01	<0.01	nm	nm

Note acrolein is not reported (see Appendix B.2.4)

n refers to the number of samples

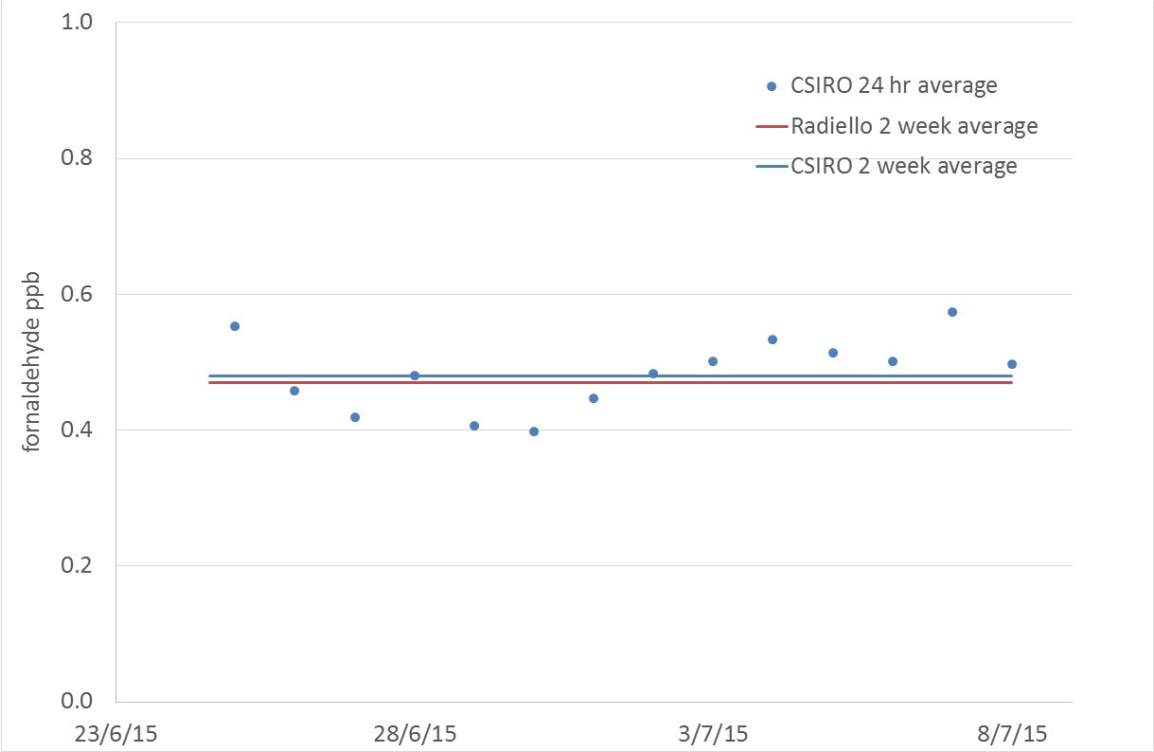

Figure 46 Formaldehyde measured using VOC Radiello passive sampler – 2 week exposure (red line), CSIRO active samples (24 hour average concentrations -blue dots) and CSIRO active samples averaged to a 2 week average concentration (blue line).

7.2.3 Comparison of VOC and aldehyde data with TVOC instrument

The TVOC instrument measures the sum of all present VOCs and aldehydes and as such gives an approximation for the sum of all individual VOCs present. The TVOC instrument has a reported measurement range of 1 – 2000 ppmC (see Section 3.2.) and during the method comparison the concentration of TVOC measured was lower than the lowest reportable concentration of 1 ppmC. As such, a comparison of results from the two techniques is not possible.

7.3 Summary and conclusion of method comparison

CSIRO undertook independent measurements of VOCs and aldehydes at Hopeland ambient air monitoring station for two weeks in June-July 2015. This provided an independent measurement of VOC and aldehyde concentrations. This also allowed comparison of results from different measurement methods used by consultants SGS Leeder and CSIRO.

