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Analysis of air quality during the Hazelwood mine fire

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Important disclaimer

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Acronyms

AMS	Air monitoring station
API	Airborne Particle Index
Ave	Average
BAM	beta attenuation monitor
B(a)P	Benzo(a)pyrene
CFA	Country Fire Authority
CO	Carbon monoxide
DNPH	Dinitrophenylhydrazine
EC	Elemental carbon
IR	Infrared
MFB	Metropolitan fire brigade
MOUDI	cascade impactor
NEPM	National Environment Protection Measure
NO_2	Nitrogen dioxide
O_3	Ozone
OC	Organic carbon
PAHs	polycyclic aromatic hydrocarbons
$PM_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 µm
PM_{10}	particulate matter with an aerodynamic diameter of 10 µm
POPs	Persistent organic pollutants
ppm	parts per million
ppb	parts per billion
PUF	Polyurethane foam
SO_2	sulphur dioxide
Stdev	standard deviation
TCDD	Dioxins
TCDF	Furans
TEOM	Tapered Element Oscillating Micro-balance
TEQ	toxic equivalency
TEF	toxic equivalency factors
VOCs	Volatile organic compounds
WHO	World Health Organisation
QZ	Quartz

Executive summary

The Hazelwood mine fire started on 9 February 2014, causing a major air pollution event that affected thousands of residents in nearby towns. The fire was declared safe on 25 March 2014, burning over a period of 45 days.

The Hazelwood mine fire was ignited by embers from nearby bushfires burning in East Gippsland and other parts of the Latrobe Valley, including land adjacent to the township of Morwell where the Hazelwood mine is located. The smoke plume from the Hazelwood mine fire and the Gippsland fires could be clearly identified in satellite images showing the extent of both smoke plumes.

This report summarises the air quality measurements made during the Hazelwood mine fire by various organisations including EPA Victoria, Country Fire Authority (CFA) Victoria and CSIRO. Pollutants measured include particulate matter with an aerodynamic diameter of 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10}), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), dioxins, furans and metals. The air quality measurements started approximately four days after the mine fire started with the more targeted monitoring commencing on 26 February.

Due to the close proximity (~500 m) of the Morwell South air monitoring station (AMS) to the Hazelwood mine, smoke concentrations measured at the Morwell South AMS were especially elevated when compared to those recorded at the Morwell East AMS and the Traralgon AMS. In particular concentrations of PM2.5, CO and benzene exceeded National Environment Protection Measure for Air Quality (Air NEPM) standards during the smoke event. Concentrations of benzo(a)pyrene were also elevated and resulted in the yearly averaged concentrations exceeding NEPM for Air Toxics standards (Air Toxics NEPM).

Concentrations were highly variable with highest concentrations occurring during south-westerly winds when the smoke from the Hazelwood mine fire was blown into the town of Morwell. The low plume buoyancy of the fire resulted in the plume being trapped within the lower boundary layer allowing for minimal dispersion and hence elevated ground concentrations. Concentrations of air pollutants were primarily elevated in February with a significant decrease observed as the fire intensity abated through March for all pollutants measured.

Large bushfires such as the Eastern Victoria Great Divide fires in 2006/07 also resulted in significant air quality impacts, and similarities and differences between that event and the Hazelwood mine fire have been highlighted:

- Impact on ambient particle concentrations between the Hazelwood mine fire and the 2006/07 bushfires that burned for 65 days were of similar magnitude and duration. Maximum hourly and daily $PM_{2.5}$ concentrations were slightly higher in the Ovens Valley than in Morwell South, but the number of hours that $PM_{2.5}$ concentrations remained above 250 µg m^{-3} was higher at Morwell South.
- During the Hazelwood mine fire EPA Victoria recorded its highest 8-hour average CO concentration ever measured. CO concentrations were higher in Morwell South compared to those measured at a staging area in Northeast Victoria during the 2006/07 bushfires, although only a short period during the fires was sampled and concentrations may have been higher. In general though, bushfires are less likely to cause increased CO levels above Australian Air NEPM air quality

guidelines in downwind communities, but are a potential health risk on the fire ground, within the immediate vicinity of the fire.

- Benzene concentrations were elevated during the Hazelwood mine fire, and were higher than those measured in Northeast Victoria during the 2006/07 bushfires. The measured benzene to toluene ratio is consistent with that of wood burning rather than traffic-related emissions. The ratios were similar to those recorded for smoke measurements in peat fires and underground coal fires.

1 Introduction

The Hazelwood mine fire started on 9 February 2014 and burned over 45 days. It was considered a major air pollution event affecting thousands of residents in nearby towns *(EPA Victoria 2015a; EPA Victoria 2015b)*.

The Hazelwood mine fire is not a unique event as worldwide a large number of uncontrolled coal fires have been reported, or in some instance are still burning after more than 50 years *(Nolter and Vice 2004; Stracher and Taylor 2004)*. In the US alone it is estimated that 150 uncontrolled surface and underground coal fires are still burning *(Finkelman 2004)*. In Australia, the 'Burning Mountain', a large coal seam in New South Wales has been smouldering for more than 6000 years *(Ellyett and Fleming 1974)*.

Despite the extent of uncontrolled coal fires, only a limited amount of research has focused on the pollutants emitted from coal fires and the human health impacts. Recent research studies have investigated exhaust gases in vents from underground coal mine fires in the US *(Hower et al. 2009; O'Keefe et al. 2010; O'Keefe et al. 2011; Engle et al. 2012)*. The results have shown a large spatial and temporal variability in concentrations of gases, some indicating incomplete combustion of the coal and some suggesting a more complete combustion. During incomplete combustion, elevated levels of benzene and aliphatic and aromatic compounds were measured. In general, studies have mainly focused on greenhouse gas pollutants such as carbon dioxide and methane or other toxic gases, but information on particulate matter emissions is scarce.

Although previous research studies provide some information on potential gases emitted during coal mine fires, the studies have focused on smouldering underground coal mine fires. As these differ from an open-cut coal mine fire, emission rates are likely to also differ. Currently there are no available data in the literature on emission characterisation from open-cut coal mine fires. Our understanding of the combustion of solid fuels such as Victorian brown coal has been focused on burning in furnaces and industrial processes and open combustion is a relatively recent area of concern.

2 Background

Air quality in the Latrobe Valley has been monitored over many years (since 1981 in Traralgon) and the ten-year PM_{10} data measured at the Traralgon AMS are shown in Figure 1. While the four power stations, Yallourn, Hazelwood and Loy Yang A and B are likely to add to the general background PM_{10} concentrations, the data shows that seasonal bushfires have the largest impact on ambient PM_{10} concentrations. Highlighted in Figure 1 are the impacts from the 2006/07 Eastern Victoria Great Divide bushfires that burned an area of ~ 1.3 million ha over 69 days, the 2009 Black Saturday bushfires and the 2014 East Gippsland fires including the Hazelwood mine fire. These were the periods when PM_{10} concentrations exceeded 50 µg m^{-3}, for 11 days in 2006/07, 2 days in 2009 and 3 days in 2014. Daily PM_{10} concentrations exceeded 50 µg m^{-3} on several occasions during autumn (March-May) most likely due to smoke from prescribed burns.

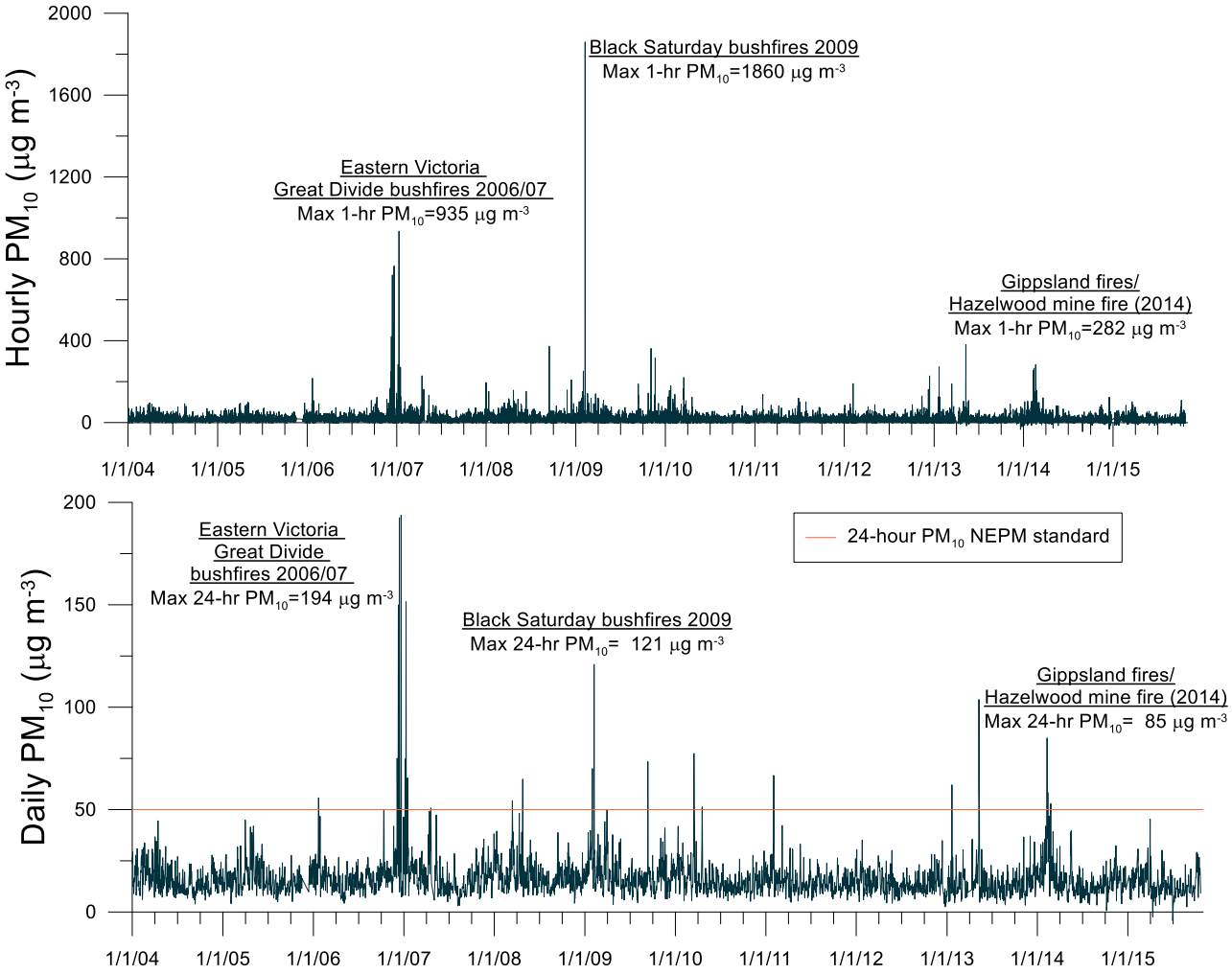

Figure 1 Ten-year time series of hourly (top graph) and daily (bottom graph) PM_{10} concentrations at Traralgon AMS

2.1 East Gippsland bushfires

In January and early February several lightning strikes started fires in forested areas in East Gippsland. On 9 February 2014 there were 18 active fires in far East Gippsland between the Snowy River and the NSW border. Due to the hot, dry and windy conditions on that day these fires grew and merged into a 166,000 ha Fire complex (850 km perimeter) with other smaller fires affecting a further 10,000 ha. NASA's MODIS satellite image taken on 11 February 2014 shows the smoke from the fires in East Gippsland being transported to Melbourne by the prevailing easterly winds (Figure 2).

