Spontaneous Combustion Emissions Study

Muswellbrook Coal Company

Ambient Monitoring and Odour Modelling

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EPL656

JACOBS

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The sole purpose of this report and the associated services performed by Jacobs is to document the results of ambient monitoring and odour modelling for Muswellbrook Coal Mine in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

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Executive Summary

This report provides outcomes of the “Spontaneous Combustion Emissions Study”, a body of work that was carried out to address Condition U1 of EPL656 for Muswellbrook Coal Mine. Overall the study involved undertaking 12 months of continuous monitoring by Muswellbrook Coal Company to determine if emissions from the spontaneous combustion of coal at Muswellbrook Coal Mine were causing exceedances of relevant air quality criteria.

All monitoring data were reviewed and the following main conclusions were made:

- There were eight (8) unique days in the 12-month period when monitored H_2S concentrations exceeded the odour detection threshold (as defined by WHO, 2003) at the installed monitoring locations. It was noted that some individuals may be able to detect H_2S at lower levels than the referenced odour detection threshold. The data showed that H_2S concentrations were generally highest in spring and autumn, depending on the location, and almost always highest in the morning, coinciding with stable atmospheric conditions.
- Most (58%) of the odour complaints in the 12-month period related to reported incidents in the morning. The H_2S monitoring data also showed that concentrations were typically highest in the morning.
- H_2S concentrations did not exceed health-based criteria at any time during the 12-month period, indicating that the measured levels would not have caused adverse health effects.
- Measured 24-hour average PM_{10} concentrations exceeded the EPA’s 24-hour average assessment criteria on six (6) days in the 12-month period. Two of the six “exceedance” days were potentially due to activities or emissions at Muswellbrook Coal Mine. The remaining four “exceedance” days were due to regional events or other, non-mine related, factors. Annual average PM_{10} concentrations did not exceed the EPA’s criteria or National standards.
- SO_2 concentrations did not exceed the EPA criteria or National standards.

In addition to analysis, the monitoring data were used to derive an estimate of spontaneous combustion emissions (as H_2S) for input to a site-specific odour dispersion model, in accordance with Condition U1.4 of EPL656. The odour dispersion model was based on one year of representative meteorological data and was prepared using the procedures outlined in the EPA’s “Approved Methods for the Modelling and Assessment of Air Pollutants in NSW” (EPA 2016). The modelling was based on emissions that were conservatively high however the process did highlight that:

- Emissions from spontaneous combustion are extremely difficult to measure and predict due to the sporadic nature, distribution and intensity of coal fires.
- Areas to the east-northeast of Muswellbrook Coal Mine may experience higher effects of spontaneous combustion emissions (as H_2S) than other locations, because of the elevated terrain. In addition, H_2S from Muswellbrook Coal Mine may be detectable in most areas of the model domain from time-to-time, depending on the location and sensitivity of the individual.

The outcomes of the monitoring and modelling also led to the following recommendations:

- Continued monitoring of H_2S (nominally until 12 months after mining ceases) to assist with the verification of community concern since the complaints data, monitoring data and modelling results indicated that off-site odour (as H_2S) is detectable from time-to-time. The availability of longer-term monitoring data may also assist with examining the effectiveness of management controls in terms of off-site odour (as H_2S). Any changes to the monitoring arrangements would need to be with the agreement of the EPA, and consistent with the Consent.
- Development of a procedure for identifying whether Muswellbrook Coal Mine may have contributed to monitored H_2S concentrations on a day of interest (for example, a day of elevated H_2S).
- Incorporation of the findings from this study into the Air Quality Management Plan (AQMP) and Spontaneous Combustion Management Plan (SCMP) during the next periodic review of these documents.

1. Introduction

Muswellbrook Coal Company (MCC) operates the Muswellbrook Coal Mine located three kilometres (km) northeast of Muswellbrook in NSW. The mine is operated in accordance with its Development Approval (DA 205/2002) and Environment Protection Licence (EPL656).

Coal self-heating ("spontaneous combustion") has historically required additional management at Muswellbrook Coal Mine. This is reflected in Condition U1 of EPL656 which requires MCC to complete a "Spontaneous Combustion Emissions Study". The "Spontaneous Combustion Emissions Study" condition of EPL656 includes the following components:

- **Condition U1.1** Undertaking a 12-month continuous monitoring program to determine if emissions from the spontaneous combustion of coal at Muswellbrook Coal Mine are causing exceedances of the air quality impact assessment criteria noted by the Environment Protection Authority (EPA).
- **Condition U1.2** Reporting the monitoring results to the EPA.
- **Condition U1.3** Ongoing demonstration of the performance of the monitoring instruments.
- **Condition U1.4** Development of an odour model which considers the results of the monitoring data from U1.1 and the range of meteorological conditions.
- **Condition U1.5** Reporting on the outcomes of the monitoring, modelling, complaints, meteorological conditions, conclusions and actions.

MCC has completed the monitoring to address conditions U1.1, U1.2 and U1.3 above. Jacobs Group (Australia) Pty Ltd (Jacobs) has been engaged by MCC to assist with satisfying the requirements of Conditions U1.4 and U1.5. **Appendix A** provides an extract of EPL656 with all details of the "Spontaneous Combustion Emissions Study" requirements.

In summary, this report provides information on the following:

- The mechanics of spontaneous combustion (**Section 2**);
- Relevant air quality criteria (**Section 3**);
- Results from monitoring (**Section 4**); and
- Methods and results from odour modelling (**Section 5**).

The odour modelling was based on CALPUFF, an air dispersion model that was used to predict hydrogen sulfide concentrations due to calculated emissions from spontaneous combustion at Muswellbrook Coal Mine. Model predictions were compared to EPA air quality impact assessment criteria and the National Environment Protection Measure (NEPM) standards and goals in order to assess the potential impacts of emissions to the surrounding environment. The modelling has been carried out in accordance with relevant guidelines published by the EPA, namely, the "Approved Methods for the Modelling and Assessment of Air Pollutants in NSW" (EPA 2016).

2. Spontaneous Combustion

"Self-heating" occurs when coal and other carbonaceous materials undergo an exothermic reaction when exposed to oxygen in the air, to generate heat. This process causes the temperature of the material to rise which in turn accelerates the oxidation and, in turn, the heat generation process. As the material temperature rises above about 70ºC the temperature acceleration is rapid enough to result in ignition of the material. This ignition is referred to as spontaneous combustion.

The propensity of coal (or carbonaceous material) to self-heat and potentially combust is governed by many factors but most commonly by the type of coal, the levels of volatile compounds, the carbon content, the size of the particles, the material temperature, the presence of oxygen and quantity of coal. Spontaneous combustion results in the emission of noxious gases including carbon dioxide, carbon monoxide, sulfur dioxide, hydrogen sulfide, nitrogen oxides and a range of volatile organic compounds.

The emissions to air have the potential to lead to the following hazards:

- Adverse health effects due to inhalation;
- Nuisance effects due to odour;
- Fire and hot material;
- Subsidence; and
- Smoke and effects on visibility.

MCC has a Muswellbrook Shire Council (MSC) approved site-specific Spontaneous Combustion Management Plan (SCMP) which outlines the ways in which MCC commits to minimise the occurrence and manages the effects of spontaneous combustion (MCC 2017). The approach taken in the SCMP is broadly as follows:

- **Prevention** – measures to avoid outbreaks.
- **Control** – measures to control outbreaks.
- **Response** – a Trigger Action Response Plan (TARP) to manage outbreaks and minimise impacts.
- **Review** – an annual review of the commitments in the Annual Plan vs actual activities on site.

More specifically, the SCMP identifies various areas of Muswellbrook Coal Mine that require spontaneous combustion management. These areas include:

- The highwall and existing underground mine workings in Open Cut 1;
- The overburden / interburden removal and coal removal in Open Cut 1;
- Active and recent emplacement areas within Open Cut 1;
- Open Cut 2;
- Coal emplacement and storage areas; and
- Elsewhere with the disturbance area.

An Independent Environmental Audit (IEA) of Muswellbrook Coal Mine was carried in January 2019 (Umwelt 2019). This audit found that the management controls and practices implemented are consistent with leading practice applied at Australian open cut coal mines. In addition, the audit did not recommend any operational changes to the way in which spontaneous combustion is managed at Muswellbrook Coal Mine.

3. Air Quality Criteria

Typically, air quality is quantified by the concentrations of air pollutants in the ambient air. Air pollution occurs when the concentration (or some other measure of intensity) of substances known to cause health, nuisance and/or environmental effects, exceeds a certain level. The air pollutants specified by the EPA in EPL656 for the Spontaneous Combustion Emissions Study include:

- Hydrogen sulfide (H_2S);
- Particulate matter (as PM_{10}); and
- Sulfur dioxide (SO_2).

Hydrogen sulfide is a colourless, toxic gas with a characteristic foul odour of rotten eggs. It is the substance generated in the spontaneous combustion process that is most likely to lead to odour complaints. Criteria for H_2S are set to protect against adverse impacts to amenity (i.e. nuisance) and compliance with the amenity based criteria can be inferred as compliance with health-based criteria.

Particulate matter (as PM_{10}) refers to all particles in the air with equivalent aerodynamic diameters less than or equal to 10 microns. These particles can enter bronchial and pulmonary regions of the respiratory tract, with increased deposition during mouth breathing which increases during exercise. The very fine particles can be deposited in the pulmonary region and it is these which are of most concern. Criteria for PM_{10} are set to protect against adverse impacts to health.

Sulfur dioxide is a toxic gas with a characteristic “burning match” smell that is produced naturally (i.e. volcano activity) and from the burning of fossil fuels, such as coal. Criteria for SO_2 are set to protect against adverse impacts to health.

EPL656 has required the analysis of monitoring and model results against the EPA’s air quality impact assessment criteria and NEPM standards and goals. **Table 1** shows the relevant EPA air quality impact assessment criteria, as noted in the “Approved Methods for the Modelling and Assessment of Air Pollutants in NSW” (EPA 2016).

Table 1 EPA air quality assessment criteria for EPL656 requirements

Substance	Averaging time as per EPL656	Criterion
Hydrogen sulfide (H_2S)	30-minute	None available
	1-hour	None available
	24-hour	None available
	Annual	None available
Sulfur dioxide (SO_2)	1-hour	200 ppb
	24-hour	80 ppb
	Annual	20 ppb
Particulate matter (PM_{10})	1-hour	None available
	24-hour	50 µg/m^3
	Annual	25 µg/m^3

Table 2 shows the relevant NEPM standards and goals (NEPC 2015).

Table 2 NEPM standards and goals for EPL656 requirements

Substance	Averaging time	Maximum concentration standard	Goal (as maximum allowable exceedances)
Hydrogen sulfide (H_2S)	30-minute	None available	-
	1-hour	None available	-
	24-hour	None available	-
	Annual	None available	-
Sulfur dioxide (SO_2)	1-hour	200 ppb	1 day a year
	24-hour	80 ppb	1 day a year
	Annual	20 ppb	None
Particulate matter (PM_{10})	1-hour	None available	-
	24-hour	50 µg/m^3	None
	Annual	25 µg/m^3	None

As can be seen from **Table 1** and **Table 2** there are no EPA criteria or NEPM standards for H_2S and PM_{10} for all averaging times specified by EPL656. In this case EPL656 indicates that the monitoring results should be compared against other published standards or goals. Other known published standards or goals are discussed below.

The World Health Organisation (WHO) indicate that the odour threshold of H_2S is 8 ppb (WHO, 2003). While this threshold has been noted as the level of detection of H_2S odours it is possible that some individuals will be able to detect H_2S odour at lower levels.

Odour impacts (as H_2S) are generally observed on a time scale in the order of less than one second, consistent with the response time of the human nose. The odour threshold therefore relates to the response time of the human nose.

DA 205/2002 also includes the health-based criteria for H_2S, namely, 500 ppb as a 1-hour average, and 100 ppb as a 24-hour average. The criteria from DA 205/2002 have been set to protect against adverse impacts to health.

Table 3 identifies the thresholds, standards, criteria or goals for H_2S. These have been used to evaluate the monitoring data.

Table 3 Other identified standards and goals for H_2S

Reference	H_2S threshold, standard, criteria or goal	Averaging time	Basis
WHO	8 ppb	Not specified	Nuisance. “Geometric mean odour threshold”
DA 205/2002	500 ppb	1-hour	Health-based criterion
DA 205/2002	100 ppb	24-hour	Health-based criterion

Dispersion models are typically only valid for predicting at averaging times of one hour or longer and require estimates of peak (i.e. nose-response time) concentrations based on established peak-to-mean ratios (EPA 2016). The dispersion model predictions have been evaluated against the EPA impact assessment criteria for H_2S as a nose-response-time average, which are shown in **Table 4**.

Table 4 EPA air quality assessment criteria for H_2S as nose-response-time average at the 99th percentile

Population of affected community	Criterion (99th percentile of dispersion model predictions)
Urban (~2000)	0.91 ppb (1.38 µg/m^3)
~500	1.36 ppb (2.07 µg/m^3)
~125	1.81 ppb (2.76 µg/m^3)
~30	2.27 ppb (3.45 µg/m^3)
~10	2.72 ppb (4.14 µg/m^3)
Single residence (~2)	3.17 ppb (4.83 µg/m^3)

There are no National or State level standards or goals for 1-hour average PM_{10}. Statistics for the 1-hour average PM_{10} monitoring data have been reported in this study but no comparison has been made to standards or goals.

4. Monitoring Data

MCC has completed 12 months of monitoring around Muswellbrook to address conditions U1.1, U1.2 and U1.3. The monitoring period of interest was carried out between 5 February 2018 to 4 February 2019 inclusive and included the measurement of:

- SO_2 at two locations; referred to as Points 15 and 16.
- H_2S at two locations; referred to as Points 9 and 10.
- PM_{10} at three locations; referred to as Points 7, 8 and 13.

In addition, MCC has continued to operate a site meteorological station throughout the air quality monitoring period. **Figure 1** shows the location of the air quality and meteorological monitoring sites. This section provides an analysis of the meteorological and air quality monitoring data as per the requirements of EPL656.

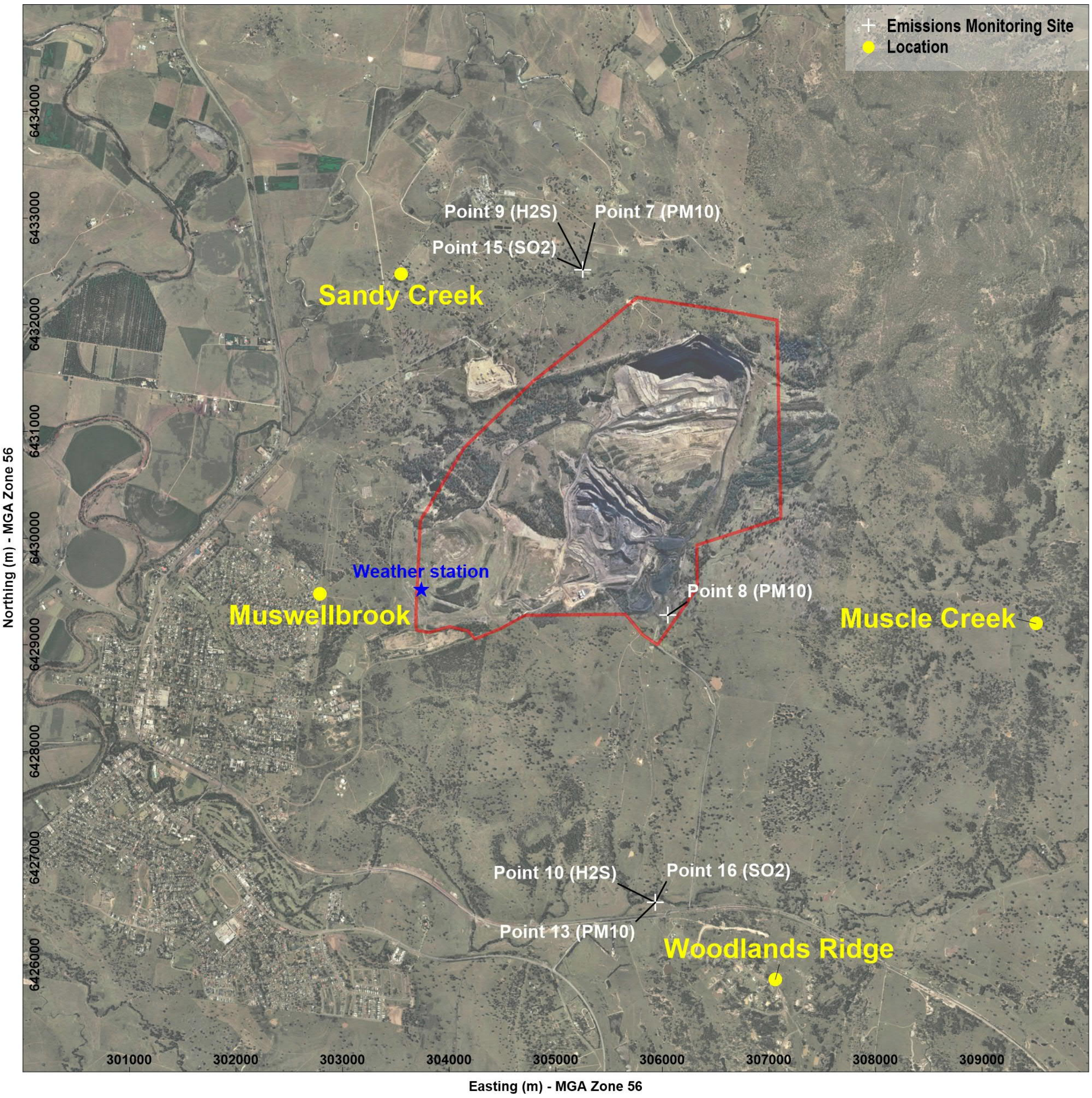

Figure 1 Location of air quality and meteorological monitoring sites

4.1 Meteorological Monitoring Data

Meteorological conditions are important for determining the direction and rate at which emissions from a source will disperse. The key meteorological requirements of air dispersion models are, typically, hourly records of wind speed, wind direction, temperature, and atmospheric stability. For air quality assessments, a minimum one year of hourly data is usually required, which means that almost all possible meteorological conditions, including seasonal variations, are considered in the model simulations.

MCC operates a meteorological station at Muswellbrook Coal Mine (**Figure 1**) for the purposes of understanding adverse weather conditions, managing operations and assisting with the analysis of air quality monitoring data. This station collects 15-minute average records of temperature, wind speed, wind direction and rainfall, among other parameters, and data for the 5 February 2018 to 4 February 2019 period have been obtained for this analysis and modelling.

Table 5 presents a range of statistics from the MCC meteorological data. Atmospheric stability class has been determined for each hour in the meteorological dataset using sigma-theta and the method recommended by the US EPA. Stability class is a measure of the turbulence of the atmosphere and, in the Pasquill-Gifford stability class assignment scheme, ranges from Class A to Class F. Some assignment schemes, for example Turner, includes Class G although in dispersion modelling Class F and Class G are grouped together. Class A is associated with highly unstable or turbulent conditions while Class F/G relate to stable conditions and typically at night. MCC reports Class A through to Class G. Based on the data in **Table 5**, stable conditions occur for 13 per cent of the time.

The data in **Table 5** show that the mean wind speed was around 3 m/s, a value that is quite typical of many parts of the Hunter Valley. Data capture was 96 per cent and this satisfies the EPA's minimum data capture requirement for use in dispersion modelling which is set at 90 per cent (EPA 2016). Rainfall in the monitoring period (437 mm) was 28 per cent lower than the long-term average for Muswellbrook (that is, 603 mm from Bureau of Meteorology's St. Helier's station). Methods used for incorporating the data into the meteorological modelling (CALMET) and air dispersion modelling (CALPUFF) are discussed in **Section 5**.