CSIRO collected 12-hour VOC and aldehyde samples twice per day over the two week sample period to coincide with the two week exposure of the Radiello VOC and aldehyde samplers. The concentration data obtained from CSIRO's VOC and aldehyde samples was averaged to compare with the two-week integrated results for the Radiello Passive VOC and aldehyde samplers.

Duplicate VOC Radiello samplers deployed side by side were analysed by two different laboratories (SGS Leeder and Eurofins) while the aldehyde Radiello sampler was analysed by SGS Leeder.

Concentrations of other pollutants measured during the method comparison (oxides of nitrogen, carbon monoxide and methane), as well as meteorology indicated that the period chosen for the inter-comparison was broadly representative of the wider measurement period at this site.

Both the Radiello Passive measurements and CSIRO tube measurements show low levels of VOCs and aldehydes. In general the CSIRO measurements had lower detection limits than the Radiello Passive measurement for most VOCs and aldehydes which meant that the CSIRO measurements were able to detect a higher number of VOCs and aldehydes in the air than the Radiello Passive technique. It should be noted however that the Radiello passive technique does have sufficient sensitivity to compare VOCs and aldehydes with relevant air quality objectives, as discussed in Section 6. All VOCs such as BTX which were detected only by the CSIRO technique during the method comparison were at very low levels, with similar to concentrations reported from rural Tasmania (Table 41). Measurements using both techniques showed that VOC and aldehyde concentrations were below air quality objectives presented in Table 39 and Table 40.

For the VOC samplers, carbon tetrachloride and n-hexane were the only VOCs that were measured above detection limit by both measurement techniques. Carbon tetrachloride concentrations agreed within 15% between the CSIRO and SGS Leeder measurements.

The reported n-hexane CSIRO concentration is about 6 times lower than the SGS Radiello concentration – however the absolute difference in n-hexane concentrations between the techniques was very small (25 parts per trillion), as in both cases the concentrations were very low (thousands of times lower than the Texas AMCV) and approaching analytical detection limits.

For the aldehyde samplers, formaldehyde and acetaldehyde were the only species that were measured above detection limit by both techniques. Measurements show very good agreement between techniques with agreement within 5% for formaldehyde and 10% for acetaldehyde.

In conclusion, CSIRO measurements indicated low levels of VOCs and aldehydes at Hopeland during the method comparison. Concentrations measured at Hopeland using the CSIRO techniques were comparable with available VOC concentration data from other rural areas in Australia.

Where direct comparison was possible between the different techniques, the CSIRO and Radiello measurements agreed within 5-15%, with the exception of n-hexane which was measured at a very low concentration (thousands of times lower than Texas Air AMCV) and approaching analytical detection limits.

Overall this method comparison shows good agreement between passive and active measurement techniques and supports the suitability of the Radiello Passive technique for monitoring VOCs and aldehydes in the study area.

7.4 References

Radiello Manual (2006), Fondazione Salvatore Maugeri- Centro di Ricerche Ambientali, Padova, Italy. Available: http://www.radiello.com/english/Radiello%27s%20manual%2001-06.pdf; Accessed 2/3/2017

8 Overall summary of Part 1 and Part 2 and next steps

The work presented here is the largest contribution to air quality data for this region to date, and provides important information about the levels and sources of air pollutants in a region of CSG production in Australia. Live streaming of air quality data allows community, government and industry to see in near real time how air quality in this region compares to other parts of Queensland and air quality objectives. This study provides air pollutant concentration data against which future measurements can be compared. Data from this study can be used to inform future health or environmental studies in this area, and can be used by government to inform future policy development around CSG. Data collected in this study will also be used to validate the performance and output of air quality models, and is being utilised in the development of CSIRO's air quality model as part of this GISERA project, which will explore the degree to which CSG emissions contribute to air pollution levels in the Surat Basin.

Individual summaries of findings from Part 1 and Part 2 are given below, as well as next steps.

8.1 Part 1 – ambient air monitoring stations

A wide variety of pollutants are being measured at 5 ambient air monitoring stations in Chinchilla – Miles-Condamine region as part of the GISERA ambient air quality in the Surat Basin project. The conclusions presented here refer to measurements from February 2015 until December 2016.