Figure 2 Image of the smoke plume from the East Gippsland bushfires on 11th February 2014 retrieved from the NASA EarthData website (https://earthdata.nasa.gov/).

Visibility measurements taken at several monitoring stations in Melbourne during the smoke events are shown in Figure 3 and highlight the smoke impact from fires on Melbourne's air quality. As a comparison, the maximum 1-hour average Airborne Particle Index (API) measured in February 2015 in Melbourne was 1.9.

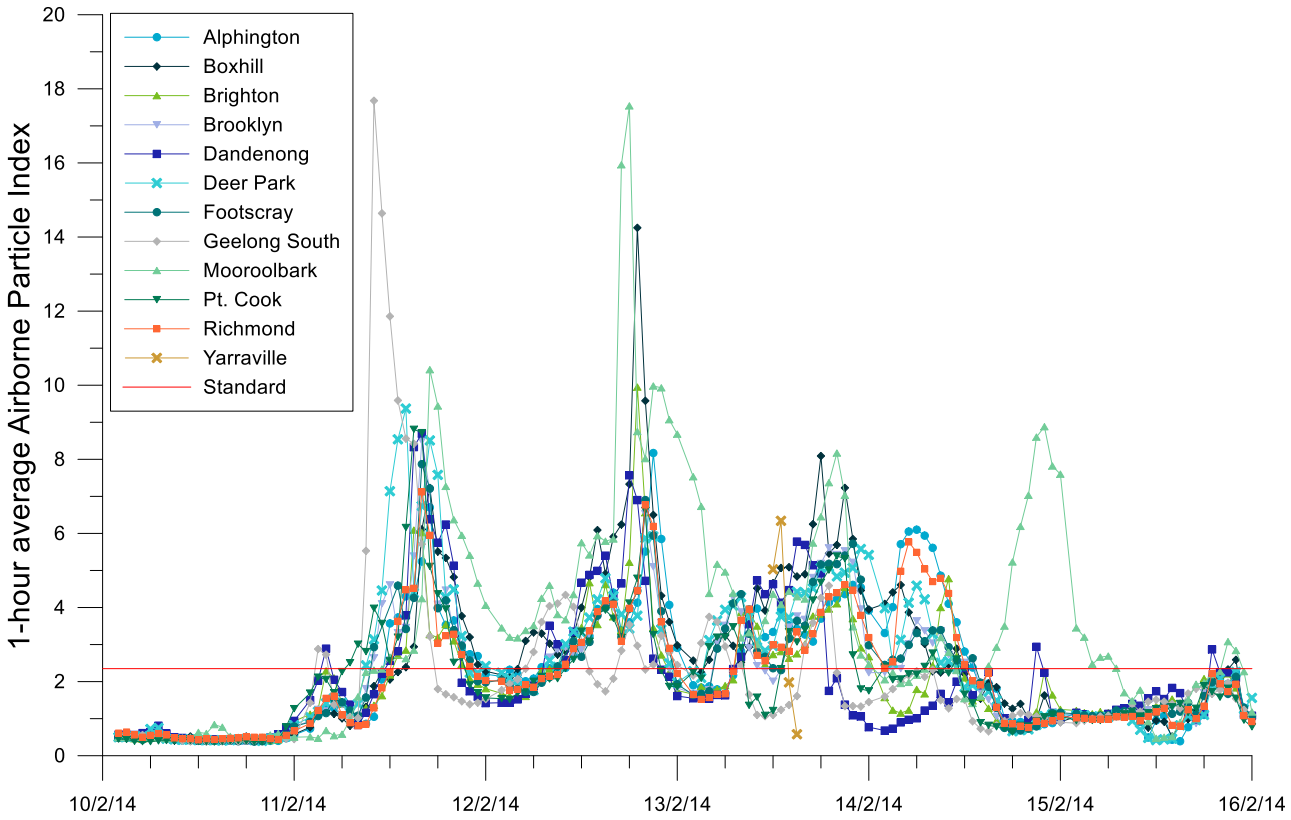

Figure 3 Visibility reduction measured across Melbourne between 10th and 15th February 2014

3 Hazelwood mine fire

The Hazelwood mine fire started on 9 February 2014 when embers from nearby bushfires spotted into the mine. Due to strong south-westerly winds with wind gust up to 74 km/h, the fire spread rapidly and extensively. By the morning of 10 February 2014, the fire had spread across three levels in the northern batters over approximately 2 km long, in the eastern batters over approximately 1 km long and on the floor mine on an approximate area of 0.25 km^2 (Figure 4) (http://report.hazelwoodinquiry.vic.gov.au/). On 13 February 2014 the Hazelwood mine fire was declared to be a HazMat incident.

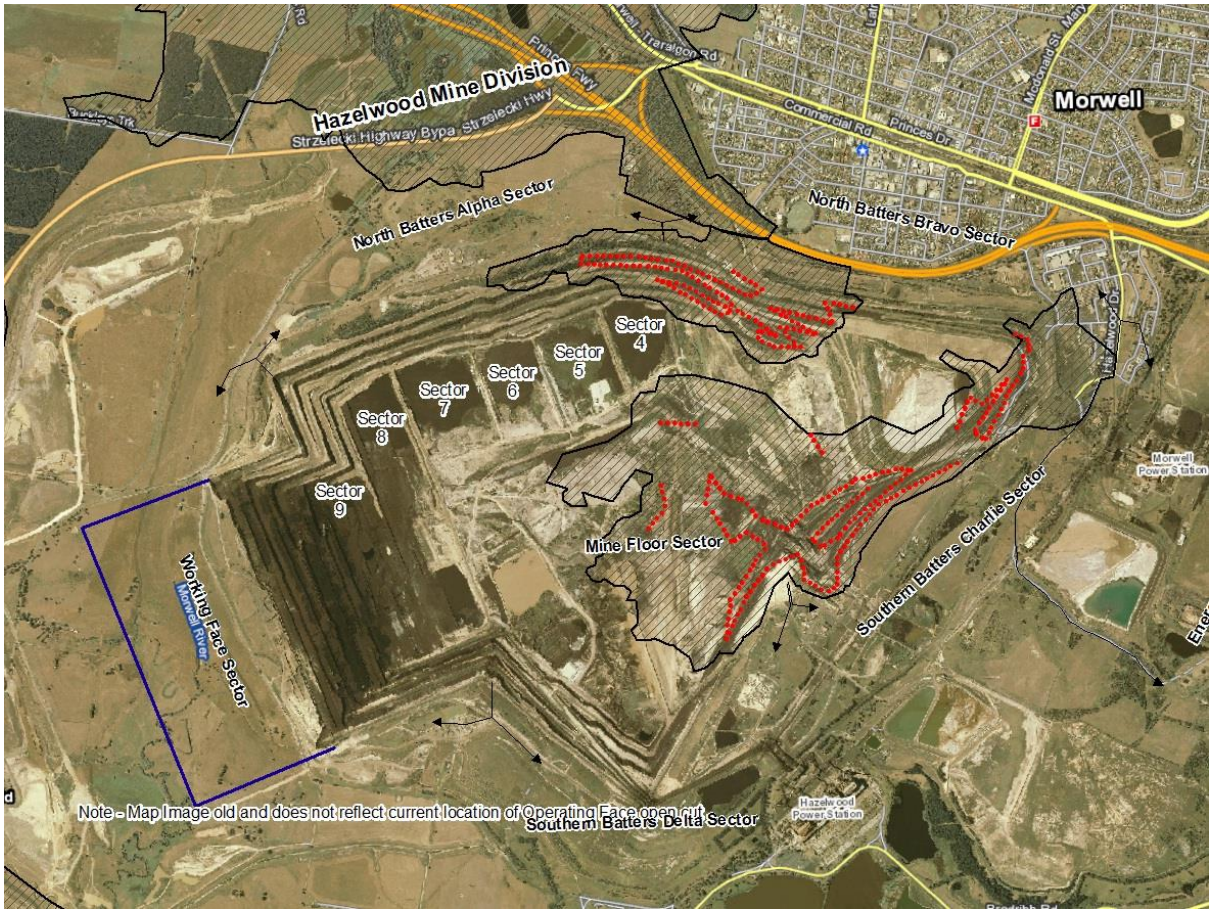

Figure 4 Map of the Hazelwood mine. Red colour indicates the batters on fire.

The extent of the smoke plume from the Hazelwood mine fire and the adjacent bushfires could be clearly identified from NASA's MODIS satellite images (Figure 5).

Figure 5 Image of the smoke plume from the Hazelwood mine fire on 10th February 2014 (top) and 23rd February 2014 (bottom) retrieved from the NASA EarthData website (https://earthdata.nasa.gov/). It is not possible to distinguish between smoke from the coal fire and bushfire at this scale.

3.1 Timeline of events

The Hazelwood mine fire started on 9 February 2014, was declared under control on 10 March 2014 and declared safe on 25 March 2014, after burning for 45 days. Figure 6 shows the timeline of the event and the environmental monitoring carried out during the Hazelwood mine fire. Monitoring of CO and PM started approximately three to four days after the fire entered the coal mine with more extensive monitoring being conducted within the second week.