Table 5 Statistics from meteorological data collected at Muswellbrook Coal Mine

Statistic	Data collected between 5 February 2018 and 4 February 2019
Percent complete (%)	96
Mean wind speed (m/s)	3.3
99th percentile wind speed (m/s)	10.3
Percentage of calms (%)	1.4
Percentage of winds >6 m/s (%)	9.8
Rainfall (mm)	437
Frequency of occurrence of A class stability (%)	12
Frequency of occurrence of B class stability (%)	4
Frequency of occurrence of C class stability (%)	7
Frequency of occurrence of D class stability (%)	50
Frequency of occurrence of E class stability (%)	15
Frequency of occurrence of F class stability (%)	12
Frequency of occurrence of G class stability (%)	1

Figure 2 shows the annual and seasonal wind patterns from data collected at the MCC meteorological station for the 5 February 2018 to 4 February 2019 period. It can be seen from these wind-roses that, on an annual basis, the most common winds were from the southeast. Winds from the northwest were also common but more so in winter. The southeast-northwest alignment of winds is a common feature of the Muswellbrook area and reflects the southeast-northwest alignment of the broader Hunter Valley.

Figure 2 Annual and seasonal wind-roses for data collected at Muswellbrook Coal Mine (5 Feb 2018 to 4 Feb 2019)

4.2 Air Quality Monitoring Data

The EPA air quality criteria and NEPM standards refer to levels of substances which, in the case of SO_2 and PM_{10}, include the source(s) of interest as well as other existing sources. This section provides a description of the existing air quality as determined by the monitoring in the period from 5 February 2018 and 4 February 2019.

It should be noted that the measurement data represent the contributions from all sources that have at some stage been upwind of each monitor. In the case of particulate matter (as PM_{10}) for example, the measured concentration may contain emissions from many sources such as from mining activities, agriculture, construction works, bushfires and 'burning off', industry, vehicles, roads, wind-blown dust from nearby and remote areas, fragments of pollens, moulds, and so on.

4.2.1 Hydrogen Sulfide (H_2S)

Figure 3 shows the measured hourly average and maximum 30-minute average H_2S concentrations from each monitoring site for data collected between 5 February 2018 and 4 February 2019. The H_2S odour detection threshold of 8 ppb has also been shown on these graphs. Inspection of the monitoring data revealed that there were eight (8) unique days when H_2S concentrations exceeded the odour detection threshold at one or more monitoring locations.

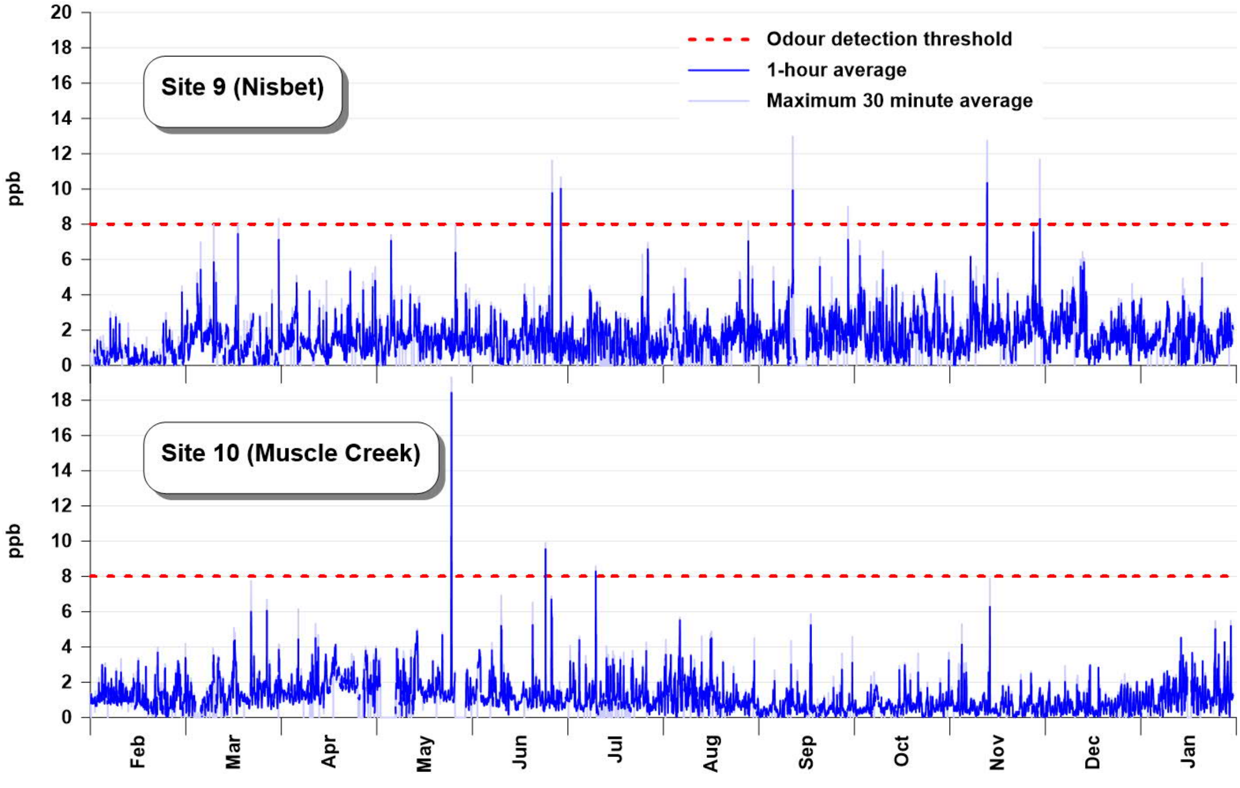

Figure 3 Measured hourly average and maximum 30-minute average H_2S concentrations with odour detection threshold

Figure 4 shows the measured hourly average and maximum 30-minute average H_2S concentrations from each monitoring site for comparison with the 1-hour average health-based criterion of 500 ppb. The data show that H_2S concentrations were well below the 500 ppb criterion indicating that the measured levels would not have caused adverse health effects.

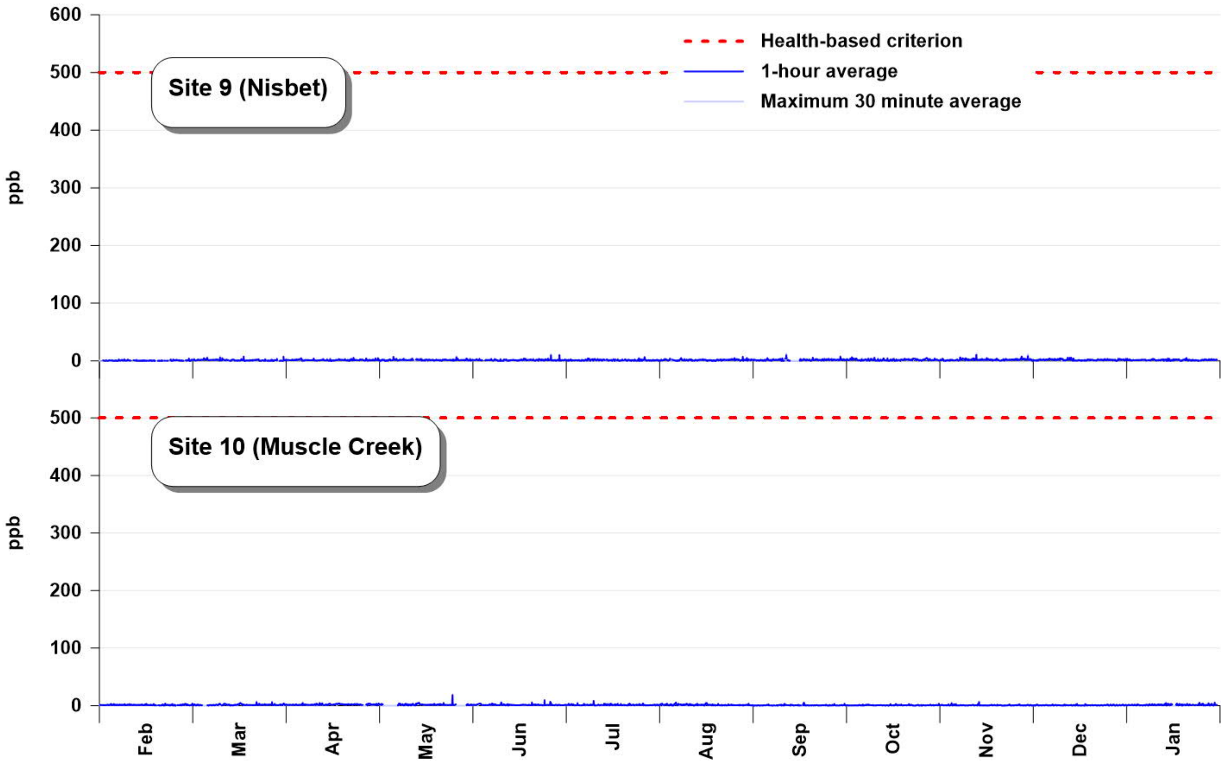

Figure 4 Measured hourly average and maximum 30-minute average H_2S concentrations with health-based criterion

Figure 5 shows the measured 24-hour average H_2S concentrations from each monitoring site for comparison with the 24-hour average health-based criterion of 100 ppb. The data show that H_2S concentrations were well below the 100 ppb criterion, again indicating that the measured levels would not have caused adverse health effects.

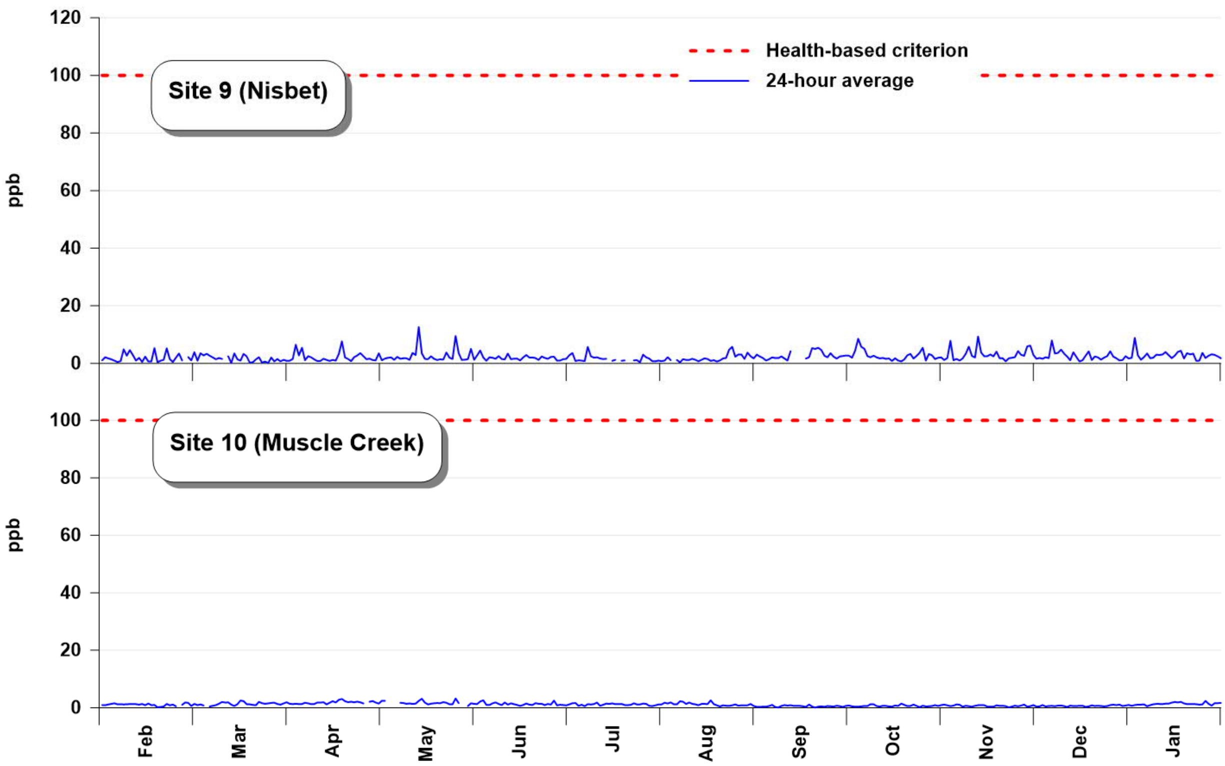

Figure 5 Measured 24-hour average H_2S concentrations with health-based criterion

Table 8 summarises the measured H_2S concentration data from each monitor for comparison with the odour detection threshold and health-based criteria. These statistics show that H_2S concentrations have exceeded the odour threshold at both locations; on five days at Site 9 and on three days at Site 10. H_2S concentrations did not exceed health-based criteria indicating that the measured levels would not have caused adverse health effects.

Table 6 Summary of measured H_2S concentrations

Statistic	Site 9 (Nisbet)	Site 10 (Muscle Creek)	Criterion
Maximum 30-minute average (ppb)	13.0	19.3	8 (odour detection threshold)
Maximum 1-hour average (ppb)	10.4	18.4	8 (odour detection threshold) 500 (health based)
No. of days when H_2S exceeded 8 ppb	5	3	-
Maximum 24-hour average (ppb)	3.5	3.2	100 (health based)
Annual average (ppb)	1.4	1.1	None available

The H_2S data were also examined by month (**Figure 6**) and by hour (**Figure 7**). Some additional trends have been determined:

- Average H_2S concentrations were typically highest in spring at Site 9 (Nisbet) and highest in autumn at Site 10 (Muscle Creek); and
- Average H_2S concentrations were typically highest around 2 am at Site 9 (Nisbet) and highest around 8 am at Site 10 (Muscle Creek).

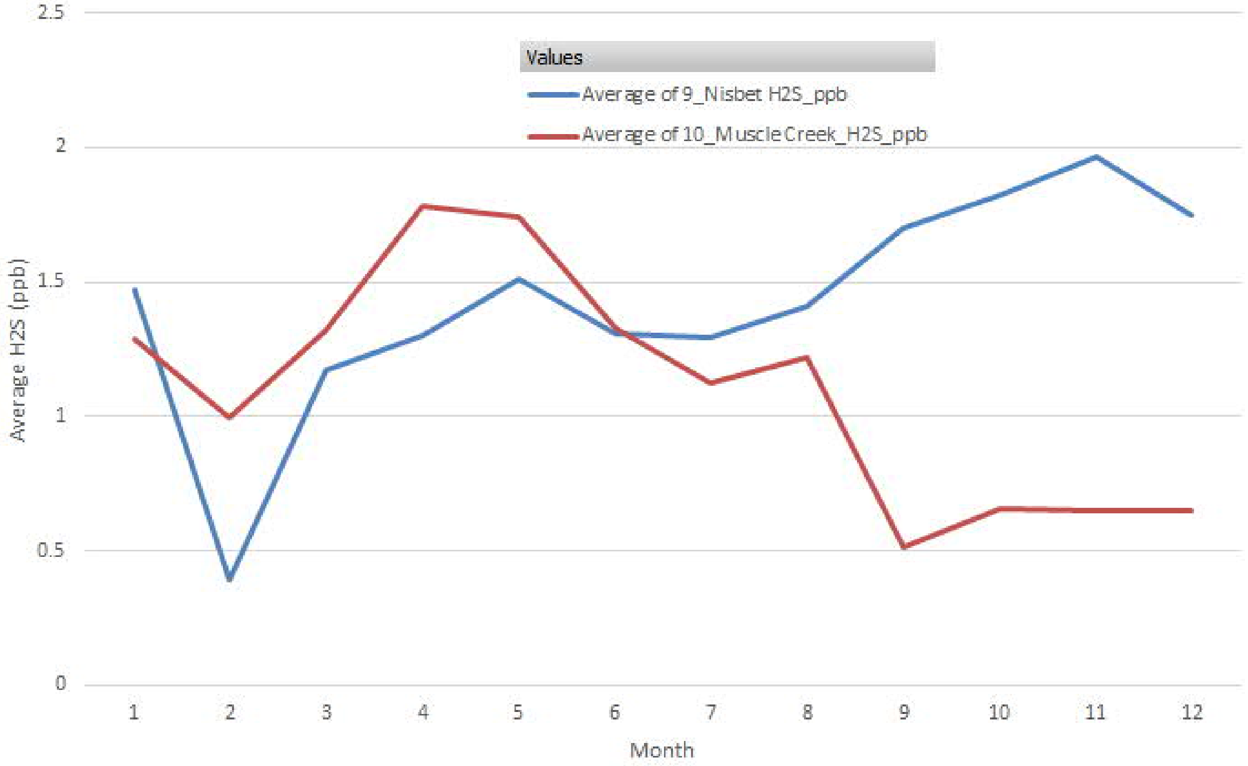

Figure 6 Average H_2S concentrations by month

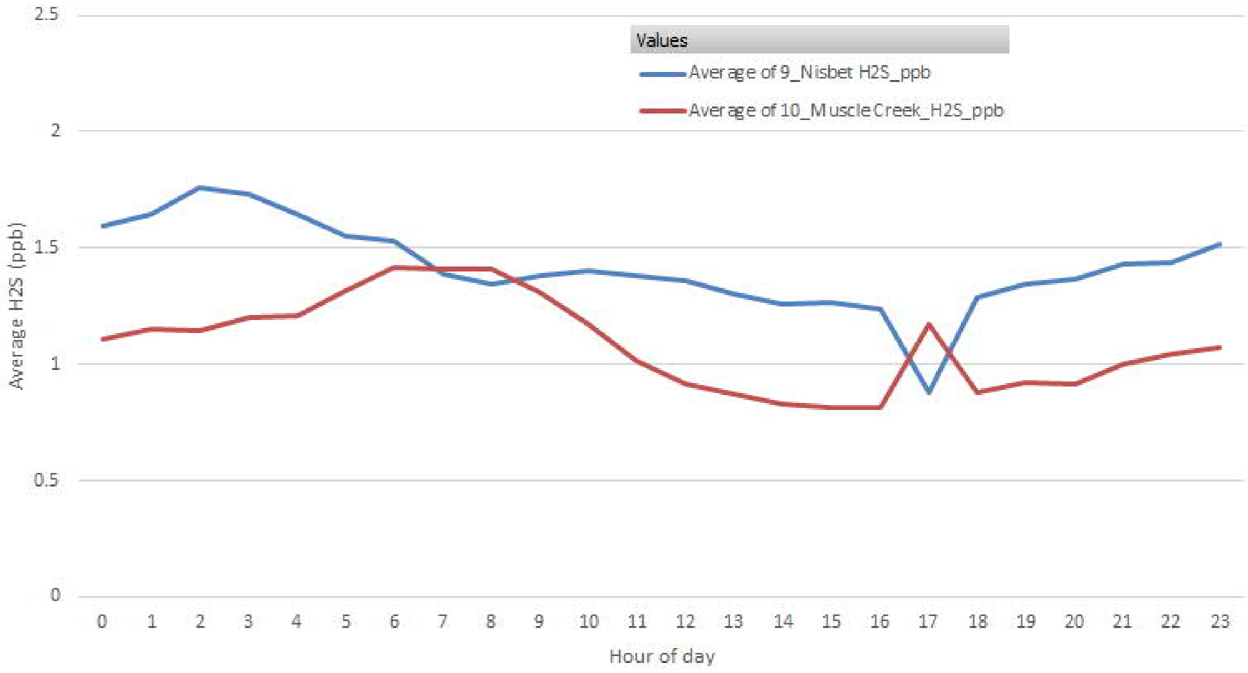

Figure 7 Average H_2S concentrations by hour of day

The air quality and meteorological monitoring data for each day when the maximum H_2S concentrations exceeded 8 ppb at either monitoring location have been analysed to identify the conditions that were associated with each event. These investigation days were used to inform the derivation of emissions for the odour modelling. **Appendix B** provides the H_2S analyses for each day of interest, and these analyses have indicated that the highest H_2S concentrations are almost always in the morning. Specifically, the highest H_2S concentrations occurred in the morning on all eight investigations days. The data for each investigation day from **Appendix B** were also used to calculate H_2S emissions from Muswellbrook Coal Mine using dispersion modelling. These calculations are discussed in **Section 5.2**.