Concentrations were compared to relevant air quality objectives including the Air (EPP), NEPM (air), and DEHP Nuisance dust Guidelines for TSP.

There were no exceedances of carbon monoxide, nitrogen dioxide or ozone air quality objectives at any of the Regional or Gas field sites.

There were 6 exceedances of the 24-hour $PM_{2.5}$ objective, and 2 exceedances of the 24-hour PM_{10} objective at the Gas field sites.

There were 8 exceedances of the TSP 24-hour nuisance dust guideline at the Gas field sites.

There were no particle measurements at the Regional sites for comparison.

The source of the exceedances have been investigated using a combination of wind speed and direction, source locations, and substance correlations and emission ratios

- All 6 $PM_{2.5}$ exceedances were attributed to vegetation fires.
- 1 PM_{10} exceedance was attributed to vegetation fire and the other source could not be determined, and
- 1 TSP event was attributed to vegetation fire, 2 to dust associated with cattle farming, 3 could not be determined, 1 was attributed to a dust from unsealed roads/CSG activities, and 1 from a combination of fire and unsealed roads/CSG activities.

A number of events where concentrations > 80% of air quality objective were also investigated and found that the following sources were likely responsible:

- $PM_{2.5}$ – smoke from vegetation fires;
- PM_{10} – combination of smoke from vegetation fires and local dust, particles associated with cattle farming, unsealed roads/CSG activities, and source undetermined;
- TSP – combination of smoke from fire and dust, particles associated with cattle farming, unsealed roads/CSG activities, source undetermined.
- Ozone – a regional event (source unknown)

Methane does not have an air quality objective and was measured at the three Gas field sites as a tracer for CSG related emissions. The annual average methane concentrations at Gas field sites were between 1.8 and 1.9 ppm, comparable to methane concentrations measured at the 2 Regional sites as part of the GISERA Regional Methane Flux study (Etheridge et al., 2017). Determination of the regional methane emissions in the study area is being addressed as part of the GISERA Regional Methane Flux project (see https://gisera.csiro.au/project/methane-seepage-in-the-surat-basin/).

The 5 largest methane events at each Gas field site were identified and the source investigated, making 15 events investigated in total. 14 of the 15 methane events investigated were attributed to sources or activities associated with the CSG industry. The source of the remaining event was unknown. The methane events attributed to CSG-related sources or activities were not associated with any exceedance of air quality objectives. The largest methane peaks from the CSG-related events were uncorrelated with other gases associated with combustion (carbon monoxide, carbon dioxide, oxides of nitrogen) which suggests the methane observed was un-combusted CSG released intentionally or through leaks.

An estimate of other components likely present in the air during the largest methane concentrations observed were undertaken, using CSG composition measurements published previously (Lawson et al., 2017). The maximum 5-minute average methane concentration observed corresponds to an approximate 1/12,000 dilution of pure CSG (composed of 96-98% methane). When diluted by this factor, the calculated concentration of other components in the CSG are likely to be well below the relevant air quality objectives for benzene, toluene and hydrogen sulphide.

Overall, we can conclude that many of the identified sources of particles in the Surat Basin study region are typical of rural Australian regions including vegetation fires, livestock activities and dust from unsealed roads and agricultural activities. CSG-related development or operational activities were likely to have contributed to some of the PM_{10} and TSP events observed. CSG emissions from infrastructure and activities were most likely the source of the largest observed methane concentration peaks at Gas field sites. These CSG-related methane peaks were not associated with any exceedance of air quality objectives. VOCs and other gases such as benzene, toluene and hydrogen sulphide which may be present in CSG alongside methane were shown to be in trace quantities in CSG. It is likely they were rapidly diluted to concentrations well below the NEPM/EPP air quality objectives when CSG is emitted to air.