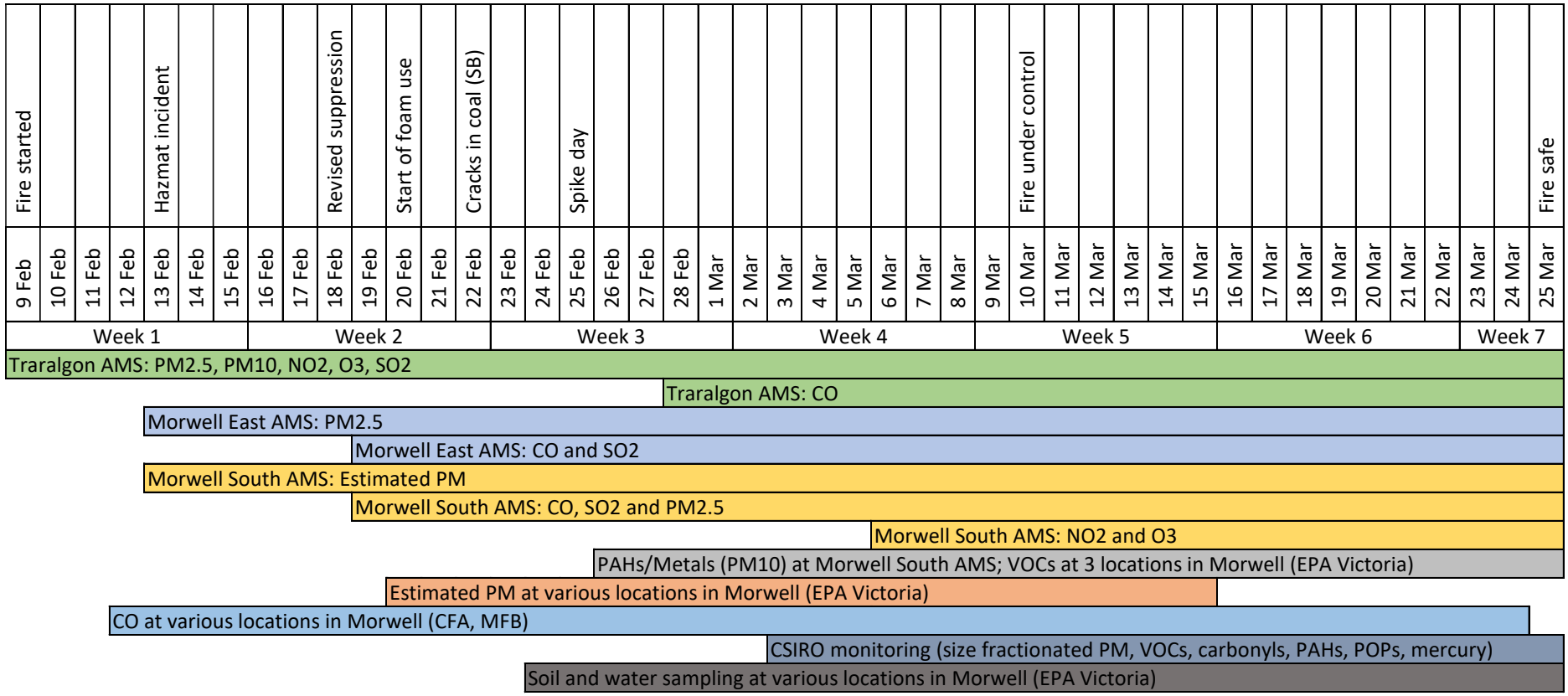

Figure 6 Timeline of events and monitoring of the Hazelwood mine fire

4 Methodology

4.1 Air quality sampling sites

Air quality was monitored in four locations during the Hazelwood mine fire, Morwell South AMS (52 Hazelwood road), Morwell East AMS (Ronald Reserve, Hourigan road), Traralgon AMS (H Osborne Park, Kay Street) and Morwell South CSIRO site (Elgin street). Short-term particulate matter (PM) monitoring was done at an additional three locations in Morwell, e.g. Kernot Hall, St Luke's church and Helen Street. During the mine fire incident PM monitors were also set up in Moe and Churchill.

VOCs were monitored at three locations, Morwell South AMS, Morwell East AMS and Maryvale Crescent Preschool while additional CO measurements were collected by CFA Victoria in a number of locations within Morwell. Details on the locations of air quality monitoring sites are shown in Table 1 and Figure 7.

Table 1 Air quality monitoring sites

ORGANISATION	DATA COLLECTED	MONITORING SITE	LATITUDE	LONGITUDE
EPA Victoria	Air monitoring & sampling	Morwell South AMS[1]	-38.242	146.393
		Morwell East AMS	-38.229	146.424
	Air monitoring	Traralgon AMS	-38.195	146.527
	PM monitoring	Kernot Hall	-38.239	146.421
		St Luke's church	-38.238	146.406
		Helen St.	-38.234	146.391
		Churchill	-38.312	146.430
		Moe	-38.176	146.262
	VOC sampling	Maryvale Crescent Preschool	-38.237	146.391
CSIRO	Air monitoring & sampling	Morwell South	-38.240	146.400
		Morwell East AMS	-38.229	146.424
		Traralgon AMS	-38.195	146.527
CFA	CO monitoring	Kerrie St.	-38.240	146.402
		Keegan St.	-38.241	146.391
		Maryvale Crescent Preschool	-38.237	146.391
		Morwell Police station	-38.235	146.395
		Sacred Heart Primary	-38.240	146.404

[1] The Morwell South AMS was set up at the Morwell Bowling Club until 6 October 2014 and moved to Maryvale Crescent Preschool on 6 October 2014 and was operational on 7 October 2014.

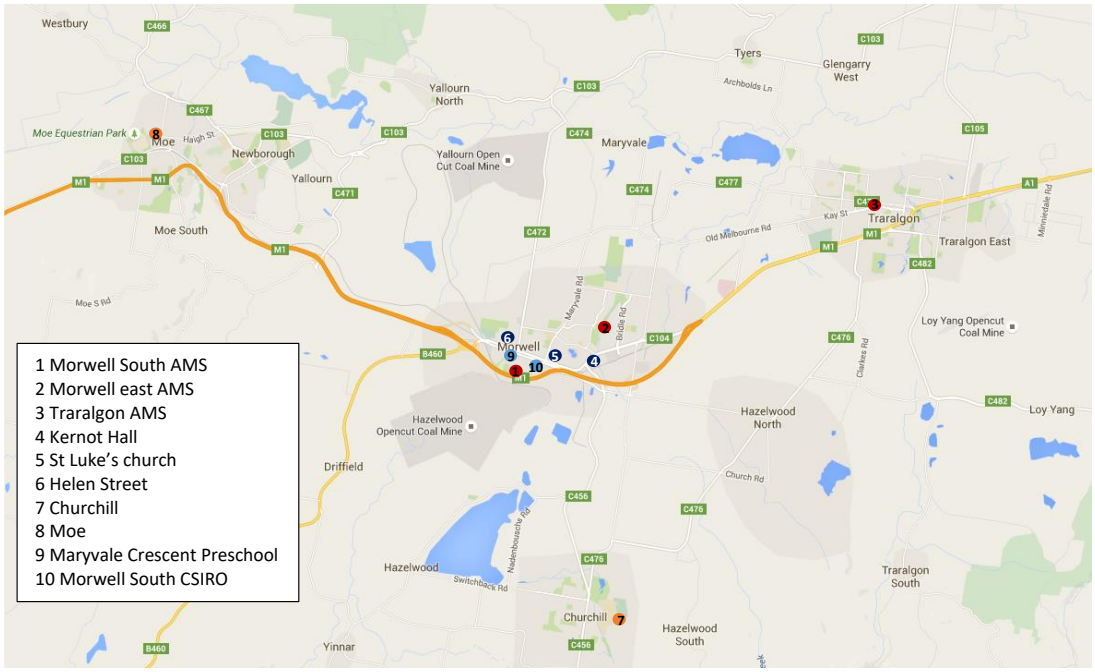

Figure 7 Location of air quality monitoring sites

4.2 Measurement methods

A summary of the instruments used, the measurement description and the frequency of the measurement is given in Table 2. Detailed information on monitoring equipment and analysis methods is provided in the Appendix A.

Table 2 Air quality measurements during the Hazelwood mine fire

	INSTRUMENT	MEASUREMENT	LOCATION	FREQUENCY [1]	PERIOD
Particles	E-sampler	$PM_{2.5}$/Metals	Morwell South	Continuous/1 week	3-28 March
			Morwell East	Continuous/1 week	28 Feb-28 March
			Traralgon	Continuous/1 week	20 Feb-28 March
	DustTrak	Indicative $PM_{2.5}$ [2]	Morwell South	Continuous	13-19 Feb
			Kernot Hall		21 Feb-2 March
			St Luke's church		5-15 March
			Helen St.		20-27 Feb
			Churchill		6 March-to date
			Moe		28 Feb-to date
	BAM	$PM_{2.5}$	Morwell South	Continuous	19 Feb-to date
			Morwell East	Continuous	13 Feb-to date
	Nephelometer	$PM_{2.5}$	Traralgon	Continuous	
	TEOM	PM_{10}	Traralgon	Continuous	
	HiVol	PM_{10} Dioxins/furans	Morwell South	24h (6-day cycle)	26 Feb-21 March
		PM_{10} PAHs/Metals	Morwell South	24h (6 day cycle)	26 Feb-to date
	Partisol	PM_{10} Metals	Morwell South	24h	28 Feb-26 March
	MOUDI	Size-resolved mass/metals	Morwell South	2-4 days	3-21 March
	HiVol MOUDI	Size-resolved OC/EC	Morwell South	2-4 days	3-21 March
	TravelBLANkET	Indicative $PM_{2.5}$	Morwell	Continuous	20-23 Feb
VOCs	Canisters	Speciated VOCs	Morwell South	24h (5 samples)	26 Feb-14 March
			Morwell East		
			Maryvale Crescent		
	Radiello	Speciated VOCs	Morwell South	7-days	26 Feb-to date
			Morwell East		
			Maryvale Crescent		
	Adsorbent tube	Speciated VOCs	Morwell South	25min/h over 24h (9 samples)	3-20 March
Carbonyls	DNPH	Speciated aldehydes & ketones	Morwell South	24h (8 samples)	3-19 March
PAHs	PUFs/QZ filters	Speciated PAHs	Morwell south	14-days (2 samples)	3-28 March
Dioxins/Furans	PUFs/QZ filters		Morwell south	14-days (2 samples)	3-28 March
CO	IR absorption spectrometer		Morwell South	Continuous	19 Feb-to date
	Area Rae		Morwell East		19 Feb-to date
			Different locations in Morwell		12 Feb-24 March

[1] Continuous measurements refer to measurements collected at least every 5-minutes

[2] Calibrated according to method described in EPAV Publication 1599 (2015) available at https://www.epa.vic.gov.au/about-epa/publications/1599

5 Results

A range of air pollutants were measured during the Hazelwood mine fire to assess the impact on air quality and population health. The pollutants measured, their respective air quality guidelines and potential health impacts are shown in Table 3. Concentrations measured are tabulated in Appendix B.

In this work we compare concentrations measured during the mine fire event to different types of standards and guidelines.

The National Environment Protection Measure for Ambient Air Quality (the 'Air NEPM') sets national standards for six key air pollutants including carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and particles. The Air NEPM aims to ensure a consistent level of air quality protection across Australia. The Air NEPM standards are legally binding at each level of Government and are applicable over defined time periods specified in Table 3. Air NEPM monitoring stations are sited in locations representative of air quality in the entire airshed.

The NEPM for Air Toxics (Air Toxics NEPM) establishes monitoring investigation levels for five air toxics - benzene; formaldehyde; benzo(a)pyrene as a marker for Polycyclic Aromatic Hydrocarbons; toluene; and xylenes.

The community Smoke, Air Quality and Health standard (community SAQH standard)[1] is one of several standards that fall under the State Smoke Framework, and is used to guide the Victorian Governments response to significant or prolonged events that generate smoke or other emissions that may affect public health. The community SAQH standard provides direction for protecting community health in response to smoke events that result in significant levels of PM2.5 in the outdoor air environment. This standard details the basis for air quality categories which trigger advice to the community during such events and specifically concerns the areas around the fire impacted by the smoke plume. The community SAQH standards focus applies to protecting community health and therefore does not apply to occupational health and safety, for example, to firefighters and other emergency service workers. The air quality categories for $PM_{2.5}$ from the SAQH standard are reproduced in Table 4.

The Standard for Managing Exposure to Significant Carbon Monoxide Emissions [2] provides direction for Victorian agencies responding to large, extended or complex fires that produce significant levels of carbon monoxide in the outdoor environment and provides a framework for decision making to manage health and safety of all personnel and affected communities. The Standard concerns the area in immediate proximity to the fire and the protection of responder health and safety as well as areas around the fire impacted by the smoke plume and the protection of community health and safety. The exposure guidelines specified in this standard are reproduced in Table 5.

These graduated standards (PM2.5) and acute exposure standards (CO) were applied during the mine fire episode[3][4].