4.2.2 Particulate Matter (as PM_{10})

PM_{10} concentrations are measured by Tapered Element Oscillating Microbalance (TEOM) at two locations and by beta attenuation monitors (BAM) at one location, as per **Figure 1**. **Figure 8** shows the measured 24-hour average PM_{10} concentrations from each monitoring site for data collected between 5 February 2018 and 4 February 2019. The EPA's air quality assessment criteria for PM_{10} (50 µg/m^3, also a NEPM standard) has been shown on these graphs.

It can be seen from **Figure 8** that all monitors have recorded at least one day above the 50 µg/m^3 criterion over the 12-month monitoring period. However, given that Site 8 is located near the weighbridge and near the entrance to Muswellbrook Coal Mine, the data from this location are not representative of conditions at off-site sensitive receptors. The data from Site 8 have therefore not been assessed for compliance against the EPA impact assessment criteria or NEPM standard.

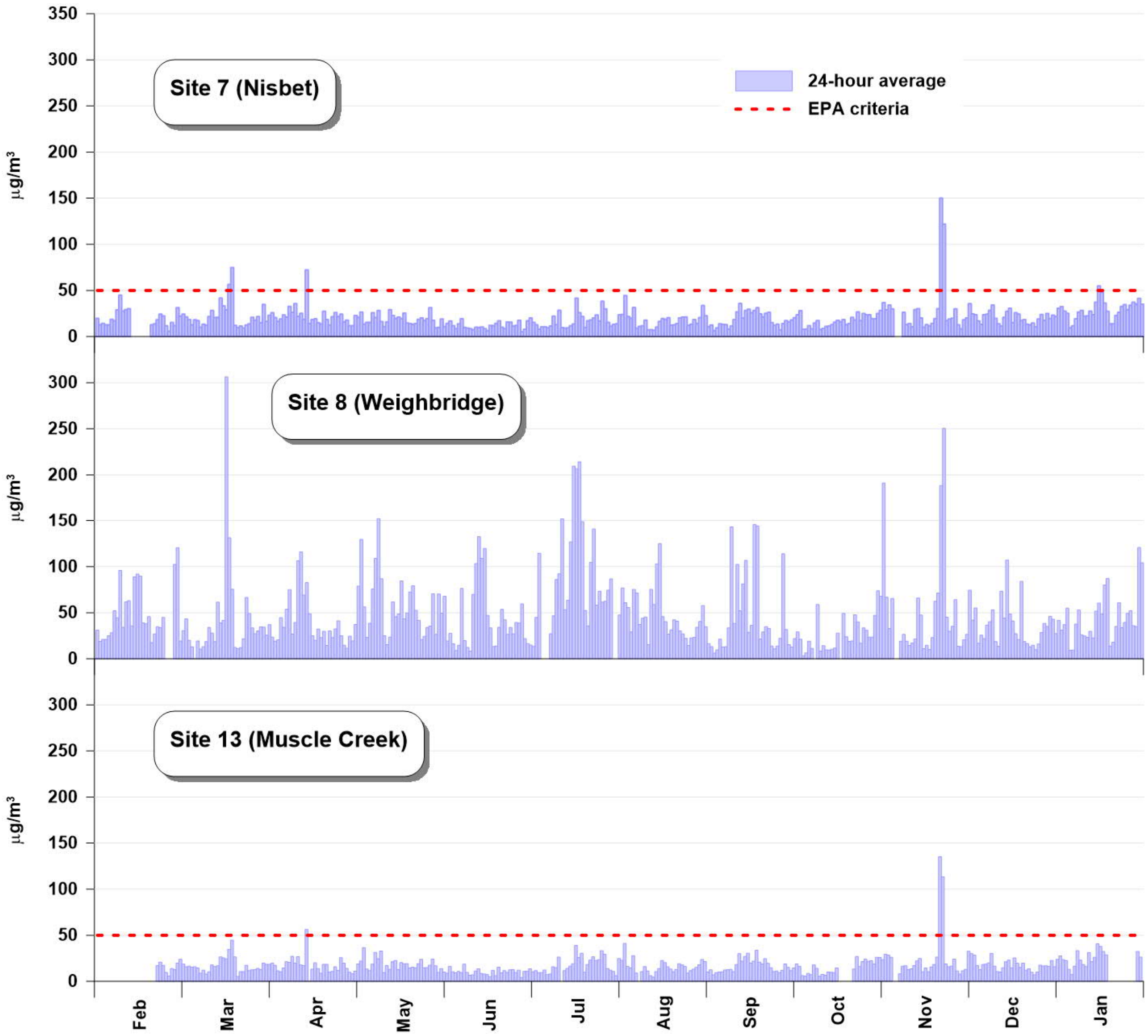

Figure 8 Measured 24-hour average PM_{10} concentrations

Table 7 summarises the measured PM_{10} concentration data from each monitor, for 24-hour and annual average periods, and for comparison with the respective EPA criteria. As noted above, all monitors have recorded at least one day per year above the 50 µg/m³ criterion in the monitoring period. Annual average PM_{10} concentrations at Site 7 and Site 13 have not exceeded the 25 µg/m³ criterion.

Table 7 Summary of measured PM_{10} concentrations

Statistic	Site 7 (Nisbet)	Site 8 (Weighbridge)	Site 13 (Muscle Creek)	Criterion
Maximum 1-hour average (µg/m³)	491	1,145	354	None available
Maximum 24-hour average (µg/m³)	150	306	135	50
Number of days above 24-hour average criteria	6	109	3	-
Annual average (µg/m³)	20	47	18	25

There were six days in the 12-month period when PM_{10} concentrations exceeded 50 µg/m³ at either Site 7 or Site 13. These days were:

- 19 March 2018 (57 µg/m³ at Site 7);

- 20 March 2018 (75 µg/m^3 at Site 7);
- 15 April 2018 (72 µg/m^3 at Site 7 and 56 µg/m^3 at Site 13);
- 22 November 2018 (150 µg/m^3 at Site 7 and 135 µg/m^3 at Site 13);
- 23 November 2018 (123 µg/m^3 at Site 7 and 113 µg/m^3 at Site 13); and
- 16 January 2019 (55 µg/m^3 at Site 7).

The air quality and meteorological monitoring data for each of the days listed above have been investigated to identify the potential cause of the exceedance. Graphical analyses are provided in **Appendix C** showing the concurrent hourly averaged records and associated interpretation. The analyses from **Appendix C** have indicated that:

- Two of the six “exceedance” days were potentially influenced by activities at, or emissions from, Muswellbrook Coal Mine. The contributions of Muswellbrook Coal Mine activities to the measured results were calculated by first determining the wind direction ranges which coincided with a wind direction from the mine towards each monitor. The site contribution to each monitor was then calculated for every 1-hour average record in each day based on the concurrent wind direction, and using downwind concentration minus upwind concentration calculations. Finally, the site contribution to each monitor was calculated as a 24-hour average. The two days identified were 19 and 20 March 2018. On each of these days the estimated PM_{10} concentration was below 50 µg/m^3 without the calculated site contribution, and above 50 µg/m^3 with the calculated site contribution. **Appendix C** provides the details including the estimated 24-hour average site contribution to the measured results.
- Two of the six “exceedance” days were a result of a dust storm that occurred across many parts of NSW.
- Two of the six “exceedance” days were a result of other factors not likely to be related to Muswellbrook Coal Mine.

4.2.3 Sulfur Dioxide (SO_2)

Figure 9 shows the measured hourly average SO_2 concentrations from each monitoring site for data collected between 5 February 2018 and 4 February 2019. The EPA’s air quality assessment criteria (and NEPM standard) for SO_2 (200 ppb) has also been shown on these graphs. The monitoring data show that SO_2 concentrations have not exceeded the EPA criterion for 1-hour averages.

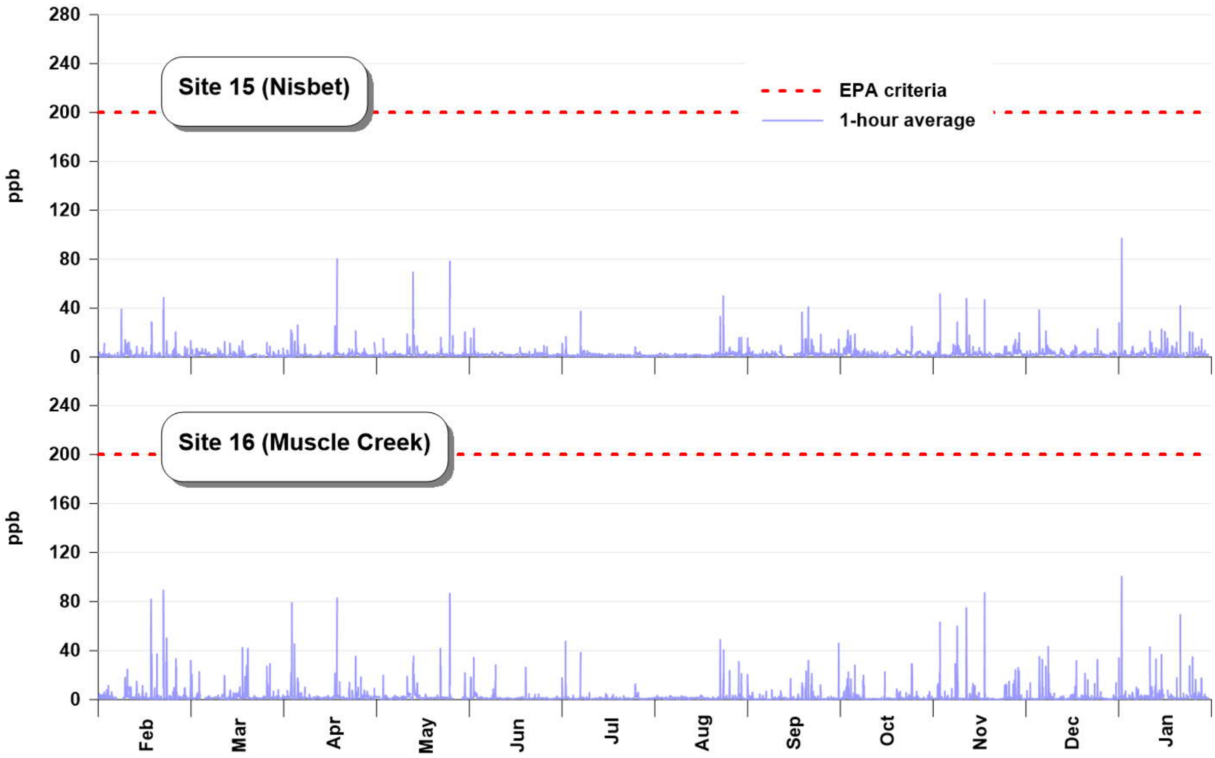

Figure 9 Measured hourly average SO_2 concentrations

Figure 10 shows the measured 24-hour average SO_2 concentrations from each monitoring site for data collected between 5 February 2018 and 4 February 2019. The EPA's air quality assessment criteria (and NEPM standard) for SO_2 (80 ppb) has also been shown on these graphs. The monitoring data show that SO_2 concentrations have not exceeded the EPA criterion for 24-hour averages.

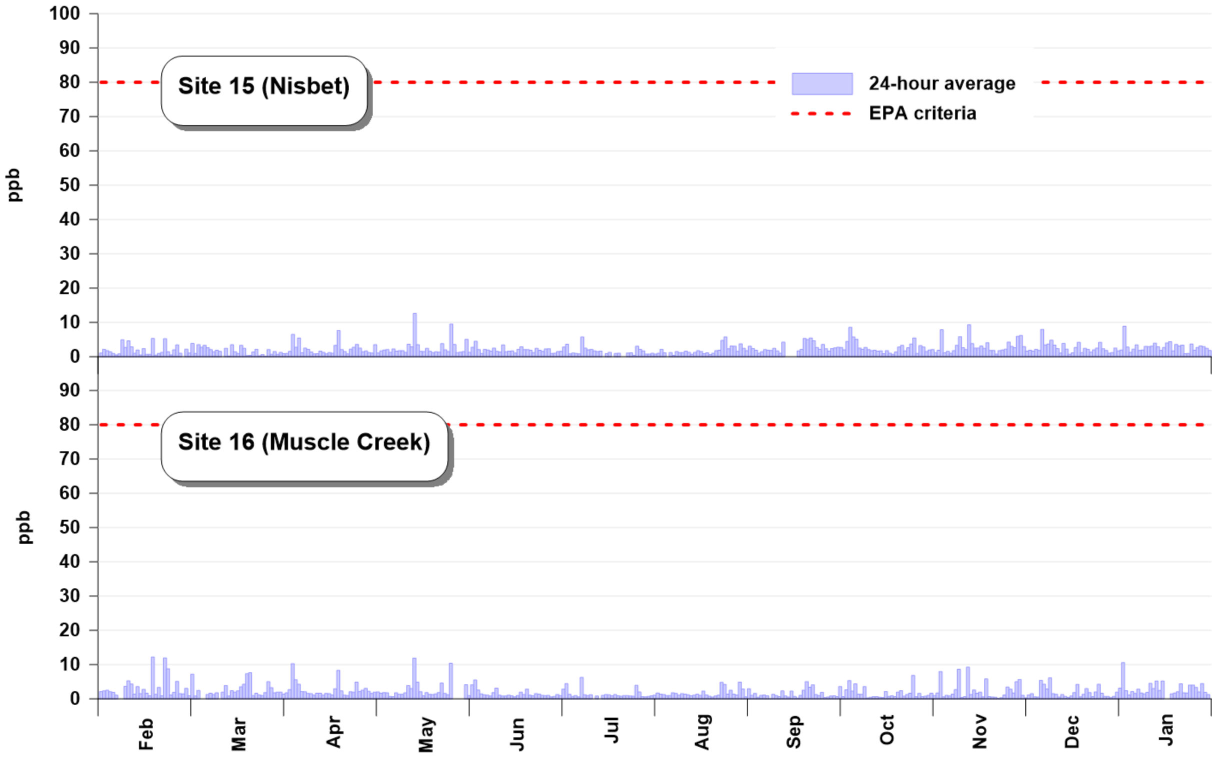

Figure 10 Measured 24-hour average SO_2 concentrations

Table 8 summarises the measured SO_2 concentration data for each monitor, for 1-hour, 24-hour and annual average periods, and for comparison with the respective EPA criteria and NEPM standards. These statistics show that SO_2 concentrations have not exceeded EPA criteria or NEPM standards.

Table 8 Summary of measured SO_2 concentrations

Statistic	Site 15 (Nisbet)	Site 16 (Muscle Creek)	Criterion
Maximum 1-hour average (ppb)	97	101	200
Maximum 24-hour average (ppb)	13	12	80
Annual average (ppb)	2.3	2.1	20

4.3 Complaints

MCC maintains a register of all complaints that may be associated with activities at Muswellbrook Coal Mine. This section provides a review of odour and dust complaints that were reported to MCC during the 12-month monitoring period.

4.3.1 Odour

Table 9 shows an extract of the complaints register, focusing on reported odour incidents during the 12-month monitoring period. There were 24 days when odour was reportedly detected from Muswellbrook Coal Mine and one of these days coincided with elevated H_2S concentrations at the closest monitoring site. The nature of these complaints suggested that H_2S was the primary substance being detected. The observations with respect to time of day can be summarised as follows:

- 58% of the reported incidents were in the morning, before 10 am. The H_2S monitoring data analysis also indicated that elevated concentrations most often occurred in the morning;
- 29% of the reported incidents were in the evening, after 6 pm; and
- 13% of the reported incidents were during the day, between 10 am and 6 pm, or where the time was not specified.

Table 9 Odour complaints in the period between 5 February 2018 and 4 February 2019

Date reported	Region	Nature of complaint	Date of incident	Time of incident
28-Feb-18	Woodlands Ridge	Strong offensive odour	28-Feb-18	8:00 AM
10-Mar-18	McCully's Gap	Odour coming over house	10-Mar-18	4:12 PM
21-Mar-18	Scone	Sulphur smell	21-Mar-18	10:00 PM
06-Apr-18	McCully's Gap	Strong offensive odour	06-Apr-18	8:54 PM
07-Apr-18	McCully's Gap	Spontaneous combustion burning family's eyes while inside their home	07-Apr-18	7:49 PM
26-Apr-18	Muscle Creek	Strong sulphur smell	26-Apr-18	5:48 AM
01-May-18	Muscle Creek	Really bad smell coming from site	01-May-18	7:54 AM
19-May-18	Muscle Creek	Odour coming from MCC	19-May-18	8:32 AM
20-Jun-18	Scone	Odour a couple of days ago and some this morning	20-Jun-18	8:00 AM
29-Jun-18	Woodlands Ridge	Smoke for three days and smell starting around 8am	27-Jun-18 - 29-Jun-18	Starting around 8am
14-Jul-18	Muscle Creek	Blue haze has strong sulphur smell	14-Jul-18	7:55 AM
17-Jul-18	Muscle Creek	Smoke and odour from hot coal has been awful	12-Jul-18	Not specified
20-Jul-18	-	Heavy air pollution from burning coal	16-Jul-18	9:02 PM

Date reported	Region	Nature of complaint	Date of incident	Time of incident
23-Jul-18	Muscle Creek	Spontaneous combustion smell in house	23-Jul-18	5:23 AM
31-Aug-18	McCully's Gap	Strong smell of sulphur	31-Aug-18	9:45 AM
10-Sep-18	Muscle Creek	Plume of smoke and bad smell across the valley	10-Sep-18	8:39 AM
11-Sep-18	Woodlands Ridge	Spontaneous combustion pollution and sulphur smell throughout the valley	10-Sep-18	8:24 AM
18-Sep-18	Muscle Creek	Smoke and disgusting smell	18-Sep-18	7:51 AM
23-Sep-18	Scone	Smell	23-Sep-18	10:46 PM
29-Sep-18	Scone	Smell	29-Sep-18	8:51 PM
07-Oct-18	Scone	Odour coming from your mine	07-Oct-18	6:40 PM
15-Nov-18	Muscle Creek	Smoke and Odour	15-Nov-18	7:45 AM
15-Nov-18	Woodlands Ridge	Environmental contamination and smell	15-Nov-18	8:14 AM
11-Dec-18	Woodlands Ridge	Concerns over smell	Various	Various

** Shaded cell represents the reported incident which was on the same day as elevated measured H_2S concentrations at the closest monitoring site.*

MCC logs all actions that are taken in response to odour (and other) complaints that may be related to activities at Muswellbrook Coal Mine. All incidents from **Table 9** above were followed up by MCC, and specific actions have included:

- Inspection of the meteorological data at the time of the reported incident to determine whether Muswellbrook Coal Mine could have contributed to the event.
- Review of the gas monitoring data at the time of the reported incident to determine whether off-site H_2S or SO_2 concentrations had increased.
- Checking that spontaneous combustion management activities were being carried out in accordance with the SCMP.
- Reviewing the status of mining operations at the time of the reported incident.
- Following up with the complainant, as required, to advise of the actions taken by MCC.