8.2 Part 2 – Radiello passive monitoring network

Ambient measurements of 54 VOCs, aldehydes and hydrogen sulphide were made us part of the Radiello passive sampler network. These measurement targeted several components of CSG as well as a variety of other VOCs at 10 sampling sites for 16 months from September 2014- January 2016. There were no exceedances of air quality objectives at any of the Gas field, Regional or Chinchilla sites. There was less than one year of data of aldehydes and hydrogen sulphide to compare to annual air quality objectives, but given the concentrations observed it would be reasonable to assume the objective would be met. These results reinforce the conclusions based on methane measurements and CSG composition made in Part 1 that emissions of CSG are unlikely to result in exceedances of VOCs, aldehydes and hydrogen sulphide at the measurement sites.

The most frequently detected gases measured by the Radiello passive sampler method in this study were BTX, carbon tetrachloride, formaldehyde and acetaldehyde. Chinchilla had higher BTEX concentrations than the Gas field and Regional sites, and concentrations were similar to a rural town in Victoria. The benzene/toluene ratio at Chinchilla was similar to other Australian urban and rural environments, indicating the source of BTX at the Chinchilla site is likely due predominantly to motor vehicles and domestic commercial sources. BTEX concentrations at Gas field and Regional sites were comparable to a rural/coastal site in Tasmania.

Carbon tetrachloride, formaldehyde and acetaldehyde concentrations were similar across Chinchilla, Regional and Gas field sites. Concentrations of carbon tetrachloride in this study are similar to concentrations measured in rural Tasmania and Melbourne while formaldehyde and acetaldehyde concentrations were comparable to rural Tasmania and half the concentration of urban areas.

While the CSG industry is a known source of several of these gases including BTX, formaldehyde and acetaldehyde (Lawson et al., 2017), levels of VOCs and aldehydes in the study region were well below air quality objectives and were comparable to rural/regional concentrations elsewhere in Australia.

CSIRO undertook independent measurements of VOCs and aldehydes alongside the Radiello Passive Samplers at Hopeland ambient air monitoring station in June-July 2015. CSIRO measurements indicated low levels of VOCs and aldehydes at Hopeland during the method comparison. Concentrations measured at Hopeland using the CSIRO techniques were comparable with available VOC concentration data from other rural areas in Australia. Where direct comparison was possible between the different techniques, the CSIRO and Radiello measurements agreed within 5-15%, with the exception of n-hexane which was measured at a very low concentration (thousands of times lower than Texas Air AMCV) and approaching analytical detection limits. Overall the level of agreement between techniques supports the suitability of the Radiello Passive technique for monitoring VOCs and aldehydes in the study area.

The work presented here is the largest contribution to air quality data for this region to date, and provides important information about the levels and sources of air pollutants in a region of CSG production in Australia. Live streaming of air quality data allows community, government and industry to see in near real time how air quality in this region compares to other parts of

Queensland and air quality objectives. This study provides air pollutant concentration data against which future measurements can be compared. Data from this study can be used to inform future health or environmental studies in this area, and can be used by government to inform future policy development around CSG. Data collected in this study will also be used to validate the performance and output of air quality models, and is being utilised in the development of CSIRO's air quality model as part of this GISERA project, which will explore the degree to which CSG emissions contribute to air pollution levels in the Surat Basin.

8.3 Next steps

Data from the ambient air monitoring stations from January 2017 - February 2018 will be reported using a similar approach in a final report in 2018. An overall conclusion about air quality in the study area will be made at the conclusion of the study.

In 2017 CSIRO undertook a 6-month particle measurement validation study at the Miles Airport site to ensure the $PM_{2.5}$ and PM_{10} data collected at the Gas field sites is equivalent to data obtained by Australian Standard Methods (see A.2). These results will be presented and assessed in the final report.

Passive Radiello sampling recommenced in October 2016 at some existing sites and 10 new sites. Data from these measurements will be available for reporting as part of the GISERA project Investigating air, water and soil impacts of hydraulic fracturing (Dunne et al., 2017).

While the measurements of air quality undertaken for this CSIRO project were scheduled to finish at Regional and Gas field sites at the end of February 2018 there is a likelihood of industry funding to extend air quality monitoring at Regional sites until mid-2018, and at Gas field sites until the end of 2018. This additional monitoring is beyond the scope of CSIRO's research and will not be incorporated into reporting for this project.

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