[1] **The Community Smoke Air Quality & Health Standard (December 2015)** http://files.portal.em.vic.gov.au/refdocs/EMK-01.19-Community-SAQH-Protocol.pdf

[2] the **Standard for Managing Exposure to Significant Carbon Monoxide Emissions (July 2015)** http://files.portal.em.vic.gov.au/refdocs/EMK-01.19-CarbonMonoxideEmissions.pdf

[3] **Hazelwood Coal Mine Fire –PM2.5 Health Protocol DOH.0005.001.0151 Endorsed 13 March 2014**

Table 3 Air pollutants measured during the Hazelwood mine fire

Air pollutant	Air quality guideline[1]
$PM_{2.5}$	25 µg m^{-3} (24-h) 8 µg m^{-3} (annual)
PM_{10}	50 µg m^{-3} (24-h)
Carbon monoxide	9 ppm (8-h)
Ozone	0.10 ppm (1-h) 0.08 ppm (4-h)
NO_2	0.12 ppm (1-h) 0.03 ppm (annual)
SO_2	0.20 ppm (1-h) 0.08 ppm (24-h) 0.02 ppm (annual)
VOCS	
Benzene	0.003 ppm (annual)
Toluene	1 ppm (24-h) 0.1 ppm (annual)
Xylenes	0.25 ppm (24-h) 0.2 ppm (annual)
Formaldehyde	0.04 ppm (24-h)
PAHs	
Benzo(a)pyrene	0.3 ng m^{-3} (annual)
Dioxins	TEQ 0.3 pg m^{-3}

[1] National Environment Protection (Ambient Air Quality) Measure and National Environment Protection (Air Toxics) Measure

[4] Latrobe Valley Coal Fires Carbon Monoxide Response Protocol Department of Health (Version 1.0) 27 February 2014

Table 4 Air quality categories for PM2.5 (rolling 24-hour and one-hour averages) and visibility.

Air quality categories	$PM_{2.5}$ (24 hour) µg/m³	$PM_{2.5}$ (1 hour) µg/m³	Visibility (by observers)
Low	0–8	0–27	>20 km
Moderate	9–25	28–62	10–20 km
Unhealthy for sensitive groups	26–39	63–97	5–10 km
Unhealthy all	40–106	98–248	2–5 km
Very unhealthy all	107–177	249–370	1.5–2 km
Hazardous high	>177	>370	1–1.5 km
Hazardous extreme	>250		0.5–1 km

Table 5 Table Emergency community exposure guidelines for CO.

Description of exposure period for monitoring CO levels	AEGL 1	AEGL-2	AEGL 3
8 hours	Nil	27 ppm	130 ppm
4 hours	Nil	33 ppm	150 ppm
1 hour	Nil	83 ppm	330 ppm
30 mins	Nil	150 ppm	600 ppm
10 mins	Nil	420 ppm	1700 ppm

5.1 Air quality measurements

Continuous measurements of criteria pollutants (PM, CO, O_3, NO_2 and SO_2) were conducted at three air monitoring stations during the Hazelwood mine fire, i.e. Morwell South AMS, Morwell East AMS and Traralgon AMS. As shown in Figure 6, monitoring of criteria pollutants in Morwell did not start until 3 to 10 days after the fire. As a result, peak concentrations observed during the initial part of the fire have not been measured. The reason for this delay is that the Morwell South station was new and specifically established to monitor the mine fire smoke, and the Morwell East station had been recently closed and was re-established for the fire. Because of the complex instruments in these stations some monitoring equipment may need several days to become operational.

5.1.1 Particulate matter

The hourly $PM_{2.5}$ (particulate matter with an aerodynamic diameter of 2.5 µm) concentrations measured during the Hazelwood mine fire are shown in Figure 8. Highest $PM_{2.5}$ concentrations were observed at Morwell South AMS with a maximum hourly $PM_{2.5}$ concentration of 1349 µg m^{-3}. $PM_{2.5}$ concentrations were particularly high in February with a significant decrease during March as the fire abated (Table 6). $PM_{2.5}$ concentrations at Morwell East AMS and Traralgon AMS were significantly lower than those measured at Morwell South, clearly shown in the frequency distribution in Figure 9. While for example Morwell South AMS recorded levels exceeding $PM_{2.5}$ concentrations of 75 µg m^{-3} and 250 µg m^{-3} for 50% and ~30% of the time in February, only ~20% and 5% of hourly $PM_{2.5}$ concentrations exceeded 75 µg m^{-3} at Morwell East AMS and Traralgon AMS respectively, while less than 1% were above 250 µg m^{-3} at Morwell East AMS. The reasons for this are essentially due to the distance from the fire (e.g. Morwell South ~0.5km, Morwell East ~3km, Traralgon ~13km).

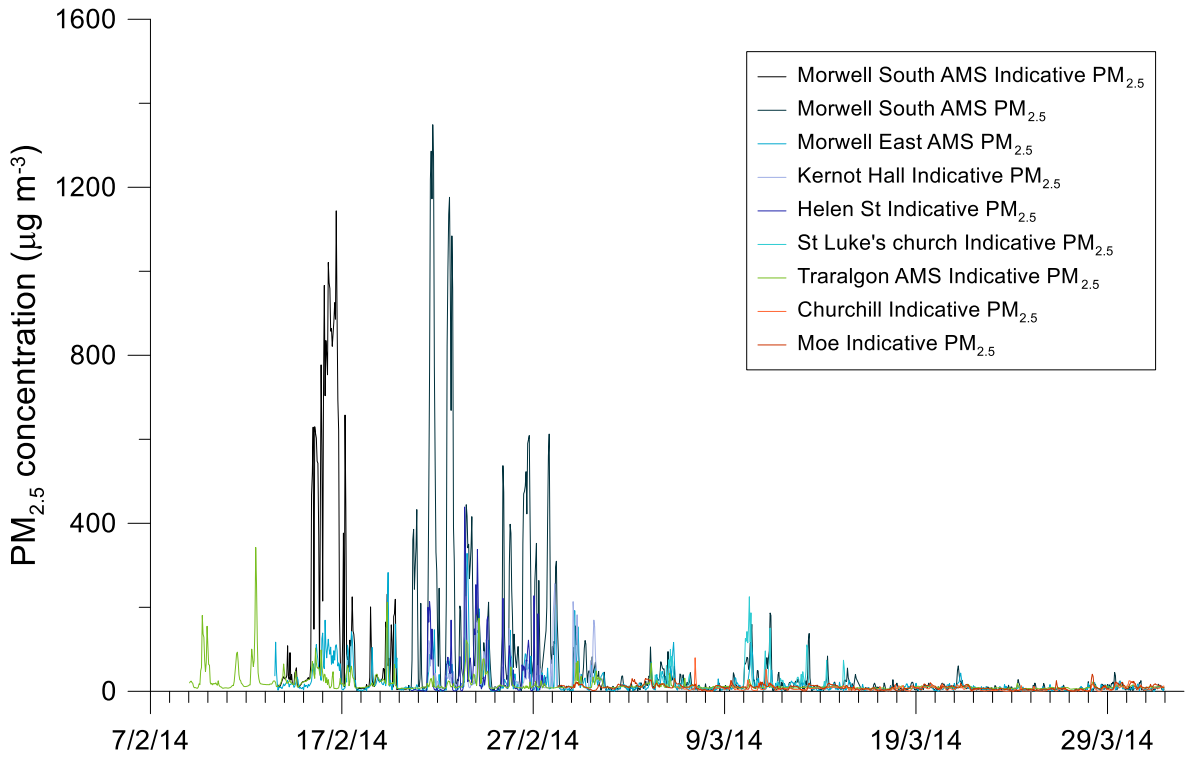

Figure 8 Hourly $PM_{2.5}$ concentrations measured during the Hazelwood mine fire

Table 6 $PM_{2.5}$ concentrations measured between February and November 2014 at Morwell South AMS, Morwell East AMS and Traralgon AMS. Data show monthly average ± stdev, monthly median, hourly maximum and daily maximum $PM_{2.5}$ concentrations in µg m^{-3}.

	Morwell South AMS				Morwell East AMS				Traralgon AMS			
	Ave ± stdev	Median	Hourly max	Daily max	Ave ± stdev	Median	Hourly max	Daily max	Ave ± stdev	Median	Hourly max	Daily max
Feb 2014	206.2 ± 194.5	128.2	1349	731	37.5 ± 21.7	32.3	328	87.8	25.3 ± 15.8	19.9	343	65.6
Mar 2014	16.9 ± 15.3	10.2	187	70.3	11.7 ± 9.3	8.4	192	41.2	10.6 ± 3.6	10.0	72.0	20.9
Apr 2014	7.2 ± 3.3	6.2	34.1	15.6	6.3 ± 3.7	5.6	34.1	12.3	7.1 ± 3.6	7.0	37.0	12.4
May 2014	8.7 ± 4.5	7.5	63.4	22.6	10.0 ± 5.7	8.3	162	23.2	11.2 ± 7.2	9.0	103	33.6
Jun 2014	6.1 ± 3.0	5.8	25.0	12.5	6.4 ± 6.8	5.1	55.4	17.2	8.6 ± 4.2	8.1	60.2	19.4
Jul 2014	5.7 ± 2.6	5.3	35.3	10.6	6.7 ± 3.5	7.0	35.0	14.7	7.8 ± 3.5	6.9	40.4	14.9
Aug 2014	6.8 ± 2.2	6.3	28.1	11.6	7.4 ± 2.8	7.2	32.6	14.5	8.3 ± 3.7	7.2	40.1	15.4
Sep 2014	6.0 ± 2.0	5.9	27.6	10.1	6.2 ± 2.3	6.1	145	11.3	6.9 ± 2.1	6.8	30.7	11.8
Oct 2014	6.3 ± 2.2	5.7	26.7	11.6	6.1 ± 2.5	6.3	25.0	11.7	6.6 ± 1.7	6.3	19.4	10.4
Nov 2014	6.5 ± 2.6	6.7	24.4	14.1	6.1 ± 2.8	5.9	24.0	11.5	6.1 ± 2.2	5.9	16.6	10.5

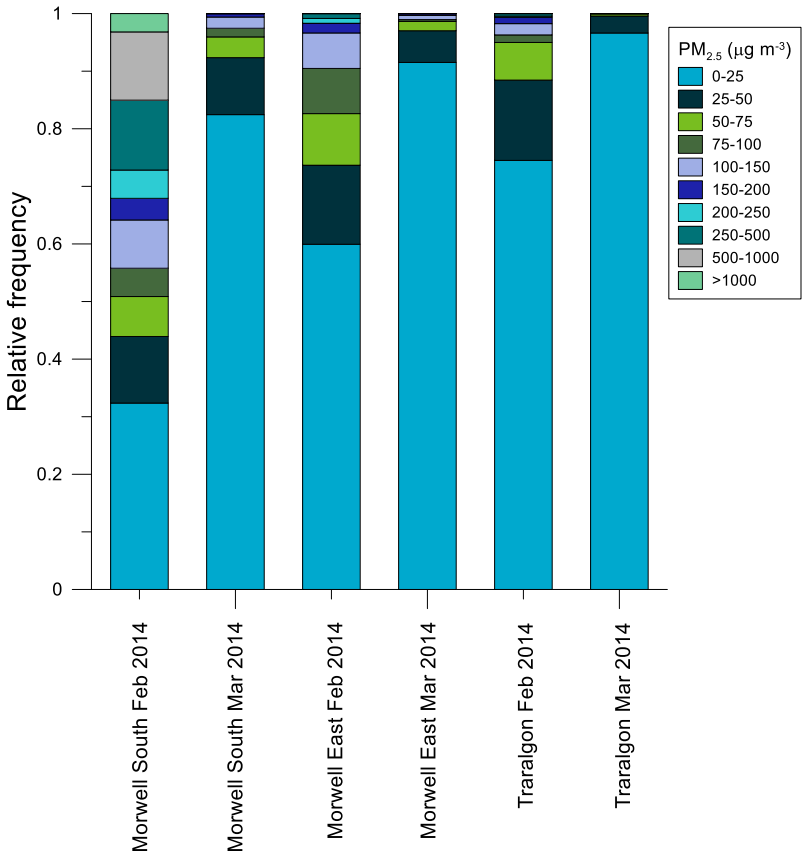

Figure 9 Frequency distribution of hourly $PM_{2.5}$ concentrations during the Hazelwood mine fire