In addition to the actions outlined above, MCC conducts daily odour and visual observations between April and October. These observations aim to detect spontaneous combustion related emissions from Muswellbrook Coal Mine and include records of meteorological conditions and odour presence and strength at five locations in the Muscle Creek area. The daily observations assist MCC with evaluations in the event of an odour complaint. As noted in **Section 4.1** and **4.2** the H_2S monitoring data have also been analysed to identify the meteorological conditions that coincided with elevated concentrations.

4.3.2 Dust

Table 10 shows an extract of the complaints register, focusing on reported dust incidents during the 12-month monitoring period. There was one day when dust was reportedly detected from Muswellbrook Coal Mine, namely 10 May 2018. This day of complaint did not coincide with elevated PM_{10} concentrations at either of the two monitoring sites. The closest monitoring site, Muscle Creek, recorded a 24-hour average PM_{10} concentration of 37 µg/m^3 which is below the EPA criteria and NEPM standard of 50 µg/m^3. MCC also visited the complainant location on 10 May 2018 but did not report any visible dust from Muswellbrook Coal Mine.

Table 10 Dust complaints in the period between 5 February 2018 and 4 February 2019

Date reported	Region	Nature of complaint	Date of incident	Time of incident
10-May-18	Woodlands Ridge	Dust issue	10-May-18	9:05 AM

5. Odour Modelling

5.1 Overview

The CALPUFF computer-based air dispersion model has been used to calculate emissions and predict ground-level H_2S concentrations from spontaneous combustion related sources at Muswellbrook Coal Mine. The approach to the modelling has followed the EPA's "Approved Methods of the Modelling and Assessment of Air Pollutants in New South Wales" (EPA, 2016) which specifies how assessments based on the use of air dispersion models should be undertaken. The "Approved Methods" include guidelines for the preparation of meteorological data, reporting requirements and air quality assessment criteria to assess the significance of dispersion model predictions.

There were two mains steps to the modelling:

1. **Calculate emissions.** This involved running the model with a generic emission rate and year-long meteorological record to predict concentrations at each of the two monitoring sites. A site-specific H_2S emission rate was then determined by "back-calculating" an emission rate from comparisons between monitoring results and model predictions.

2. **Predict impacts.** This involved running the model with the calculated site-specific H_2S emission rate to predict H_2S concentrations across the entire model domain.

Model selection has considered the expected transport distances for the emissions, as well as the potential for temporally and spatially varying flow fields due to influences of the locally complex terrain, non-uniform land use, and potential for stagnation conditions characterised by calm or very low wind speeds with variable wind directions. The CALPUFF model, through the CALMET meteorological pre-processor, simulates complex meteorological patterns that exist in a particular region. The effects of local topography and changes in land surface characteristics are accounted for by this model. The model comprises meteorological modelling as well as dispersion modelling, both of which are described in **Sections 5.3** and **5.4** below. CALPUFF is an air dispersion model which has been approved by the EPA. It has been used extensively in the Hunter Valley for quantifying impacts from mining operations.

5.2 Estimated Emissions

There are no known national or international methods for quantifying emissions from spontaneous combustion of coal at open cut or underground coal mines. The approach taken in this study was to, as indicated above, derive a site-specific average (and constant conservative) H_2S emission rate by:

- Modelling a generic emission rate (1 g/s) to predict concentrations at the two H_2S monitoring sites, using the influence of topographical data and year-long hourly records of meteorological conditions;
- Modelling with a single point source that covers the main regions of spontaneous combustion outbreaks. A point source type was chosen so that buoyancy due to coal fire heat could be simulated.
- "Back-calculating" an emission rate from comparisons between the 8,856 hours of monitoring results and model predictions.

The H_2S monitoring data were initially examined on all days when measured concentrations were greater than 8 ppb (see **Appendix B**). This was done to identify all hours that may be appropriate for relating an emission from Muswellbrook Coal Mine to an increase in concentration at the monitors; that is, identifying cases where an emission could be back-calculated based on winds from Muswellbrook Coal Mine towards a monitor that recorded an elevated H_2S concentration. The process is conceptually straight-forward for a single day of interest. For example, **Figure 11** shows the measured hourly average H_2S concentrations on 1 July 2018. There was an elevated H_2S concentration at Site 9 (Nisbet) between 5 and 6 am which coincided with winds from the direction of Muswellbrook Coal Mine towards the monitor, that is, a southerly wind. This represented a case when the measured concentration could be compared to a model predicted concentration (using a generic emission rate) to back-calculate a site emission rate. In this case the calculated H_2S emission rate from the site was in the order of 173,000 grams per second (g/s). This calculation assumes that the measured H_2S concentration at the monitor was only being influenced by emissions from Muswellbrook Coal Mine at the time, which is unlikely to be the case as there will be other H_2S sources in the Hunter Valley that will contribute to monitored levels. Therefore the approach will likely lead to an over-estimate of emissions.

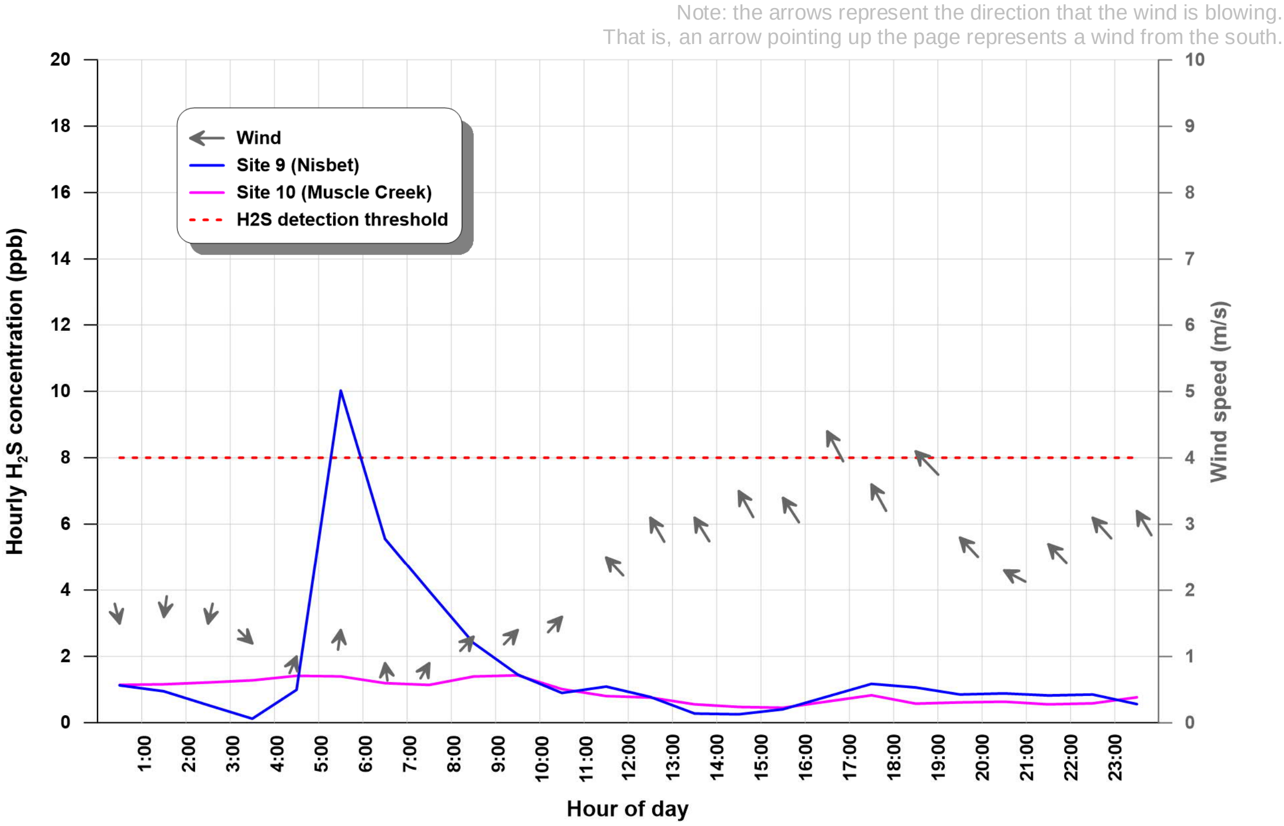

Figure 11 Measured hourly average H_2S concentrations on 1 July 2018

The complication with the emission estimation approach outlined above, which is based on evaluating for specific days of interest, is that the site emission is assumed to be constant for every hour in modelling period. This is not the case in practice. For other investigation days the calculated site emission varies by, in some cases, orders of magnitude. This variation in emission arises because of the following key factors:

- Emissions from coal fires are sporadic in time and influenced by mining activities and efforts at the site to control and extinguish these fires;
- Emissions from coal fires are not evenly distributed and are often underground; and
- Emissions from coal fires will be of varying intensity.

An annualised average approach to calculating an H_2S emission rate was therefore adopted. This involved extracting the maximum predicted hourly average concentration at each monitoring site for the whole year, based on a generic 1 g/s emission rate, and extracting the maximum measured hourly average H_2S concentration at each monitoring site for the whole year. The two results were then used to calculate an annualised maximum H_2S emission rate to be used for the purposes of modelling worst-case impacts from assumed constant emissions over a year. **Table 11** shows the calculations and final emission rate. This approach has been intended to derive an emission rate that provided reasonable agreement with the outcomes of the 12-month H_2S monitoring program.

Table 11 Calculation of H_2S emission rate

Statistic	Site 9 (Nisbet)	Site 10 (Muscle Creek)
Measured maximum 1-hour average H_2S (µg/m^3)	15.7	28.0
Predicted maximum 1-hour average H_2S based on 1 g/s (µg/m^3)	0.019	0.014
Calculated H_2S emission rate to match predicted to measured (g/s)	829	1,996
Assumed maximum, constant site H_2S emission rate to be used for dispersion modelling (g/s)	1,996	

Table 12 shows the emission parameters that were used in the dispersion modelling.

Table 12 Emission parameters used for the dispersion modelling

Parameter	Value
Source type	Point
Source location (MGA Zone 56, m)	305495, 6430062
Source release height (m)	2
Source base elevation (m)	252
Source diameter (m)	500
Source temperature (deg C)	150
Source H_2S mass emission rate (g/s)	1,996 (constant for every hour of the year)

5.3 Meteorological Modelling

The air dispersion model used for this study, CALPUFF, requires information on the meteorological conditions in the modelled region. This information is typically generated by the meteorological pre-processor, CALMET, using surface observation data from local weather stations and upper air data from radio-sondes or numerical models, such as the CSIRO's prognostic model known as TAPM (The Air Pollution Model). CALMET also requires information on the local land-use and terrain. The result of a CALMET simulation is a year-long, three-dimensional output of meteorological conditions that can be used as input to the CALPUFF air dispersion model.

There are no known meteorological stations in the Upper Hunter region that collect suitable upper air data for CALMET. The closest station with suitable data is operated by the Bureau of Meteorology at Williamtown, approximately 100 km to the east-southeast of Muswellbrook. The necessary upper air data were therefore generated by TAPM, using influence from the surface observations at the MCC meteorological station. CALMET was then set up with one surface observations station (the MCC meteorological station) and one upper air station (based on TAPM output for the MCC meteorological station). The meteorological modelling followed the guidance of TRC (2011) and adopted the "observations" mode.

Key model settings for TAPM are shown below in **Table 13**.

Table 13 Model settings and inputs for TAPM

Parameter	Value(s)
Model version	4.0.5
Number of grids (spacing)	4 (30 km, 10 km, 3 km, 1 km)
Number of grids point	35 x 35 x 25
Year(s) of analysis	1 Feb 2018 to 4 Feb 2019 (including 4 days model spin-up)
Centre of analysis	Muswellbrook Coal Mine (32º15' S, 150º56' E)
Terrain data source	Shuttle Research Topography Mission (SRTM) 30 m
Land use data source	Default
Meteorological data assimilation	MCC meteorological station. Radius of influence = 5 km. Number of vertical levels for assimilation = 4

Table 14 lists the model settings and input data for CALMET. This information has been provided so that the user can reproduce the results if required.

Table 14 Model settings and inputs for CALMET

Parameter	Value(s)
Model version	6.334
Terrain data source(s)	SRTM 30 m
Land-use data source(s)	Digitized from aerial imagery
Meteorological grid domain	10 km x 10 km
Meteorological grid resolution	0.1 km
Meteorological grid dimensions	100 x 100 x 9
Meteorological grid origin	300000 mE, 6425000 mN. MGA Zone 56
Surface meteorological stations	MCC meteorological station (observations of wind speed and wind direction. TAPM for temperature, relative humidity, ceiling height, cloud cover and air pressure)
Upper air meteorological stations	Upper air data file for the location of MCC meteorological station derived by TAPM Biased towards surface observations (-1, -0.8, -0.6, -0.4, -0.2, 0, 0, 0, 0)
Simulation length	8856 hours (1 Feb 2018 to 4 Feb 2019)
R1, R2	0.5, 1
RMAX1, RMAX2	5, 20
TERRAD	5

Terrain information was extracted from the NASA Shuttle Research Topography Mission database which has global coverage at approximately 30 metre resolution. Land use data were extracted from aerial imagery. **Figure 12** shows the model grid, land-use and terrain information, as used by CALMET.

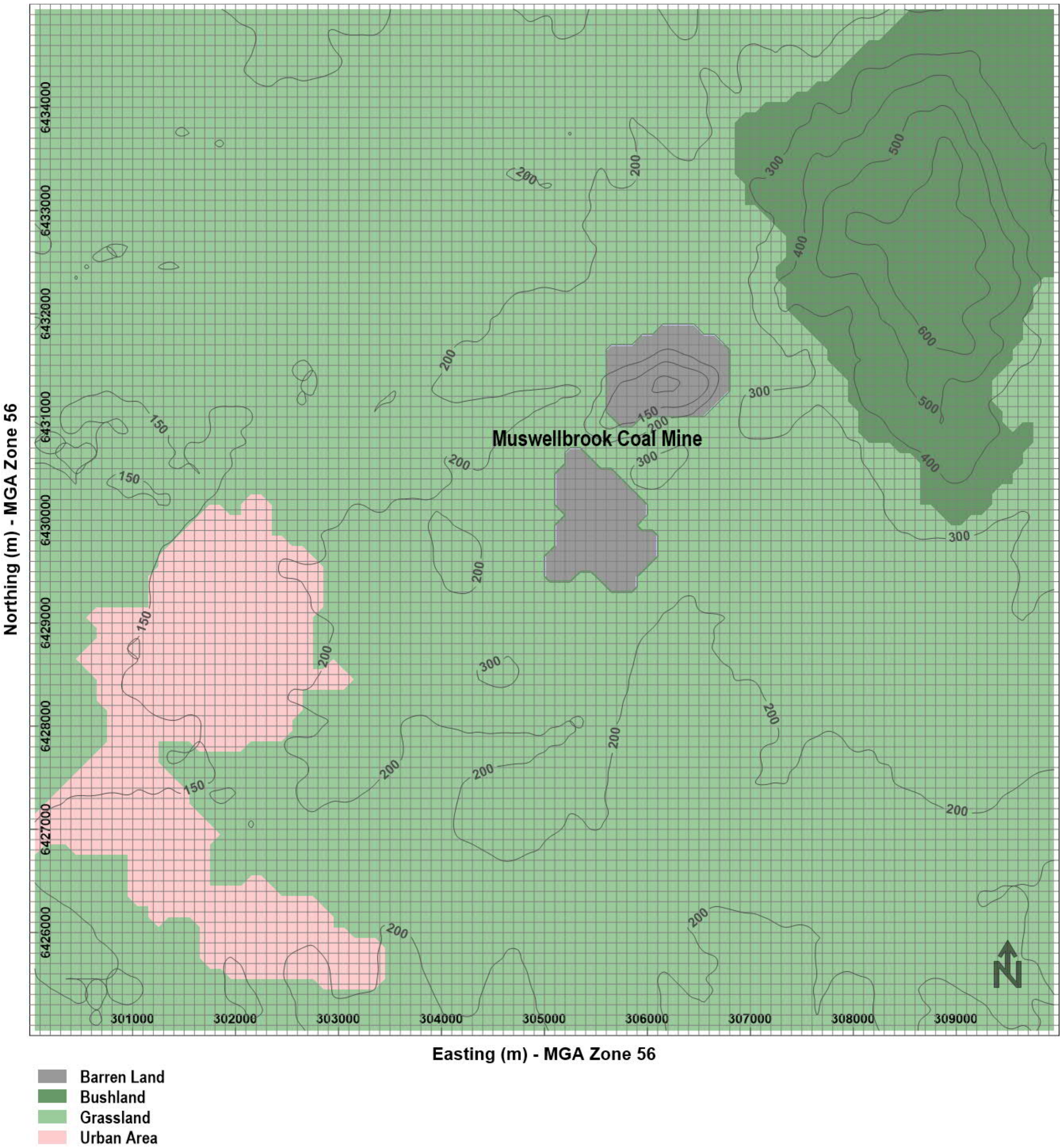

Figure 12 Model grid, land-use and terrain information

Figure 13 shows a snapshot of winds at 10 metres above ground-level as simulated by the CALMET model under stable conditions. This plot shows the effect of the topography on local winds (for this particular hour) and highlights the non-uniform wind patterns in the area, which further supports the use of a non-steady-state model such as CALPUFF.

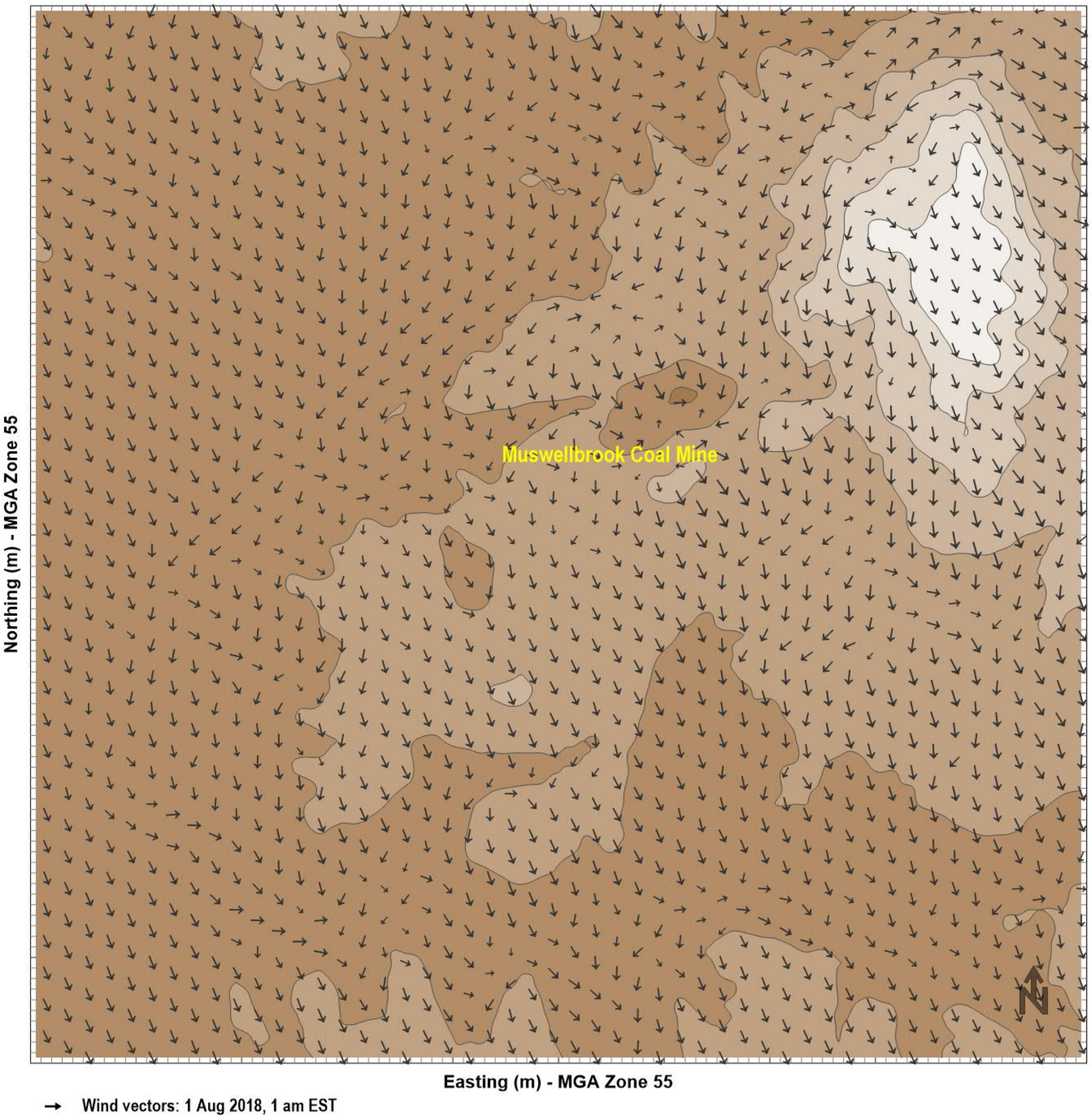

Figure 13 Example of CALMET simulated wind flows at 10 m above ground-level

5.4 Dispersion Modelling

Ground-level H_2S concentrations due to the calculated spontaneous combustion emissions have been predicted using the air dispersion model known as CALPUFF (Version 6.42). CALPUFF is a Lagrangian dispersion model that simulates the dispersion of pollutants within a turbulent atmosphere by representing emissions as a series of puffs emitted sequentially. Provided the rate at which the puffs are emitted is sufficiently rapid, the puffs overlap and the serial release is representative of a continuous release.

The CALPUFF model differs from traditional Gaussian plume models (such as AUSPLUME and ISCST3) in that it can model spatially varying wind and turbulence fields that are important in complex terrain, long-range transport and near calm conditions. CALPUFF has the ability to model the effect of emissions entrained into the thermal internal boundary layer that forms over land, both through fumigation and plume trapping. CALPUFF is an air dispersion model which has been approved by the EPA for these types of assessments (EPA 2016).

The modelling was performed using the emission estimates from **Section 5.2** and using the meteorological information provided by the CALMET model, described in **Section 5.3**. Predictions were made at 499 discrete receptors (including sensitive receptors and monitoring locations) to allow for contouring of results.

Key model settings and inputs for CALPUFF are provided in **Table 15**.

Table 15 Model settings and inputs for CALPUFF

Parameter	Value(s)
Model version	6.42
Computational grid domain	100 x 100
Chemical transformation	None
Dry deposition	No
Wind speed profile	ISC rural
Puff element	Puff
Dispersion option	Turbulence from micrometeorology
Time step	3600 seconds (1 hour)
Terrain adjustment	Partial plume path
Point source parameters	Location: 305495 mE, 6430062 mN (MGA Zone 56) Height above ground: 2 m Base elevation: 252 m Diameter: 500 m Temperature: 150 deg C H_2S emission: 1,996 g/s (corrected to nose-response time using a peak-to-mean factor of 2.3)
Number of discrete receptors	499

Finally, the model predictions at identified sensitive receptors were then compared with the EPA air quality criteria, previously discussed in **Section 3**. Contour plots have also been created to show the spatial distribution of model predictions.

5.5 Model Results

Figure 14 shows the predicted 99th percentile nose-response time H_2S concentrations at ground-level. These results reflect a constant modelled H_2S emission from Muswellbrook Coal Mine for every hour of meteorological model year (1 Feb 2018 to 4 Feb 2019). As such results represent the effect of almost all possible meteorological conditions that occur in this area but as noted previously the estimated emissions, and therefore predicted concentrations, will be conservatively high.

Figure 14 Predicted ground-level 99th percentile nose-response time H_2S concentrations

Two key observations have been made from the results. These are as follows:

- Areas to the east-northeast of Muswellbrook Coal Mine may experience higher effects of spontaneous combustion emissions (as H_2S) than other locations. This is likely to be because of the interaction of emissions with the elevated terrain to the east-northeast. However, there are no private sensitive receptors to the east-northeast. The model also identifies Woodlands Ridge as a slightly higher risk.

- H_2S from Muswellbrook Coal Mine may be detectable in most areas of the model domain from time-to-time, depending on the sensitivity of the individual. This is based on model predictions of 99th percentile H_2S concentrations which exceed the EPA's impact assessment criteria, namely, 0.91 ppb (urban), 1.36 ppb (~500 people) and 3.17 ppb (single residence). Again, this outcome assumes that the calculated maximum H_2S emission occurs continuously for every hour of the year; an unavoidably simplistic assumption as the sporadic nature, distribution and intensity of coal fires cannot be accurately reproduced.

The model results have also been examined for trends. **Figure 15** shows the predicted maximum H_2S concentrations at the monitoring sites by month. These results suggest that autumn and spring would represent the higher risk times of year, an outcome that is also consistent with the monitored results.

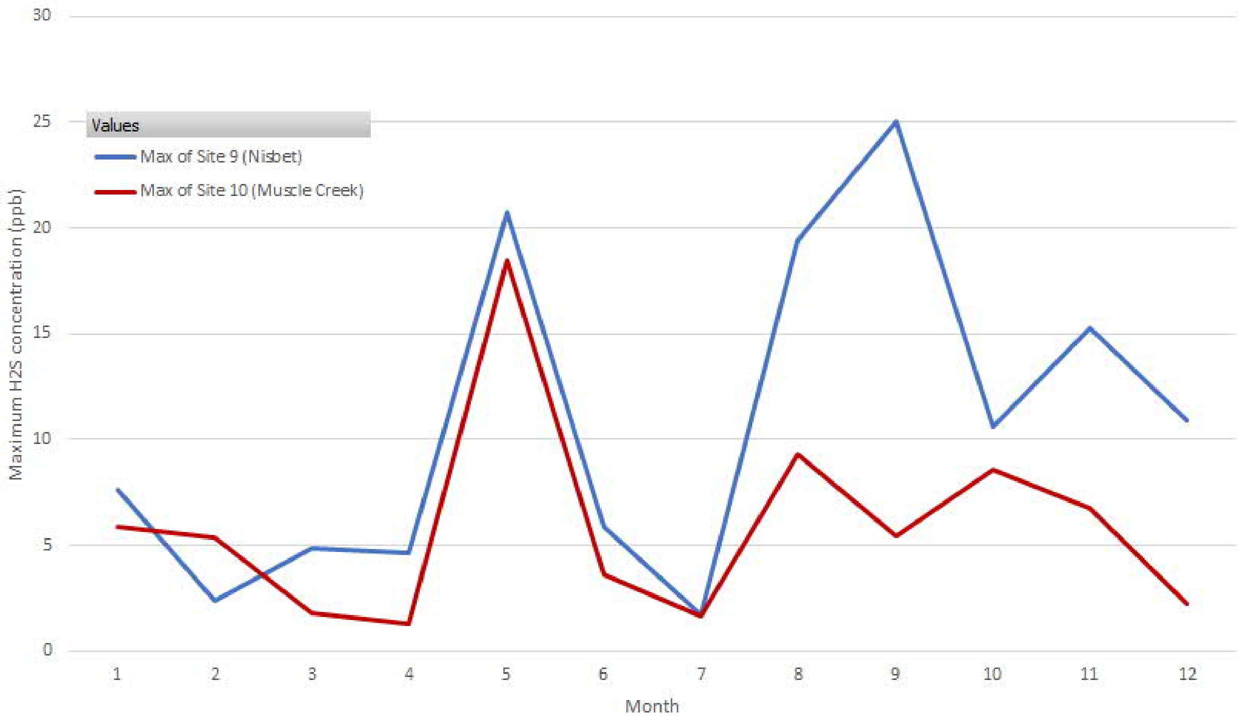

Figure 15 Predicted maximum H_2S concentrations at the monitoring sites by month

Figure 16 shows the predicted maximum H_2S concentrations at the monitoring sites by hour of day. The model has predicted that the highest concentrations occur around 10 am (morning) and around 10 pm (late evening). These times of day would reflect stable conditions. The monitored results also indicated the highest concentrations most often occurred in the morning, albeit at slightly earlier times than predicted by the model.

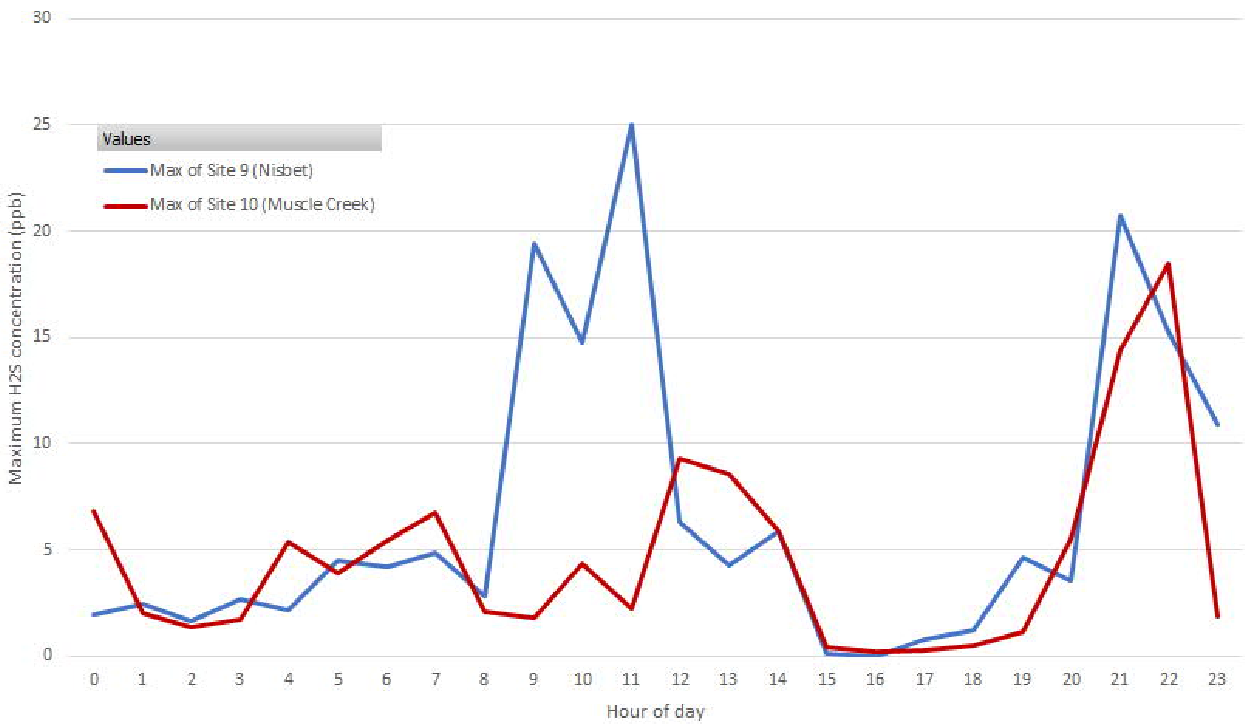

Figure 16 Predicted maximum H_2S concentrations at the monitoring sites by hour of day

6. Monitoring Program Review

A review of the monitoring program has been carried out based on the outcomes of this study and other factors. The review has focused on H_2S as the key air quality issue and involved evaluating the existing monitoring program based on the design considerations including monitoring objectives, locations of potential air pollution sources, prevailing winds patterns and proximity and direction to sensitive receptors.

The basic principles that need to be considered in the design of air quality monitoring programs are described in a number of texts including WHO (1976) and Stern et al. (1984). The main principles that need to be considered are:

- the needs of the data users including the quantity, quality, location and sampling times;
- the available resources and in particular funds and labour availability;
- legal requirements;
- available technology for monitoring, and
- operational criteria including economic, social, legal and cost effectiveness.

WHO (1976) identifies that information from a monitoring program should also be able to provide:

- the geographical distribution of pollutants;
- air pollution trends;
- the origin of air pollutants at any given locality;
- the effects of air pollution;
- level of air quality relative to air quality standards (or objectives);
- information to allow the assessment and control of air pollution; and
- information for air pollution warning systems.

The monitoring program should also be designed to meet to any specific objectives for the site of interest. To date, the main objective of the MCC monitoring program has been to enable the collection of data to comply with the requirements of EPL 656 Condition U1. This condition requires SO_2 monitoring at two locations (Points 15 and 16), H_2S monitoring at two locations (Points 9 and 10) and PM_{10} monitoring at three locations (Points 7, 8 and 13).

Figure 1 shows the current monitoring program. The outcomes of this study do not highlight a need to modify the current monitoring program. The rationale for maintaining the current monitoring program is as follows:

- The monitoring complies with the requirements of EPL 656 Condition U1.
- Monitors are positioned to reflect the most common northwest-southeast wind directions. This allows for monitoring to best assess the mines contribution to the total contaminant level in the air and is consistent with other EPA air quality monitoring location requirements in the Hunter Valley.
- Monitors are positioned at locations near where the majority of the complaints relating to activities at Muswellbrook Coal Mine have occurred.
- Monitors are not located in urban areas where contamination by other non-mine sources is more likely.
- Data showed that H_2S concentrations are well below health-based criteria.
- Uncertainty in the dispersion modelling meaning that results should only be treated as a guide on the likely areas of higher and lower impacts from Muswellbrook Coal Mine.

Continued monitoring of H_2S is recommended to assist with the verification of nuisance impacts since the complaints data, monitoring data and modelling results indicate that off-site odour (as H_2S) is detectable from time-to-time.

7. Conclusions

This report provides outcomes of the “Spontaneous Combustion Emissions Study”, a body of work that was carried out to address Condition U1 of EPL656 for Muswellbrook Coal Mine. Overall the study involved undertaking 12 months of continuous monitoring by MCC to determine if emissions from the spontaneous combustion of coal at Muswellbrook Coal Mine are causing exceedances of the air quality impact assessment criteria noted by the EPA. In addition to analysis, the monitoring data have been used to derive an estimate of spontaneous combustion emissions (as H_2S) for input to a site-specific odour dispersion model, in accordance with Condition U1.4 of EPL656. The odour dispersion model is based on one year of representative meteorological data and has been prepared using the procedures outlined in the EPA’s “Approved Methods for the Modelling and Assessment of Air Pollutants in NSW” (EPA 2016).

This study has led to the following main conclusions:

- No EPA criteria or NEPM standards exist for 30-minute, 1-hour, 24-hour or annual average H_2S. The closest applicable criteria is 8 ppb as an odour detection threshold, as noted by the WHO. There were eight (8) unique days when monitored 1-hour average H_2S concentrations exceeded the odour detection threshold at the installed monitoring locations. On average, the 12-month monitoring data records showed that H_2S concentrations were highest in spring and autumn, depending on the location, and almost always highest in the morning, coinciding with stable atmospheric conditions.
- H_2S concentrations did not exceed health-based criteria indicating that the measured levels would not have caused adverse health effects.
- Measured 24-hour average PM_{10} concentrations exceeded the EPA’s 24-hour average assessment criteria on six (6) days in the 12-month period. Each of these days was investigated to identify the likely cause. Two of the six “exceedance” days were potentially due to activities or emissions at Muswellbrook Coal Mine based on calculating site contributions using data from upwind and downwind monitors. The remaining four “exceedance” days were due to regional events or other, non-mine related, factors. Annual average PM_{10} concentrations did not exceed the EPA’s annual average assessment criteria or NEPM standards.
- Monitored SO_2 concentrations did not exceed the EPA criteria or NEPM standards for 1-hour, 24-hour or annual average periods.
- Most (58%) of the odour complaints in the monitoring period related to reported incidents in the morning. The H_2S monitoring data also showed that concentrations were typically highest in the morning.
- Emissions from spontaneous combustion are difficult to measure and predict due to the sporadic nature, distribution and intensity of coal fires. Nevertheless an annualised maximum H_2S emission rate was determined using the monitored results and site-specific odour dispersion modelling.
- The odour dispersion modelling showed that areas to the east-northeast of Muswellbrook Coal Mine may experience higher effects of spontaneous combustion emissions (as H_2S) than other locations, because of the elevated terrain. In addition, H_2S from Muswellbrook Coal Mine may be detectable in most areas of the model domain from time-to-time, depending on the location and sensitivity of the individual. This is based on model predictions of 99th percentile H_2S concentrations which exceeded the EPA’s impact assessment criteria.
- The model results are conservatively high as it was assumed that the calculated maximum H_2S emission occurred continuously for every hour of the year.

The outcomes of the monitoring and modelling have led to the following recommendations:

- Continued monitoring of H_2S (nominally until 12 months after mining ceases) to assist with the verification of community concern since the complaints data, monitoring data and modelling results indicate that off-site odour (as H_2S) is detectable from time-to-time. The availability of longer-term monitoring data may also assist with examining the effectiveness of management controls in terms of off-site odour (as H_2S). Any changes to the monitoring arrangements would need to be with the agreement of the EPA, and consistent with the Consent.

- Develop a procedure for identifying whether Muswellbrook Coal Mine may have contributed to monitored H_2S concentrations on a day of interest (for example, a day of elevated H_2S).
- Incorporation of the findings from this study into the Air Quality Management Plan (AQMP) and Spontaneous Combustion Management Plan (SCMP) during the next periodic review of these documents.

8. References

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WHO (1976) "Manual on Urban Air Quality Management". Copenhagen : World Health Organisation, 1976.

WHO (2003) "Hydrogen Sulfide: Human Health Aspects". Concise Chemical Assessment Document 53. World Health Organisation 2003.

Appendix A. Extract from Environment Protection Licence 656

d) Spontaneous combustion areas mined out in square meters
e) Areas under water infusion
f) Map of the approximate location of the areas subject to spontaneous combustion, areas capped, areas mined out and areas under water infusion
g) Number of complaints received in relation to spontaneous combustion.

7 General Conditions

G1 Copy of licence kept at the premises or plant

G1.1 A copy of this licence must be kept at the premises to which the licence applies.

G1.2 The licence must be produced to any authorised officer of the EPA who asks to see it.

G1.3 The licence must be available for inspection by any employee or agent of the licensee working at the premises.

8 Pollution Studies and Reduction Programs

U1 Spontaneous Combustion Emissions Study

U1.1 The licensee must undertake a 12 month continuous monitoring program to investigate whether air emissions from spontaneous combustion of coal at the premises are exceeding EPA's air impact assessment criteria as identified in the 'Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales' (Approved Methods). The monitoring program must commence by 5 February 2018 and include:

a) continuous monitoring of sulfur dioxide at Points 15 and 16 in accordance with the EPA' s Approved Methods, unless otherwise agreed in writing by the EPA;
b) continuous monitoring of hydrogen sulfide at Points 9 and 10 with equipment able to detect and monitor hydrogen sulfide below the odour threshold (0.008 ppm has been recognised as the level of detection of hydrogen sulfide odours) in accordance with the EPA's Approved Methods, unless otherwise agreed in writing by the EPA;
c) continuous monitoring of PM10 at Points 7, 8 and 13, in accordance with the EPA's Approved Methods, unless otherwise agreed in writing by the EPA; and
d) reporting on the licensees website of hourly averages and daily averages within 14 days of capture of a months worth of data.