The significant spatial variability in pollutant concentrations was also clearly visible in the instantaneous $PM_{2.5}$ levels measured by the TravelBLANkET on 22 February 2014. The TravelBLANkET is the mobile Baseline Air Network of EPA Tasmania that was used from 20 February 2014 and captured smoke levels while driving around Morwell. The height and colour in Figure 10 represent concentrations of $PM_{2.5}$, with red markers indicating higher concentrations and blue markers indicating lower concentrations. Many studies have shown that the DustTrak systematically overestimates PM concentrations relative to gravimetric methods (e.g. *(Heal et al. 2000; Kingham et al. 2006)*), however these papers also suggest the overestimation can be corrected using a site specific calibration factor, which significantly reduces uncertainty. The TravelBLANkET system was calibrated using the procedure outlined in the BLANkET Technical Report 31 available at http://epa.tas.gov.au/Documents/BTR_31_overview_OA_compressed_size.pdf.

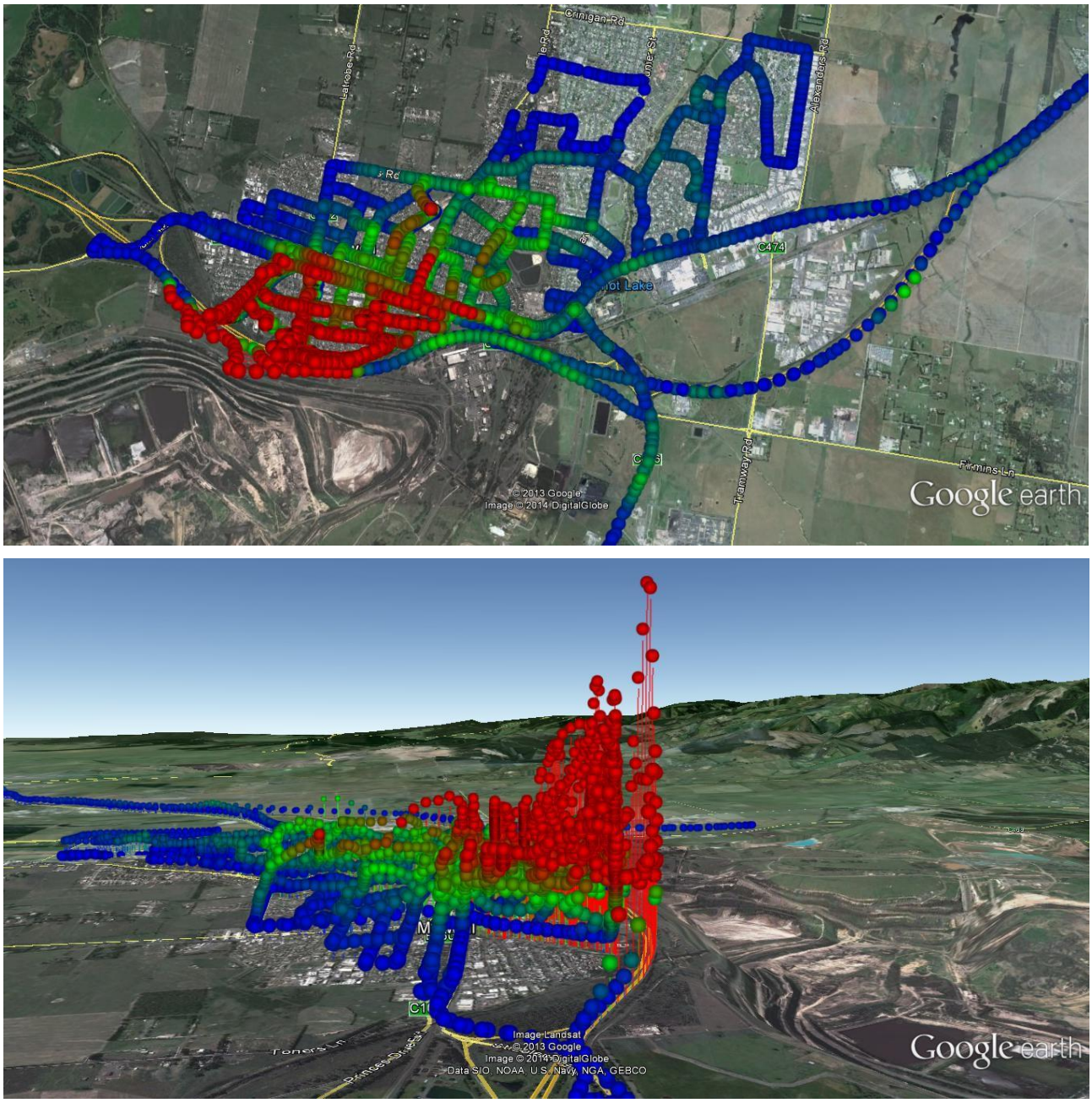

Figure 10 Instantaneous $PM_{2.5}$ levels measured by the TravelBLANkET on 22 February 2014 (top: aerial view; bottom: looking east). Concentration levels of 0-100 µg m^{-3} (blue), 100-250 µg m^{-3} (green) and >250 µg m^{-3} (red).

$PM_{2.5}$ concentrations were highly variable during the day. Elevated concentrations in Morwell occurred mainly in the afternoon/early evening and were strongly associated with south-westerly winds (Figure 11).

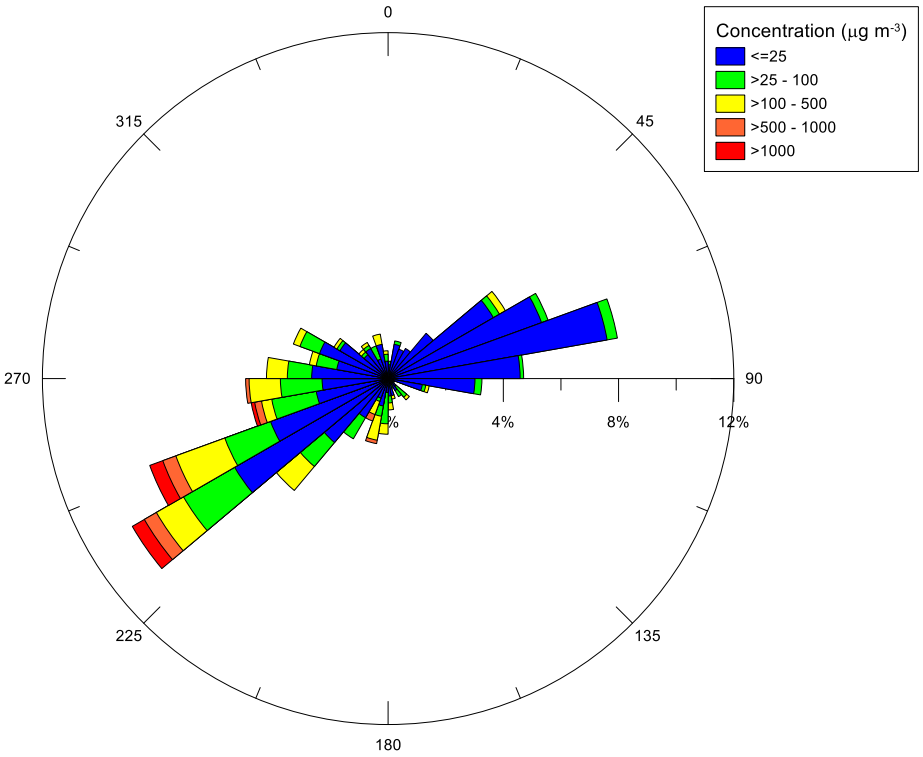

Figure 11 Pollution roses of $PM_{2.5}$ measured between 21 February and 31 March 2014 at Morwell South AMS

The daily $PM_{2.5}$ concentrations are shown in Figure 12. Maximum daily $PM_{2.5}$ concentration reached 731 µg m^{-3}, approximately 30 times higher than the 24-hour advisory National Environment Protection Measure (NEPM) of 25 µg m^{-3} and 3 times greater than the community SAQH standard for PM2.5 category of Hazardous Extreme (Table 4). $PM_{2.5}$ concentrations were significantly higher in Morwell South AMS, but exceedances of the 24-hour advisory NEPM were also observed in Traralgon AMS (8 days), located approximately 13 km from the fire, where a maximum daily $PM_{2.5}$ concentration of 65.6 µg m^{-3} was recorded when the concentrations were in the Unhealthy All category (Table 4).

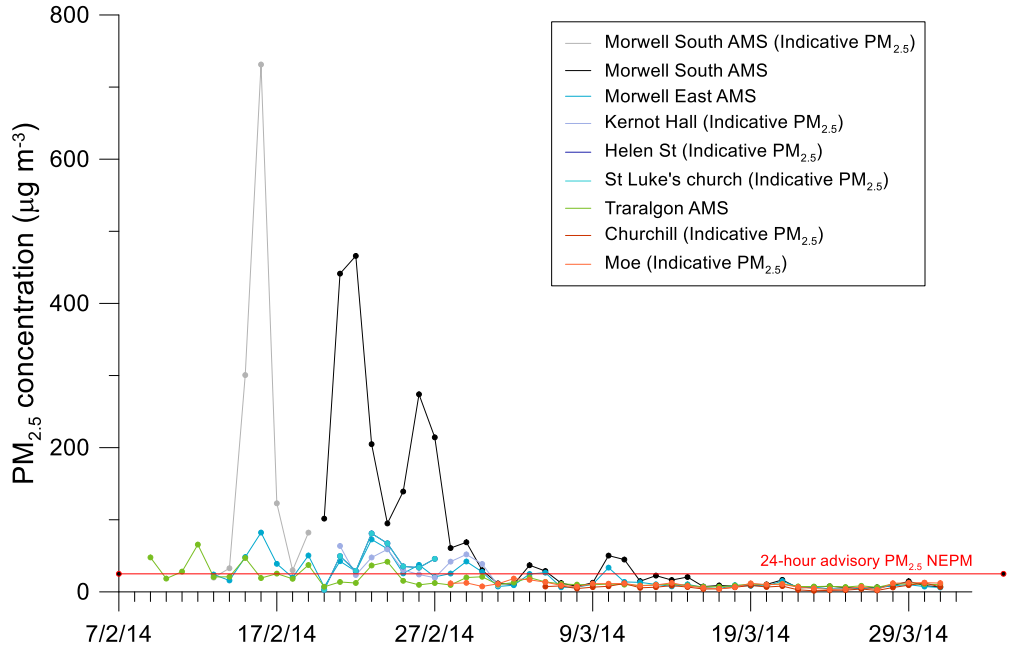

Figure 12 Daily $PM_{2.5}$ concentrations measured during the Hazelwood mine fire

Measurements of $PM_{2.5}$ at Morwell South started on 13 February 2014, four days after the start of the fire. Considering the elevated $PM_{2.5}$ concentrations measured at Traralgon on 9 and 12 February, it is expected that higher concentrations were likely to have occurred between 9 and 12 February at Morwell South.