U1.2 The licensee must provide the EPA quarterly reports within one (1) month of completion of each quarter of monitoring. The reports must include a summary table and graphical illustration of data averages as described in the table below for the points referenced in the adjacent columns. The report must also include an analysis of results against EPA's air impact assessment criteria identified in the Approved Methods, and the National Environment Protection Measure (NEPM) standards and goals.

Pollutant	Averaging Period	Averaging Period	Averaging Period	Point Number
Hydrogen sulfide	30 minutes	1 hour	24 hours	9 & 10
Sulfur dioxide		1 hour	24 hours	15 & 16
PM10		1 hour	24 hours	7, 8 & 13

U1.3 For the duration of the spontaneous combustion study in condition U1.1 the licensee must:

Demonstrate ongoing performance of the Serinus 51 analyser and SO2 scrubber through regular calibration records, linearity checks and monitor performance reports and/ or comparison of results against a co-located instrument.
Conduct regular audits of the entire measurement process from sample inlet to data acquisition system.
Meet a minimum data capture of 90%. If the proponent cannot meet 90%, the EPA must be informed.
The proponent should provide a contingency plan in the case where monitoring cannot occur due to, but not limited to, equipment failure, logging issues, poor monitor performance.
Calibrate, zero and span the analyser for SO2 and H2S using gas standards that are representative of the concentration range expected to be measured during the study
i.e. 10 – 50 ppb, the calibration must be performed across the entire system, including the scrubber.
The instrument performance must, at a minimum, meet all specifications of AS3580.8.1 (1990) for H2S, and AS3580.4.1 (2008) for SO2.
Upon request Instrument performance reports, must be made available to the Environment Protection Authority for review.

U1.4 The licensee must develop an odour model which is prepared by an appropriately qualified and experienced person and developed in accordance with the EPAs approved methods. The model must;

a) use the outputs of 12 months of monitoring data collected in condition U1.1;
b) consider the range of meteorological conditions experienced during the study period; and
c) consider any other monitoring required to develop the model.

U1.5 Within three (3) months of completion of monitoring in accordance with Conditions U1.1 and U1.4 the licensee must provide a report to the EPA Director Hunter prepared by a suitably qualified and experienced person. The report must include but is not limited to:

a) a summary table and graphical illustration of data averages as described in the table below for the points referenced in the adjacent columns;
b) a description of the monitoring study, methods and odour modelling;
c) an analysis of results against EPA's Air Impact Assessment Criteria and National Environment Protection Measure (NEPM) standards and goals;
d) an analysis of results against community complaints about odours and dust;
e) odour model outputs including discussion of the outputs of the odour modelling including any particular olefactory surveys or odour surveys that may have been undertaken to compare monitoring results with complaints;
f) an analysis of meteorological conditions during the monitoring period, including temperature inversions, and a discussion of how meteorological conditions may have influenced sampling results;
g) details of actions taken by the licensee in response to any air quality monitoring results indicating exceedance of the EPA's air quality impact criteria or NEPM goals;
h) details of actions taken by the licensee to manage spontaneous combustion during the monitoring

period including any changes that were developed as a result of the Independent Audit detailed in Condition E2; and
i) any recommendations, with particular attention of mitigating impacts if monitoring and modelling indicate impacts above the EPAs air impact assessment criteria.

Pollutant & Monitoring Point	Averaging Period	Averaging Period	Averaging Period	Averaging Period
Hydrogen sulfide Points 9, 10	30 minutes	1 hour	24 hours	1 year
Sulfur dioxide Points 15, 16		1 hour	24 hours	1 year
PM10 Points 7, 8 & 13		1 hour	24 hours	1 year

Note: Note: If EPA Air Assessment Criteria or NEPM goals do not exist, the licensee must compare monitoring results against other published standards or goals.

Monitoring must continue after completion of this condition, unless the EPA authorises removal of monitoring conditions

9 Special Conditions

E1 Independant Audit of Spontaneous Combustion Management

E1.1 The licensee must engage an independent auditor with appropriate skills and experience in spontaneous combustion management to review the licensee's management and mitigation of spontaneous combustion against Best Practice.

a) The licensee must provide a report in writing to the EPA Director Hunter by 7 May 2018 that includes the details of the Best Practice Literature that was used in the audit, and any recommendations for improvements in implementation of the monitoring and the long-term management of spontaneous combustion.

E2 Hunter Valley Dust Risk Forecasting Trial - Spring 2017

E2.1 From 1 September 2017 to 30 November 2017 inclusively, the licensee must electronically record the following information:
1) Daily Total Tonnes Moved; and
2) Timestamped PM10 concentrations from upwind and downwind of the premises, recorded in ten minute intervals at monitoring points: 7 and 8.

For the purposes of this condition 'Total Tonnes Moved' is calculated as:
Total Tonnes Moved = Run of Mine (ROM) coal moved + Total Overburden Moved (TOM)

Where:

Appendix B. Investigations days for H_2S

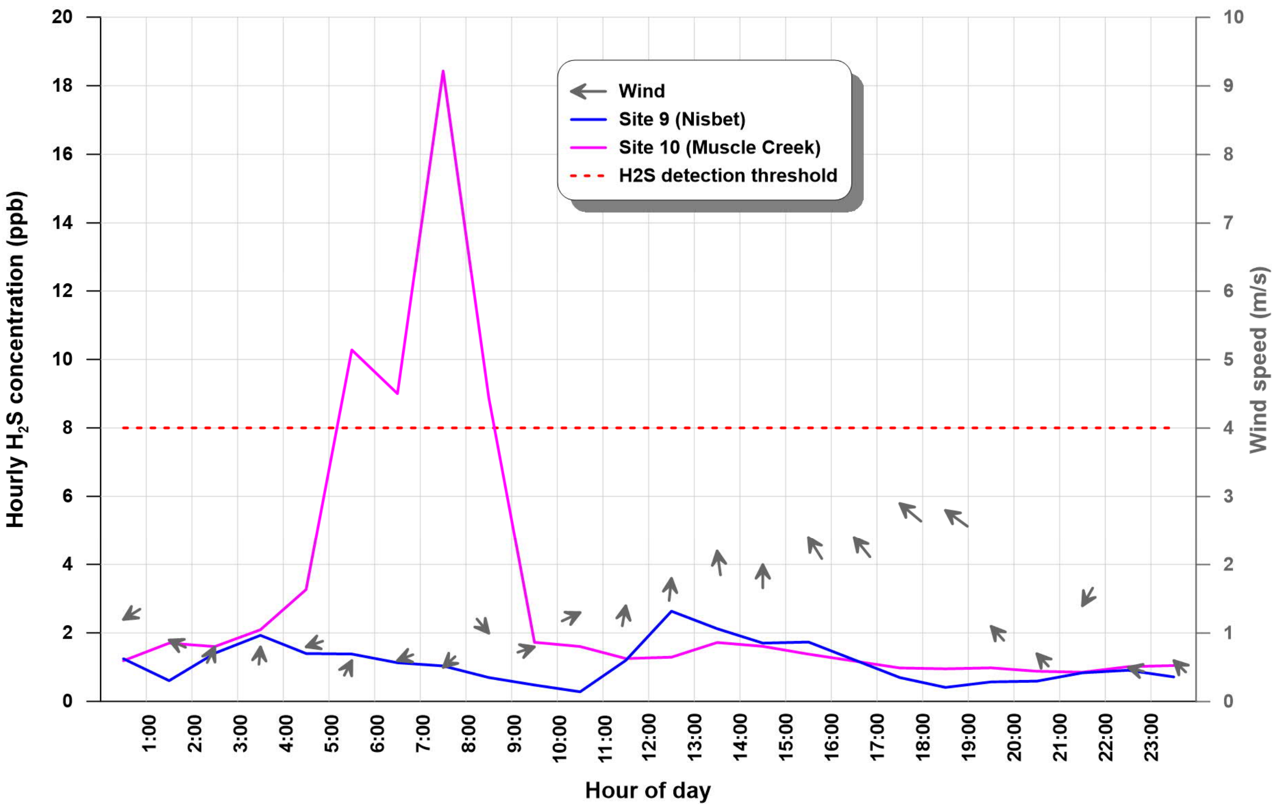

Figure B1 Measured hourly average H_2S concentrations on 27 May 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included dump and cover activities.

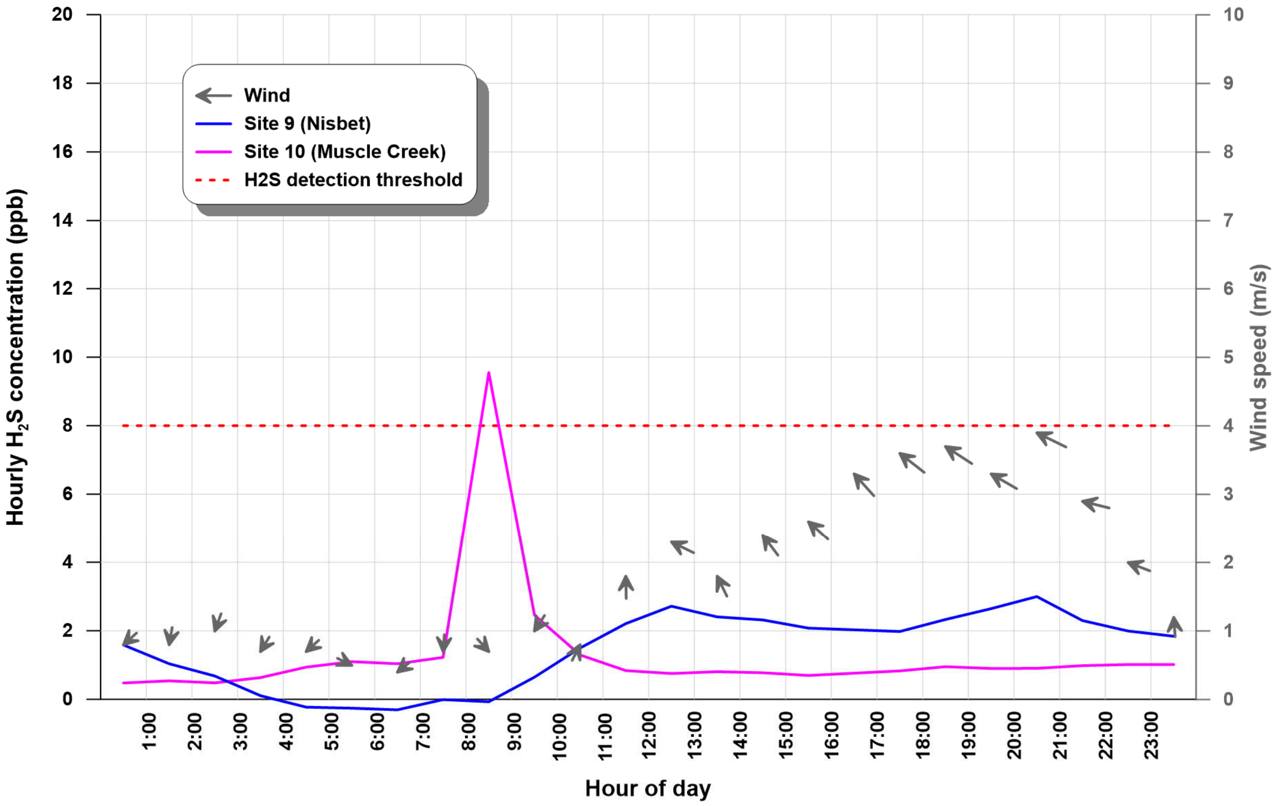

Figure B2 Measured hourly average H_2S concentrations on 26 June 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water carts on hot spot cooling and clay capping activities.

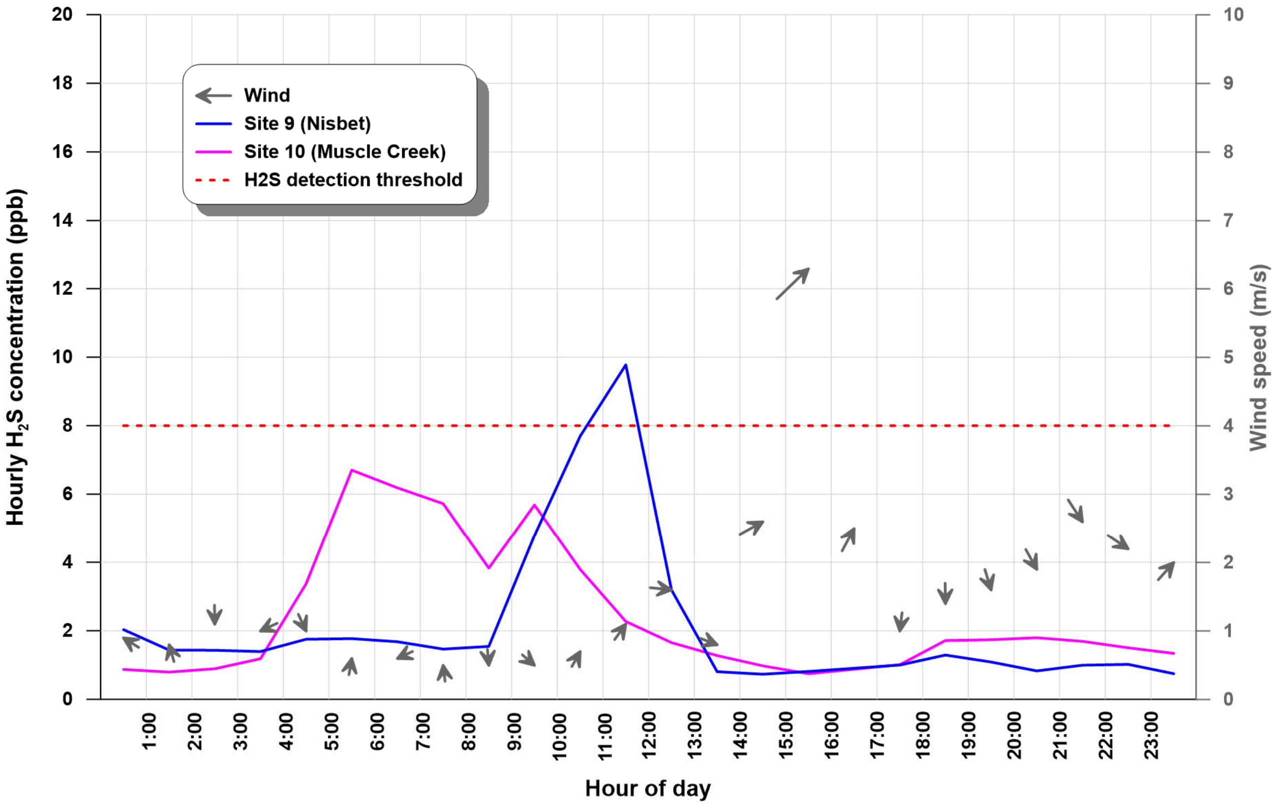

Figure B3 Measured hourly average H_2S concentrations on 28 June 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water carts hot spot cooling, and dump and cover activities.

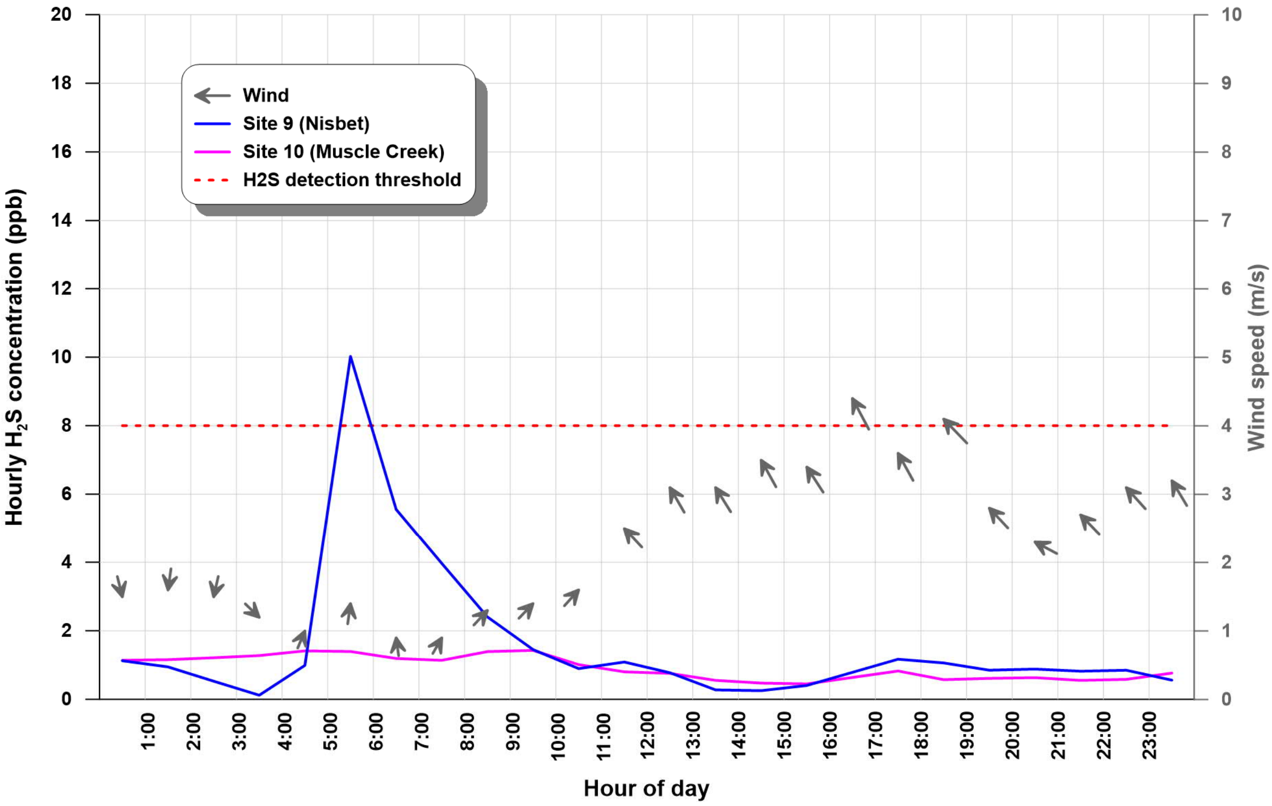

Figure B4 Measured hourly average H_2S concentrations on 1 July 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water carts hot spot cooling activities.

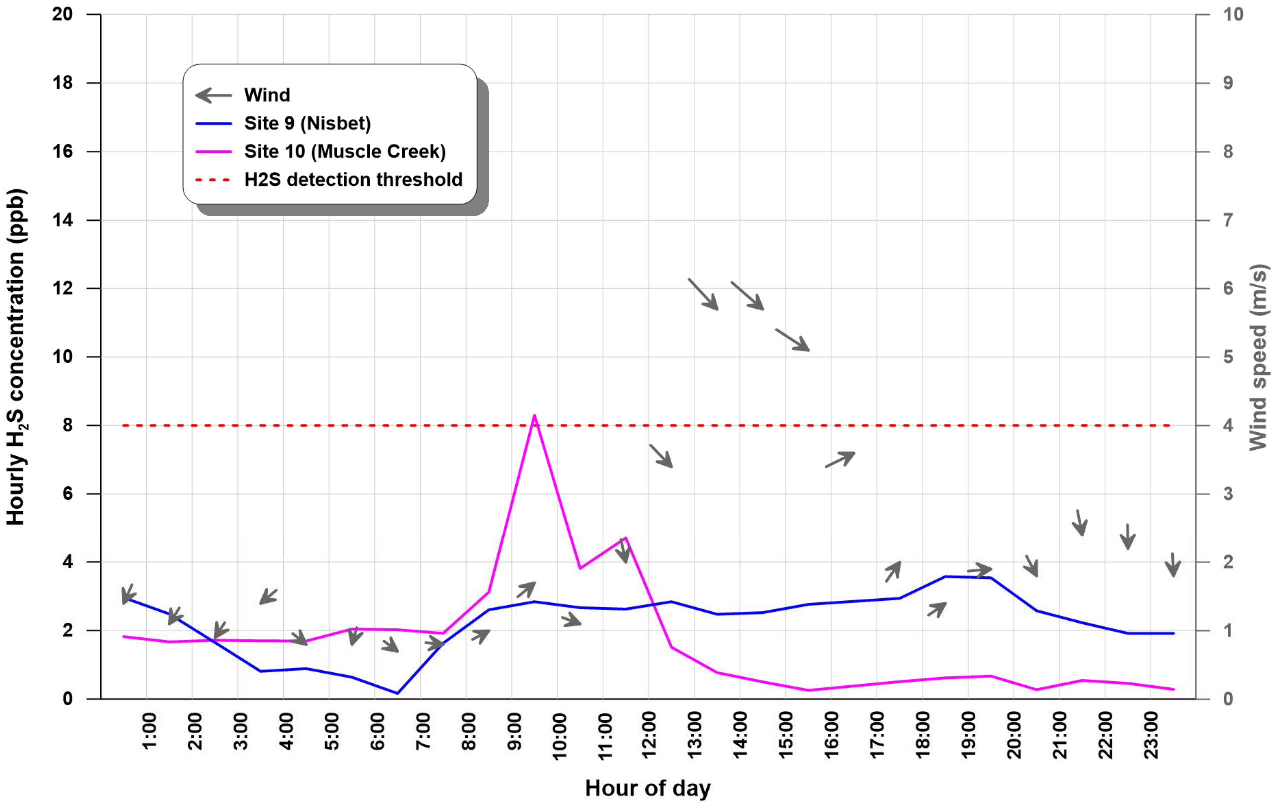

Figure B5 Measured hourly average H_2S concentrations on 12 July 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water carts on hot spot cooling activities.

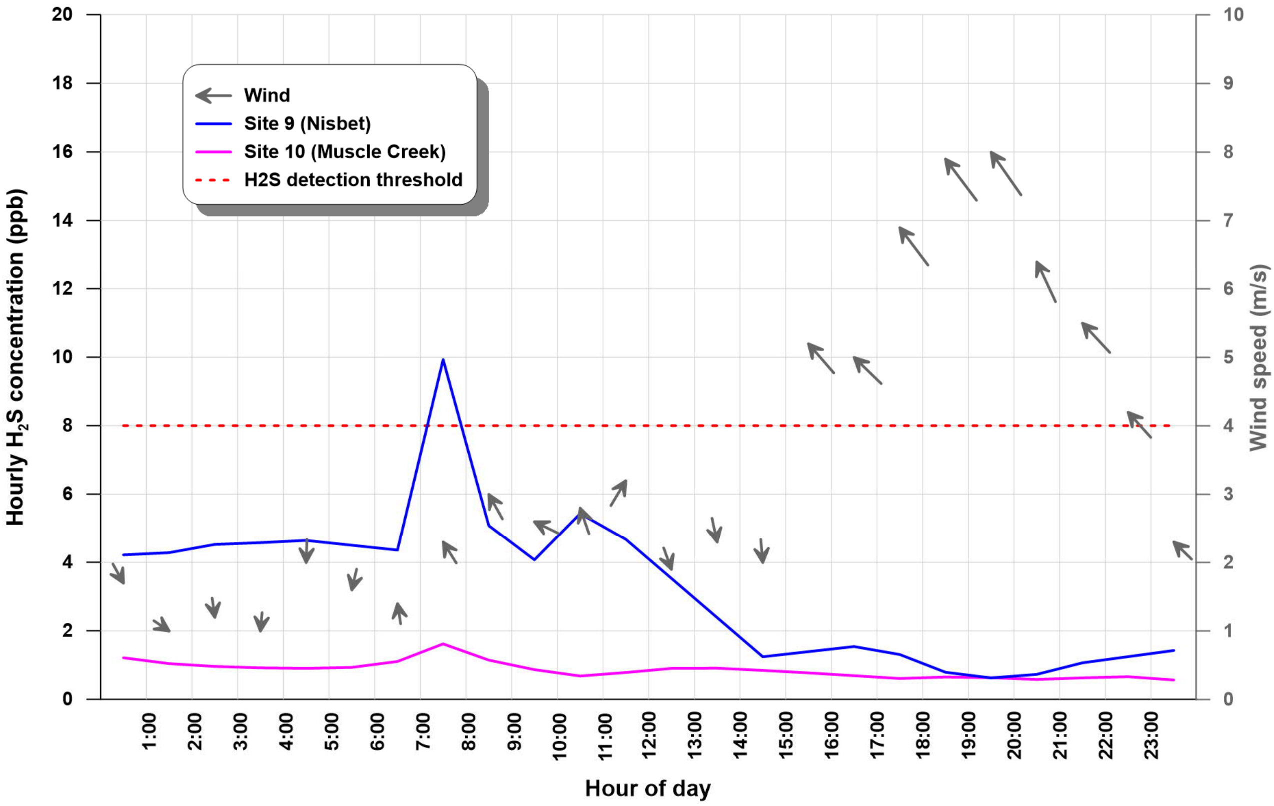

Figure B6 Measured hourly average H_2S concentrations on 13 September 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water carts on hot spot cooling, water infusion sprays, and removal and treatment of material activities.

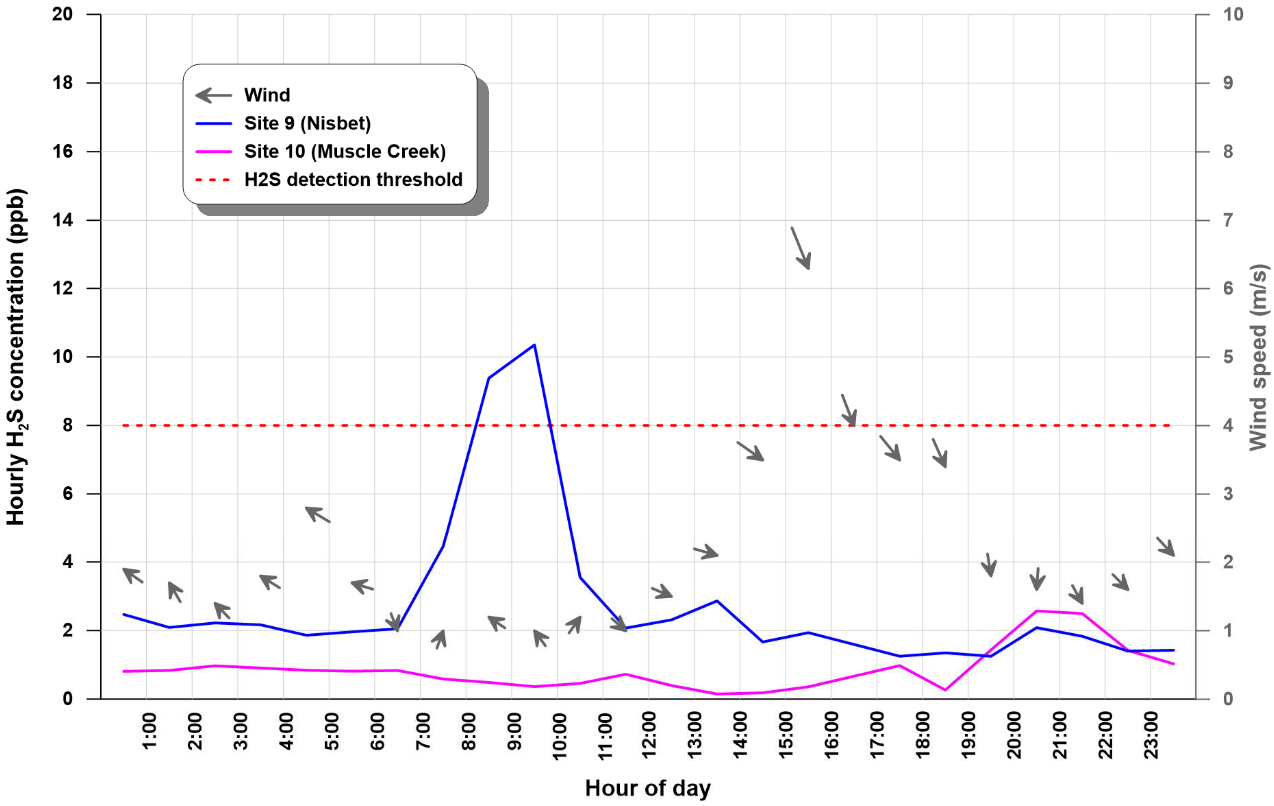

Figure B7 Measured hourly average H_2S concentrations on 14 November 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included clay capping, water carts on hot spot cooling, and hot material removal and treatment activities.

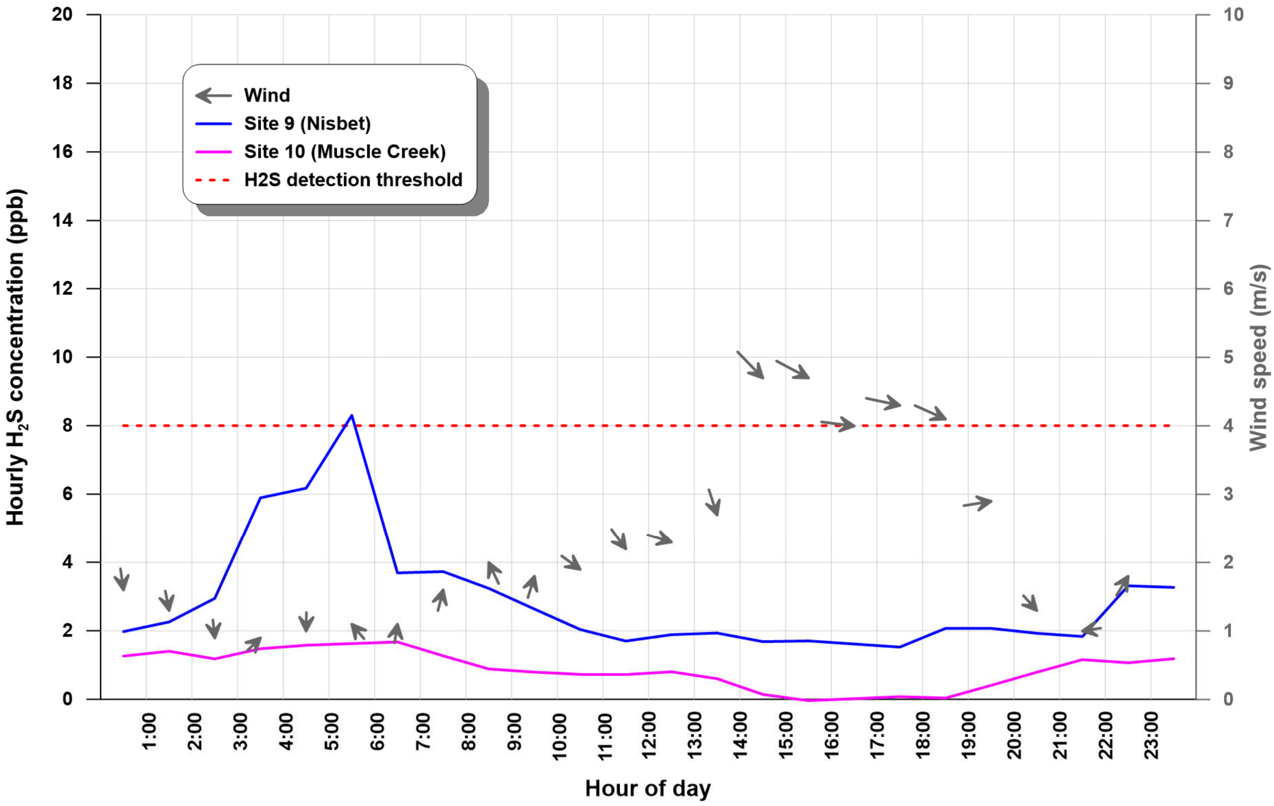

Figure B8 Measured hourly average H_2S concentrations on 1 December 2018

MCC continued to implement inspections, planning and mining of hot areas to manage the effects of spontaneous combustion over this period, in accordance with the SCMP. Additional spontaneous combustion control measures for this day included water infusion manifold, water carts hot spot cooling, and clay capping activities.

Appendix C. Investigations days for PM_{10}

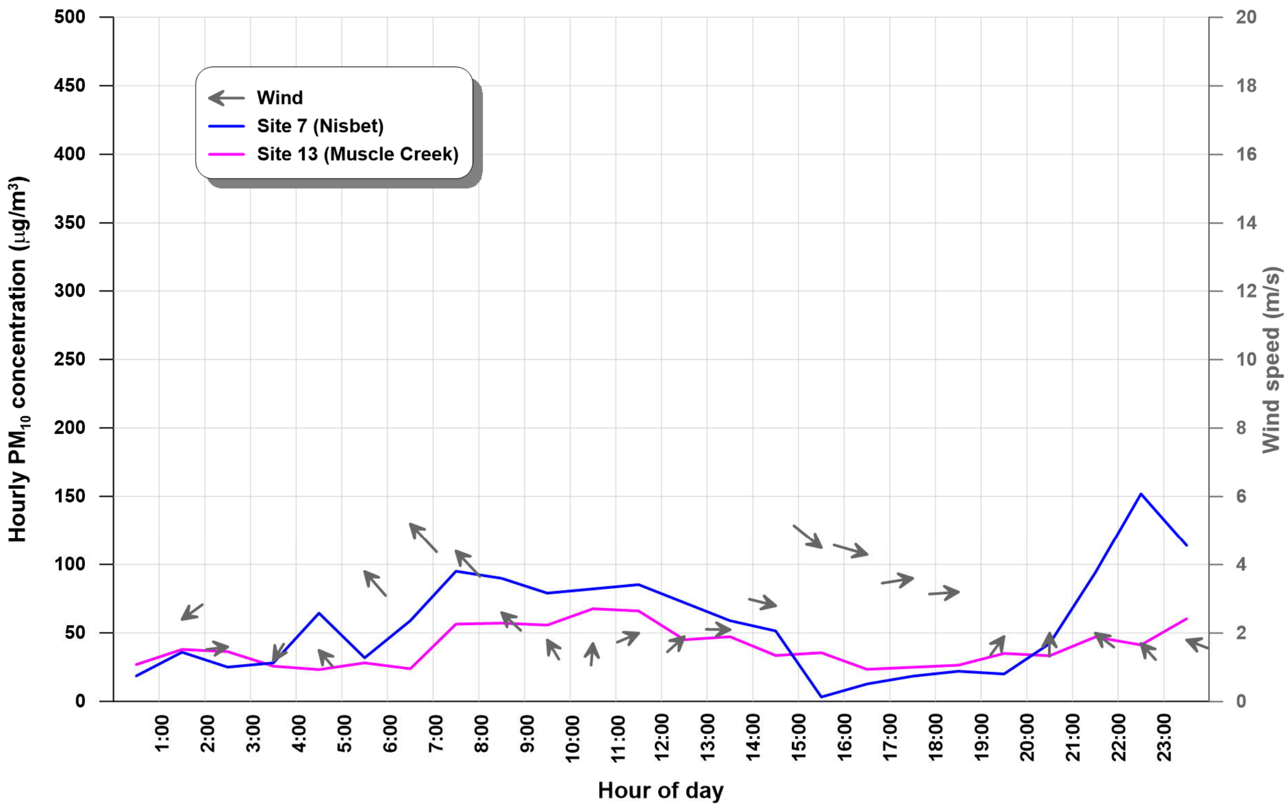

Figure C1 Measured hourly average PM_{10} concentrations on 19 March 2018

Date / time	Wind speed (m/s)	Wind direction (deg)	Site 7 (Nisbet) PM10	Site 13 (Muscle Creek) PM10	Calculated site contribution to Site 7	Calculated site contribution to Site 13
19/03/2018 1:00	2.6	265	18.6	26.9	0	0
19/03/2018 2:00	2.4	54	35.9	37.9	0	0
19/03/2018 3:00	1.6	263	25	36.3	0	0
19/03/2018 4:00	1.2	32	28.1	25.7	0	0
19/03/2018 5:00	1.5	140	64.4	23.2	41.2	0
19/03/2018 6:00	3.8	139	31.8	28.1	3.7	0
19/03/2018 7:00	5.2	137	58.9	23.8	35.1	0
19/03/2018 8:00	4.4	137	95	56.4	38.6	0
19/03/2018 9:00	2.6	133	89.8	57.1	32.7	0
19/03/2018 10:00	1.8	149	79	55.7	23.3	0
19/03/2018 11:00	1.7	185		67.6	-67.6	0
19/03/2018 12:00	2	247	85.2	66	0	0
19/03/2018 13:00	1.9	228		45	0	0
19/03/2018 14:00	2.1	271	58.9	47.2	0	0
19/03/2018 15:00	2.8	284	51.4	33.5	0	0

Date / time	Wind speed (m/s)	Wind direction (deg)	Site 7 (Nisbet) PM10	Site 13 (Muscle Creek) PM10	Calculated site contribution to Site 7	Calculated site contribution to Site 13
19/03/2018 16:00	4.5	309	3.2	35.5	0	0
19/03/2018 17:00	4.3	286	12.7	23.4	0	0
19/03/2018 18:00	3.6	261	18.4	24.9	0	0
19/03/2018 19:00	3.2	266	22	26.4	0	0
19/03/2018 20:00	1.9	216	20	35	0	0
19/03/2018 21:00	2	181	42.2	33.3	8.9	0
19/03/2018 22:00	2	127	94	47	47	0
19/03/2018 23:00	1.7	138	151.8	41.2	110.6	0
20/03/2018 0:00	1.8	111	113.9	60.3	53.6	0
		Average	55	40	14	0

- 19 March 2018 (55 µg/m^3 at Site 7)
- Exceedance was potentially influenced by activities at Muswellbrook Coal Mine, based on wind directions and upwind monitoring results
- Highest influence was late evening
- Calculated 24-hour average contribution of Muswellbrook Coal Mine to the 55 µg/m^3 was 14 µg/m^3