5.1.2 Carbon monoxide

Figure 13 shows the hourly CO concentrations measured at various locations in Morwell. Elevated CO levels were primarily observed in the early stages of the fire. The maximum 8-hour averaged CO concentration was measured at 33 ppm in Morwell South, approximately 4 times higher than the NEPM standard and slightly higer than the AEGL-2 graduated guideline for CO specified in Table 5. No exceedances of the 8-hour NEPM standard for CO were observed at either Morwell East AMS (max=2.9ppm) or Traralgon AMS (max=0.7ppm).

Elevated CO levels were measured between 15-22 February and 26 February and significantly decreased in March (Table 7). Measurements of CO in Morwell started approximately 5 days after the fire started and concentrations may have been higher at the start of the fire.

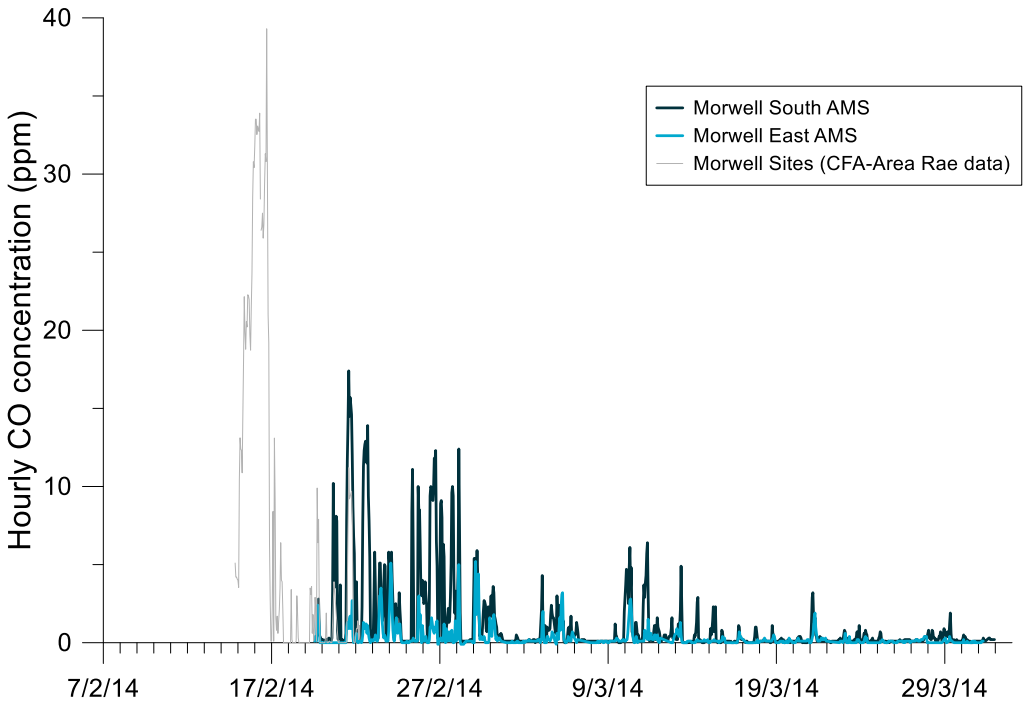

Figure 13 Hourly CO concentrations measured during the Hazelwood mine fire

The highest impact was observed in Morwell South AMS with elevated concentrations occurring primarily late afternoon/early evening and under south-westerly winds (Figure 14).

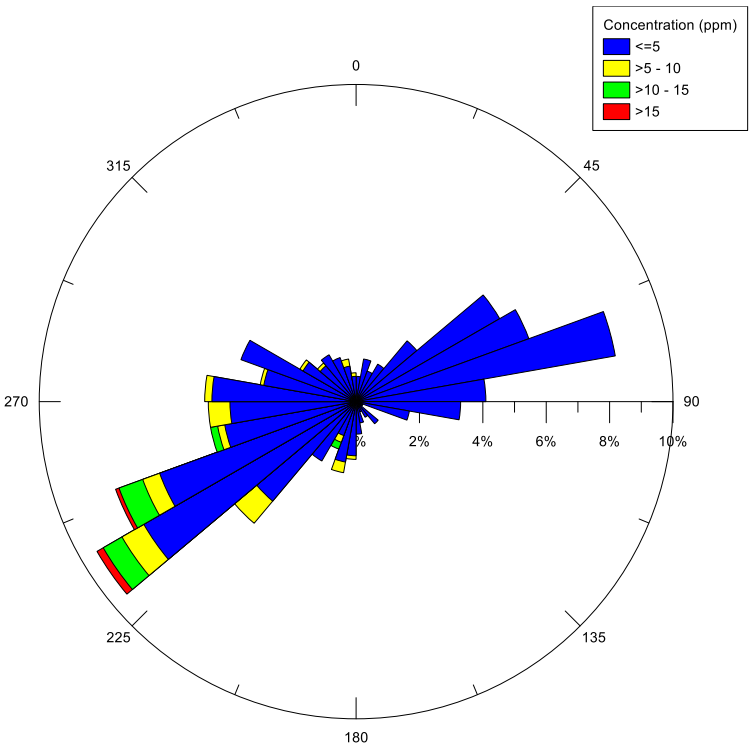

Figure 14 Pollution roses of CO measured between 21 February and 31 March 2014 at Morwell South AMS

Table 7 CO concentrations measured between February and November 2014 at Morwell South AMS, Morwell East AMS and Traralgon AMS. Data show monthly average ± stdev, median and hourly maximum CO concentrations in ppm.

	Morwell South AMS			Morwell East AMS			Traralgon AMS		
	Ave ± stdev	Median	Hourly max	Ave ± stdev	Median	Hourly max	Ave ± stdev	Median	Hourly max
Feb 2014	3.65 ± 4.31	1.90	17.4	0.54 ± 0.90	0.10	5.1	NM	NM	NM
Mar 2014	0.50 ± 0.94	0.10	6.4	0.17 ± 0.50	0.10	5.2	0.18 ± 0.18	0.10	1.6
Apr 2014	0.17 ± 0.14	0.10	1.3	0.00 ± 0.17	0.00	0.7	0.23 ± 0.23	0.20	1.4
May 2014	0.19 ± 0.14	0.20	1.2	0.01 ± 0.28	0.00	1.2	0.35 ± 0.32	0.30	1.8
Jun 2014	0.19 ± 0.13	0.10	1.0	0.25 ± 0.22	0.20	1.4	0.12 ± 0.25	0.10	1.6
Jul 2014	0.15 ± 0.12	0.10	0.8	0.19 ± 0.22	0.10	1.1	0.29 ± 1.70	0.10	35.9
Aug 2014	0.15 ± 0.09	0.10	0.8	0.17 ± 0.16	0.10	1.0	0.31 ± 1.34	0.10	12.3
Sep 2014	0.14 ± 0.14	0.10	1.0	0.14 ± 0.14	0.10	0.7	0.20 ± 0.16	0.20	1.1
Oct 2014	0.16 ± 0.29	0.10	2.1	0.08 ± 0.09	0.10	0.4	0.13 ± 0.12	0.10	0.6
Nov 2014	0.09 ± 0.03	0.10	0.2	0.06 ± 0.08	0.10	0.4	0.12 ± 0.14	0.10	0.7

NM: Not measured

5.1.3 Other criteria pollutants

Hourly concentrations of O_3, NO_2 and SO_2 are shown in Figure 15. All three criteria pollutants remained within NEPM air quality guidelines.

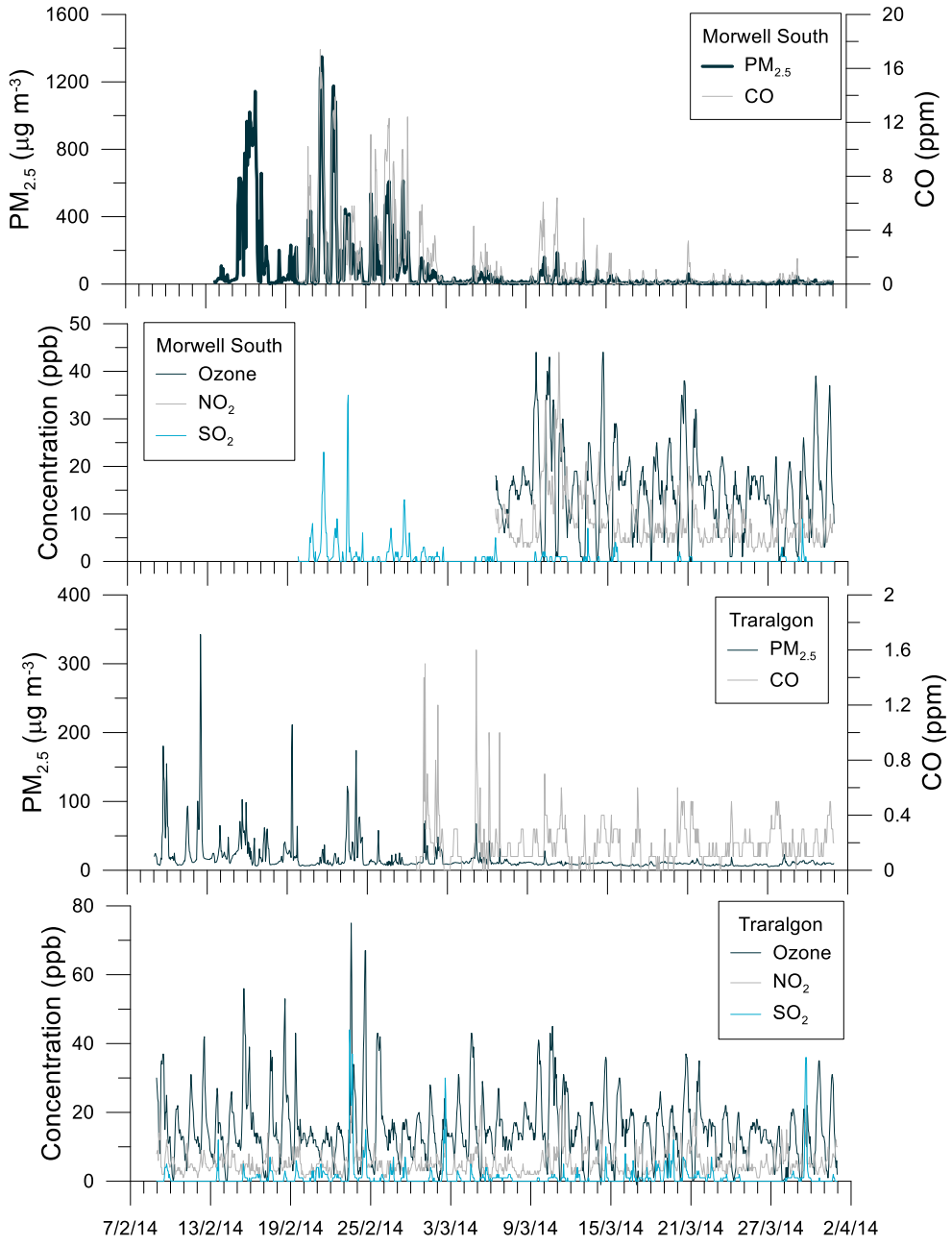

Figure 15 Time series of criteria pollutants measured at Morwell South AMS and Traralgon AMS

5.2 Targeted monitoring

Monitoring of air toxics (e.g. VOCs, carbonyls, PAHs, dioxins and metals) started on 26 February, when particle and CO concentrations had already considerably subsided. Therefore it is highly likely that concentrations would have been higher during the initial phase of the fire.

5.2.1 Volatile organic compounds

24-hour canister samples were collected in February/March at three locations, Morwell South AMS, Morwell East AMS and Maryvale Crescent Preschool. The time series of the 24-hour concentrations of benzene and toluene are shown in Figures 16 and 17. As for PM and CO, concentrations at Morwell South AMS were higher than those observed at Morwell East AMS. Benzene was the only measured VOC that exceeded NEPM air toxic guidelines.

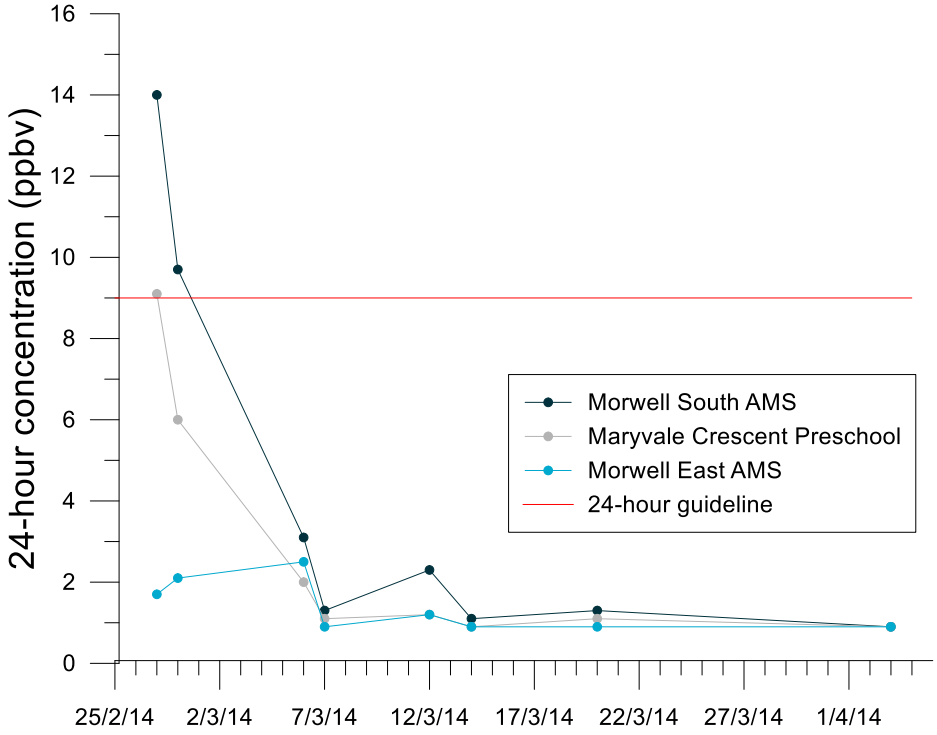

Figure 16 Time series of 24-hour concentrations of benzene at Morwell South AMS, Maryvale Crescent Preschool (MCP) and Morwell East AMS

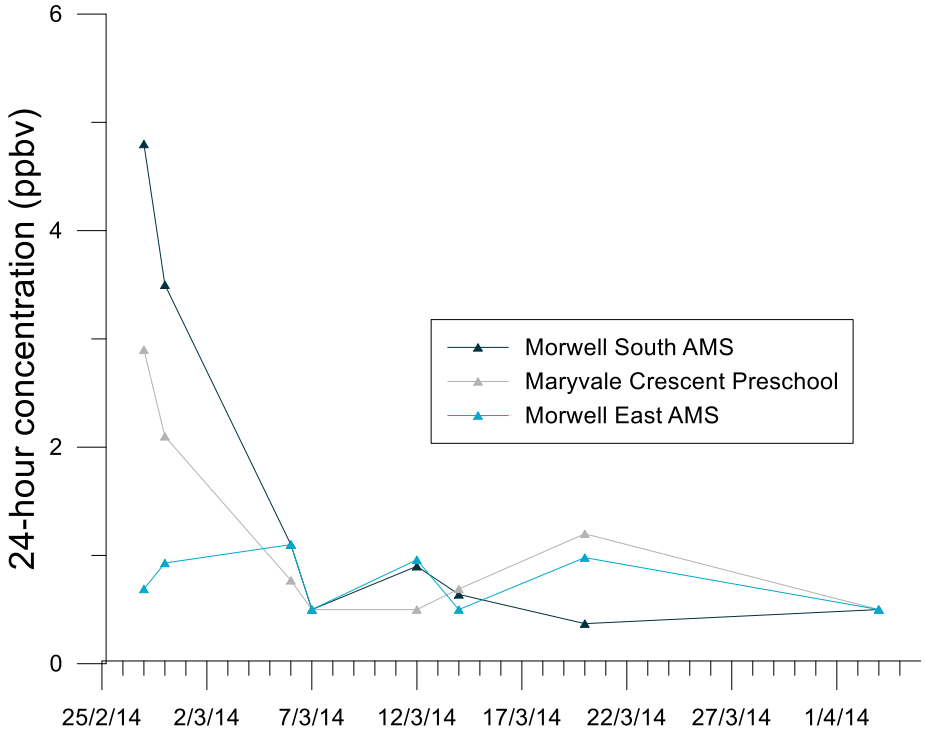

Figure 17 Time series of 24-hour concentrations of toluene at Morwell South AMS, Maryvale Crescent Preschool (MCP) and Morwell East AMS

The weekly time series of benzene and toluene measured at Morwell South AMS is summarised in Figure 18 and clearly shows that concentrations were elevated during the Hazelwood mine fire and decreased significantly once the fire was declared under control. It's also interesting to note that benzene concentrations were higher than toluene concentrations during the Hazelwood mine fire, while toluene concentrations exceeded benzene concentrations for the remaining period.

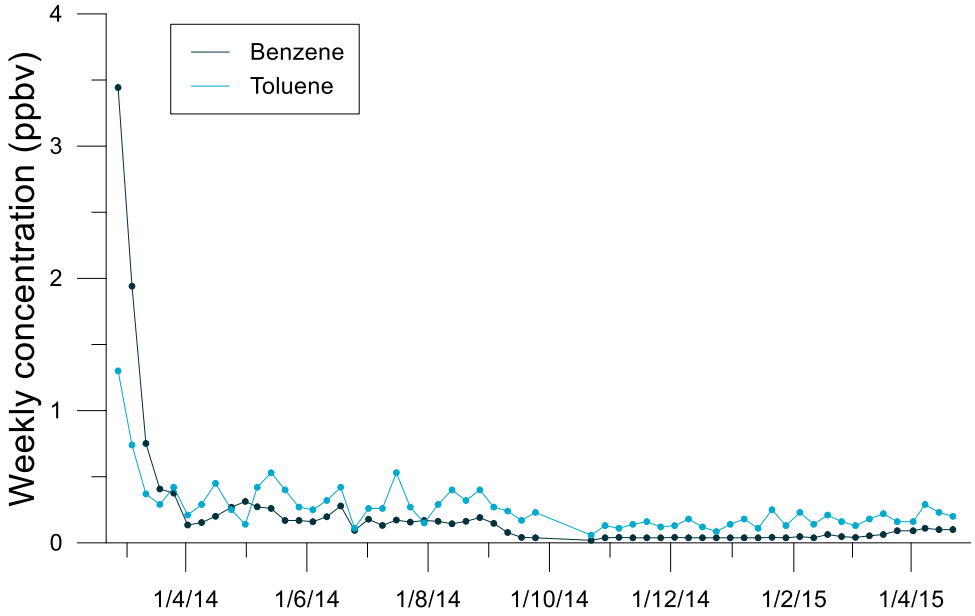

Figure 18 Time series of weekly ambient concentrations (in ppb) of benzene and toluene measured at Morwell AMS

Table 8 provides the average weekly concentrations of major VOCs measured during the Hazelwood mine fire (February-March 2014) in comparison to a background period (February-March 2015) and shows higher

concentrations of aliphatic and aromatic compounds during the Hazelwood mine fire. The annual average concentration was calculated from measurements made between February 2014 and February 2015.

Table 8 Weekly averaged concentrations (in ppb) of selected volatile organic compounds: Annual average (Feb 2014-Feb 2015), average during the Hazelwood mine fire (incident Feb/Mar 2014) and during a background period (recovery Feb/Mar 2015).

Compound	Morwell South			Maryvale Preschool			Morwell East			Annual guideline NEPM Air Toxics
	Annual average	Incident	Recovery	Annual average	Incident	Recovery	Annual average	Incident	Recovery	
Benzene	0.24	1.38	0.059	0.19	1.05	0.052	0.18	0.51	0.076	3
Ethylbenzene	0.064	0.093	0.033	0.051	0.050	0.033	0.068	0.041	0.038	60
Toluene	0.28	0.62	0.17	0.21	0.45	0.15	0.33	0.36	0.25	100
Xylenes	0.21	0.31	0.11	0.17	0.20	0.091	0.24	0.17	0.16	200
n-Hexane	0.12	0.21	0.075	0.082	0.19	0.060	0.10	0.11	0.088	n/a
n-Heptane	0.055	0.11	0.041	0.046	0.085	0.041	0.044	0.056	0.041	n/a
n-Octane	0.044	0.077	0.040	0.042	0.060	0.040	0.041	0.044	0.040	n/a
n-Decane	0.066	0.068	0.083	0.048	0.058	0.065	0.044	0.045	0.059	n/a
2-Methylpentane	0.11	0.20	0.13	0.075	0.14	0.072	0.11	0.15	0.11	n/a
Methylethylketone	0.049	0.057	0.043	0.047	0.056	0.042	0.049	0.050	0.042	900

24-hour measurements of formaldehyde were also made during the Hazelwood mine fire (Table 9). Concentrations were highest in February at Morwell South AMS, but never exceeded the 24-hour air quality NEPM Air Toxics guideline of 40 ppb. No formaldehyde measurements were made after the Hazelwood mine fire.

The measured levels compare with an average background concentration of around 0.3 ppb and a nominal 1-20 ppb found in urban environments (http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=219&tid=39).