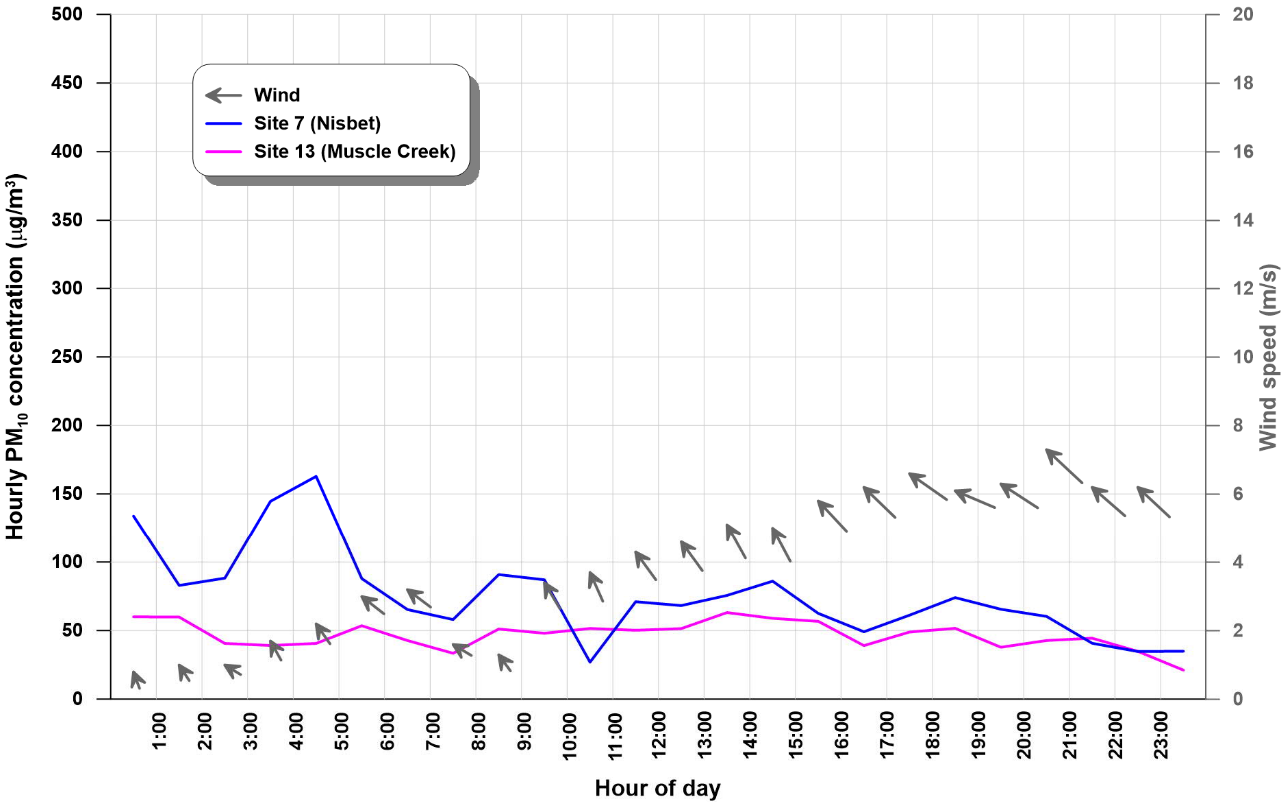

Figure C2 Measured hourly average PM_{10} concentrations on 20 March 2018

Date / time	Wind speed (m/s)	Wind direction (deg)	Site 7 (Nisbet) PM10	Site 13 (Muscle Creek) PM10	Calculated site contribution to Site 7	Calculated site contribution to Site 13
20/03/2018 1:00	0.8	160	133.8	60	73.8	0
20/03/2018 2:00	1	147	82.9	59.8	23.1	0
20/03/2018 3:00	1	121	88.2	40.6	47.6	0
20/03/2018 4:00	1.7	151	144.6	39.1	105.5	0
20/03/2018 5:00	2.2	145	162.8	40.6	122.2	0
20/03/2018 6:00	3	128	87.9	53.5	34.4	0
20/03/2018 7:00	3.2	127	65.3	42.7	22.6	0
20/03/2018 8:00	1.6	121	58	33.4	24.6	0
20/03/2018 9:00	1.3	144	90.8	51.1	39.7	0
20/03/2018 10:00	3.4	149	87	48	39	0
20/03/2018 11:00	3.7	156	26.9	51.5	-24.6	0
20/03/2018 12:00	4.3	144	71	50.2	20.8	0
20/03/2018 13:00	4.6	144	68.2	51.4	16.8	0
20/03/2018 14:00	5.1	151	75.6	63.1	12.5	0
20/03/2018 15:00	5	152	86	58.9	27.1	0
20/03/2018 16:00	5.8	137	62.5	56.7	5.8	0
20/03/2018 17:00	6.2	134	49.1	39	10.1	0
20/03/2018 18:00	6.6	125	61.2	48.9	12.3	0
20/03/2018 19:00	6.1	113	74	51.6	22.4	0

Date / time	Wind speed (m/s)	Wind direction (deg)	Site 7 (Nisbet) PM10	Site 13 (Muscle Creek) PM10	Calculated site contribution to Site 7	Calculated site contribution to Site 13
20/03/2018 20:00	6.3	123	65.5	37.8	27.7	0
20/03/2018 21:00	7.3	133	60.3	42.7	17.6	0
20/03/2018 22:00	6.2	131	40.7	44.4	-3.7	0
20/03/2018 23:00	6.2	133	34.7	34.8	-0.1	0
21/03/2018 0:00	5.2	133	34.9	21.1	13.8	0
		Average	75	47	29	0

- 20 March 2018 (75 µg/m^3 at Site 7)
- Exceedance was potentially influenced by activities at Muswellbrook Coal Mine, based on wind directions and upwind monitoring results
- Highest influence was early morning
- Calculated 24-hour average contribution of Muswellbrook Coal Mine to the 75 µg/m^3 was 29 µg/m^3

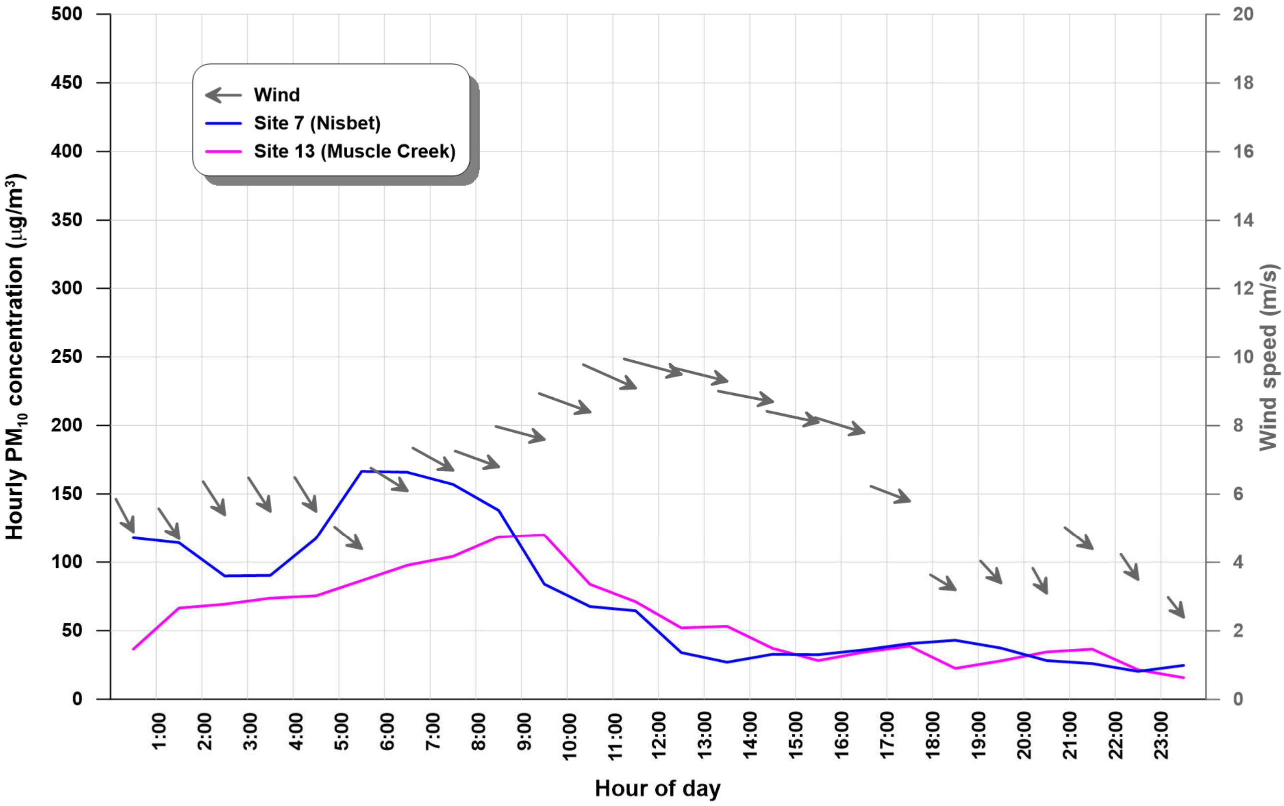

Figure C3 Measured hourly average PM_{10} concentrations on 15 April 2018

- 15 April 2018 (72 µg/m^3 at Site 7 and 56 µg/m^3 at Site 13)
- Exceedance was not influenced by activities at Muswellbrook Coal Mine, based on wind directions
- Likely source was to the northwest of Site 7

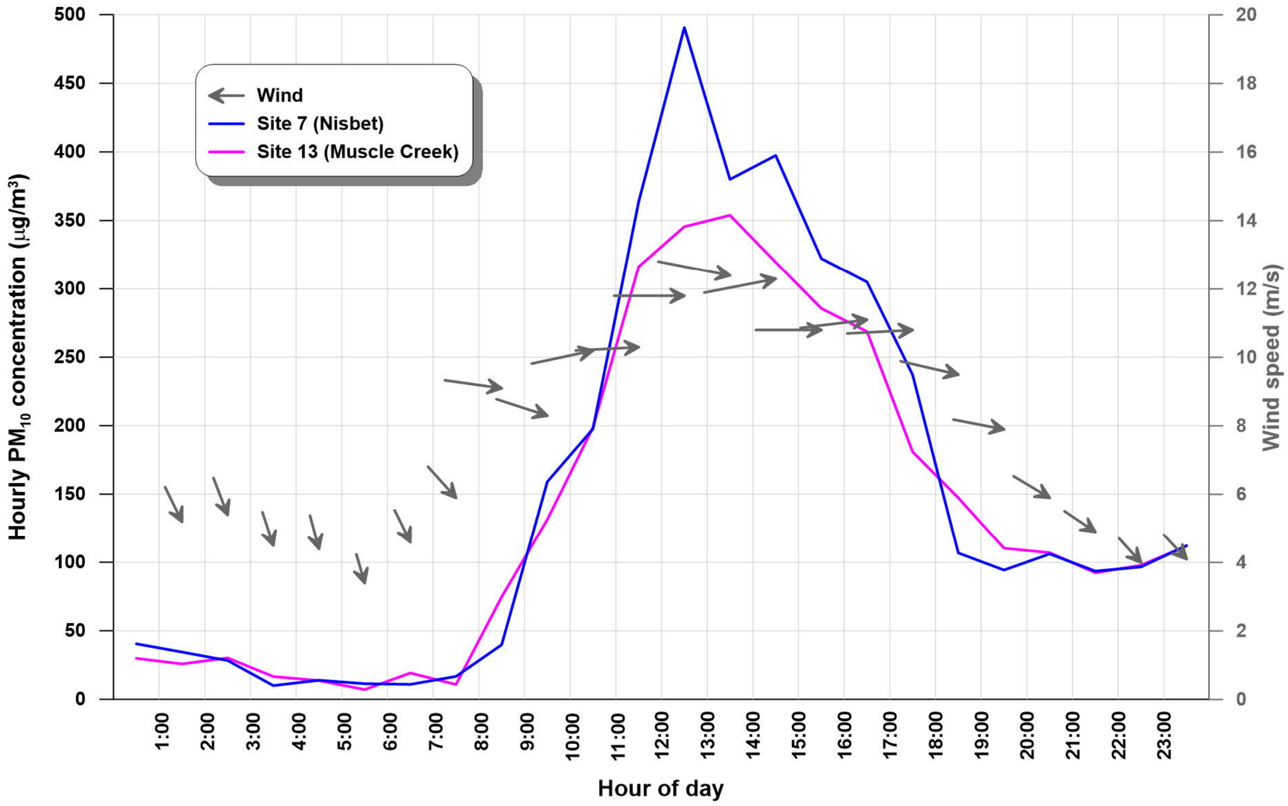

Figure C4 Measured hourly average PM_{10} concentrations on 22 November 2018

- 22 November 2018 (150 µg/m^3 at Site 7 and 135 µg/m^3 at Site 13)
- Exceedance due to a regional event, based on elevated levels both upwind and downwind of Muswellbrook Coal Mine
- Reported dust storm across NSW (https://www.theguardian.com/australia-news/2018/nov/22/dust-storm-nsw-air-quality-warning-as-front-descends-on-sydney)

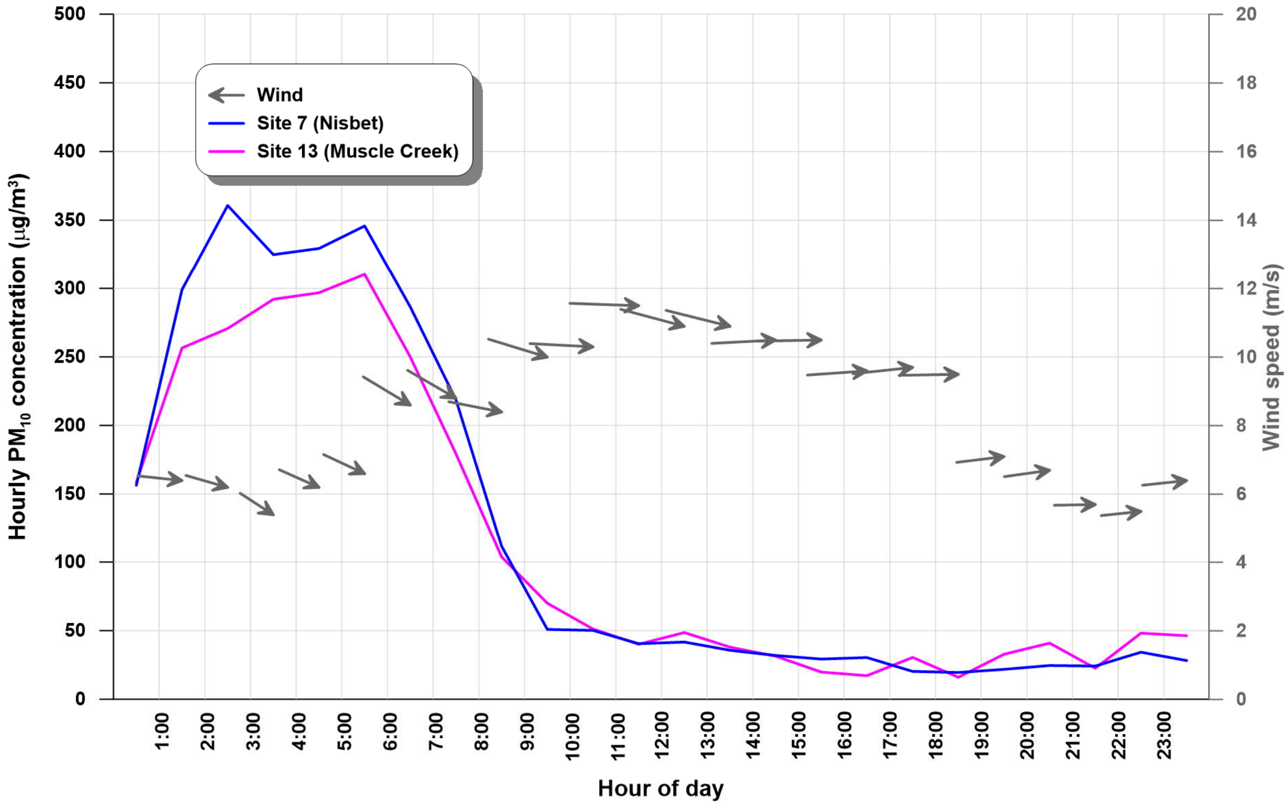

Figure C5 Measured hourly average PM_{10} concentrations on 23 November 2018

- 23 November 2018 (123 µg/m^3 at Site 7 and 113 µg/m^3 at Site 13)
- Exceedance due to a regional event, based on elevated levels both upwind and downwind of Muswellbrook Coal Mine
- Reported dust storm across NSW (https://www.theguardian.com/australia-news/2018/nov/22/dust-storm-nsw-air-quality-warning-as-front-descends-on-sydney)

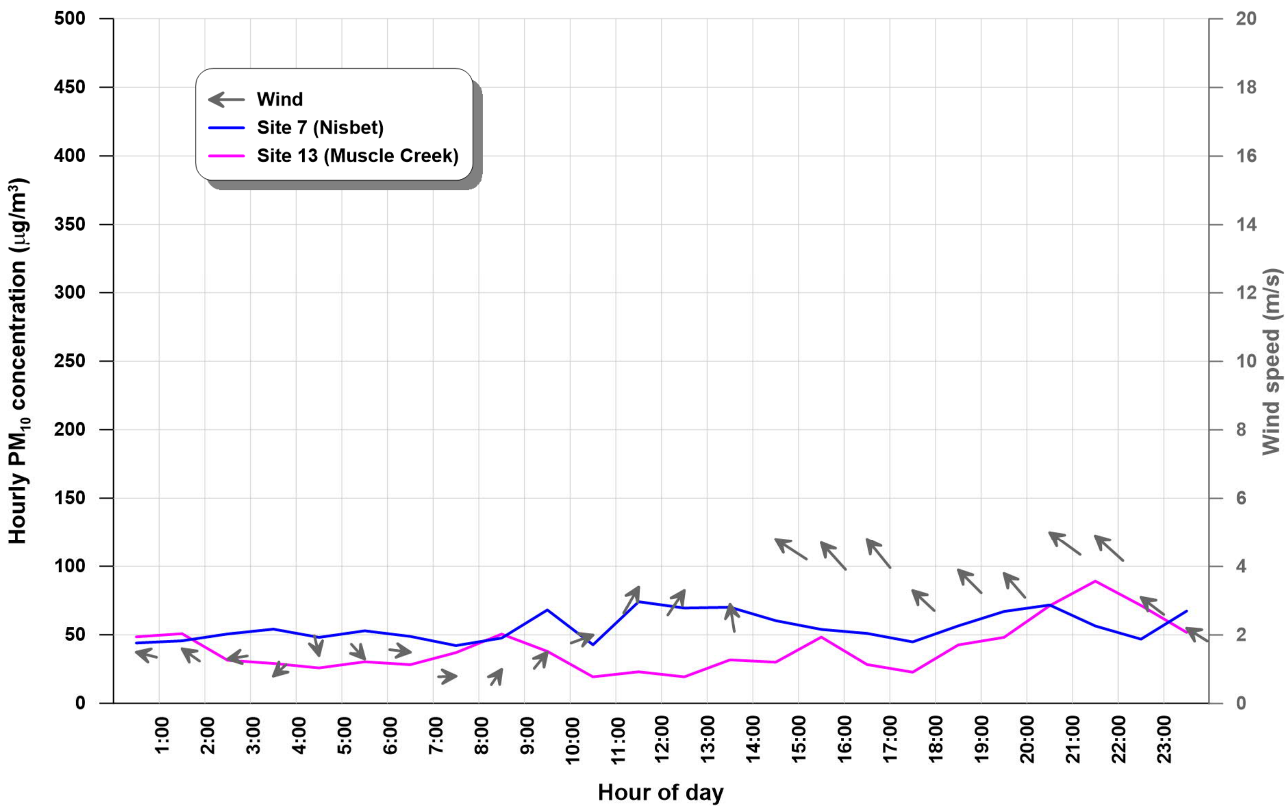

Figure C6 Measured hourly average PM_{10} concentrations on 16 January 2019

- 16 January 2019 (55 µg/m³ at Site 7)
- Exceedance was unlikely to have been influenced by activities at Muswellbrook Coal Mine, based on wind directions