Table 9 24-hour measurements of formaldehyde (in ppbv) at Morwell South AMS, Maryvale Crescent Preschool, Morwell East AMS and Morwell South CSIRO site

Date	Morwell South	Maryvale Crescent Preschool	Morwell East	Morwell South (CSIRO)
26/02/14	7.58	6.36	2.69	
27/02/14	5.38	3.91	2.28	
6/03/14	2.61	2.37	2.04	
7/03/14	2.77	2.85	2.45	0.57
8/03/14	1.79	1.88	1.55	
11/03/14				1.39
12/03/14				1.65
14/03/14	1.39	1.63	1.39	1.68
16/03/14				0.97
19/03/14				0.95
21/03/14	3.10	2.85	3.02	

5.2.2 PAHs and dioxins

Figure 19 shows the 24-hour PAH concentrations collected on PM_{10} filters between 26 February and 20 March. A significant decrease in PAH concentrations was observed over time in particular between February and March. Major particle-bound PAHs included chrysene, benzo(a)anthracene and benzo(e)pyrene, followed by benzo(a)pyrene, benzo(b)fluoranthene and pyrene. Fluorene was an important contributor to total PAH concentrations for samples collected in March.

In March, 2-week PAH samples were collected on both filters and polyurethane foams (PUFs). The results show higher concentrations of semi-volatile PAHs compared to particle-bound PAHs. The major semi-volatile PAHs included naphthalene, phenanthrene and fluorene.

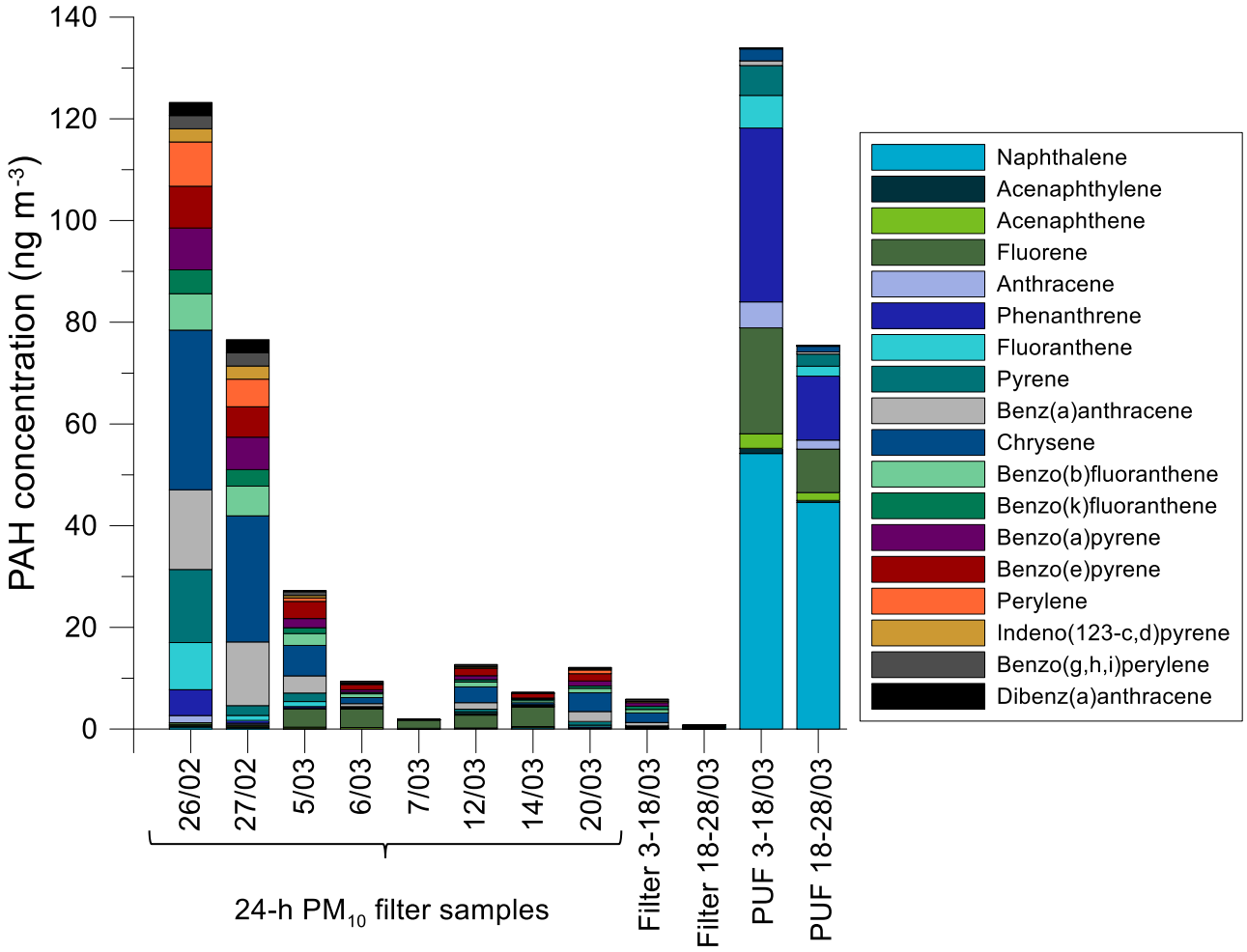

Figure 19 PAH concentrations measured at Morwell South (24-hour PM_{10} filter samples collected on 26 Feb, 27 Feb, 5 March, 6 March, 7 March, 12 March, 14 March and 20 March at Morwell South AMS; TSP filter samples and PUF samples from 3-18 March and 18-28 March collected at Morwell South CSIRO site)

Figure 20 shows the toxic equivalency (TEQ) of dioxins and dioxins-like compounds of 24-hour PM_{10} samples collected at Morwell South AMS using a High-Volume sampler and of total suspended particle filter and PUF samples collected at Morwell South CSIRO site over a 10-14 days period. The presented TEQ is based on toxic equivalency factors (TEFs) set by the World Health Organisation (WHO)-International Programme on Chemical Safety in 2005. The TEF expresses the toxicity of dioxins, furans and PCBs in terms of the most toxic dioxin, e.g. 2,3,7,8-TCDD. The TEQ results from the product of the concentration and individual TEF values of each congener.

Similar to PAHs there is a significant decrease in concentrations between the samples collected in February and March. The particle congeners were dominated by OCDD (Octachlorodibenzodioxin), which has a TEF of 0.0003, while the semi-volatile congeners were dominated by TCDF (2,3,7,8-tetrachlorodibenzofuran) and TCDD (2,3,7,8-Tetrachlorodibenzo-p-dioxin), which have a TEF of 0.1 and 1 respectively.

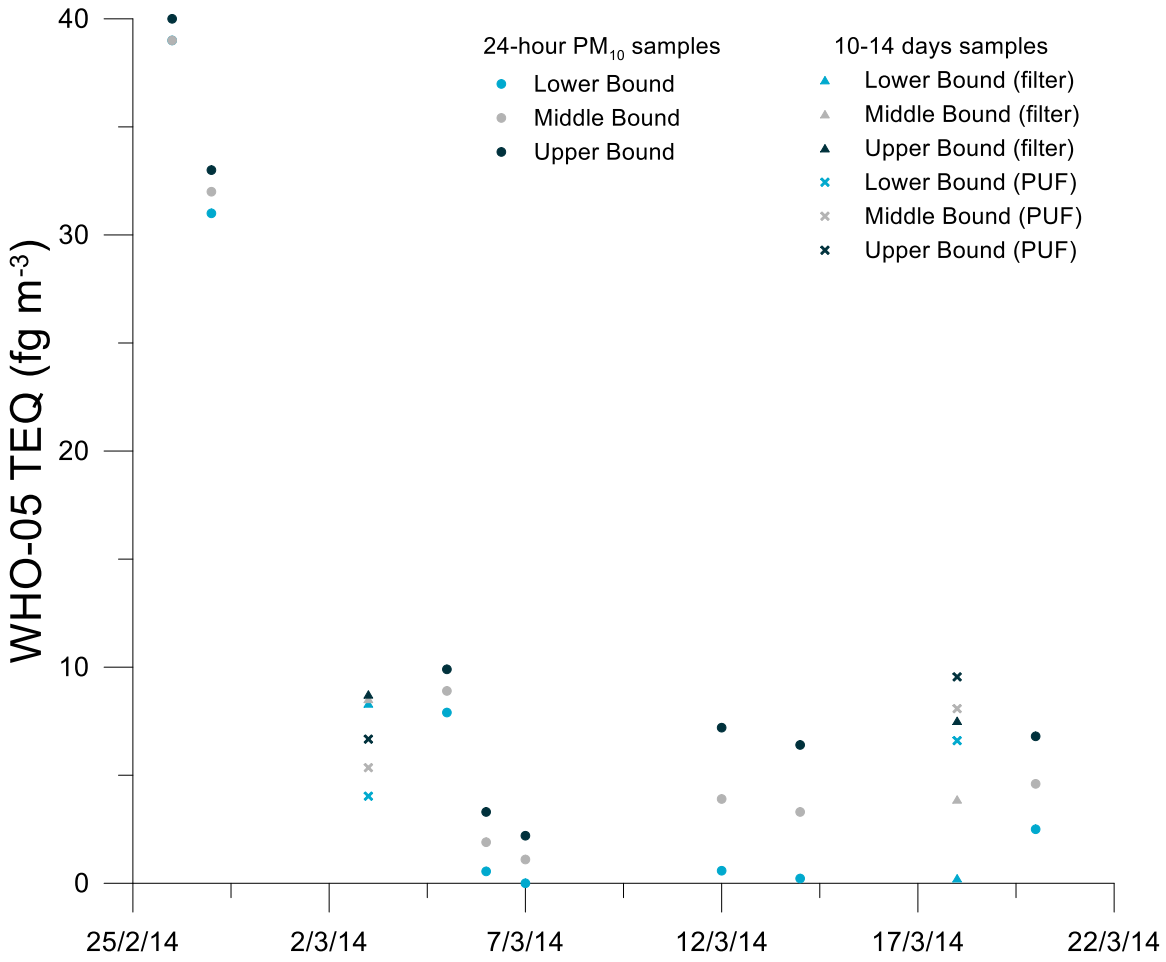

Figure 20 Time series of the TEQ of dioxins and dioxins-like compounds measured at Morwell South AMS (24-hour PM_{10} samples) and at Morwell South CSIRO site (10-14 day Filter and PUF samples). Lower Bound, Middle Bound and Upper Bound TEQ defines all congener values reported below the LOD as equal to zero, as equal to half the LOD and as equal to the LOD, respectively.

5.2.3 Metals and inorganic compounds

Measurements of metals and inorganics were performed on PM_{10} filter samples collected at Morwell South AMS over a 24-hour period on a one-day in-six cycle. The major compounds identified included calcium (Ca), sulphur (S), magnesium (Mg), silicon (Si), sodium (Na), iron (Fe) and aluminium (Al) followed by titanium (Ti), potassium (K), strontium (Sr), zinc (Zn) and manganese (Mn). The time series of the 24-hour measurements during February and March 2014 is shown in Figure 21. It should be noted that due to different analysis techniques magnesium and sodium were only measured on 8 days. Concentrations all remained within guidelines defined by the US Texas Commission on Environmental Quality (TCEQ) that were used in the EPA Victoria Hazelwood Recovery program air quality assessment (EPAV 2015) (Table 10).

Figure 21 also shows the relative proportions of the major elements measured on 26 February 2014 (representative of the incident period) and on 27 February 2015 (representative of the recovery period) in comparison to the relative proportions of these elements in Victorian brown coal *(Perry et al. 2009)*. Relative concentrations measured during the Hazelwood mine fire are consistent with those measured in Victorian brown coal.

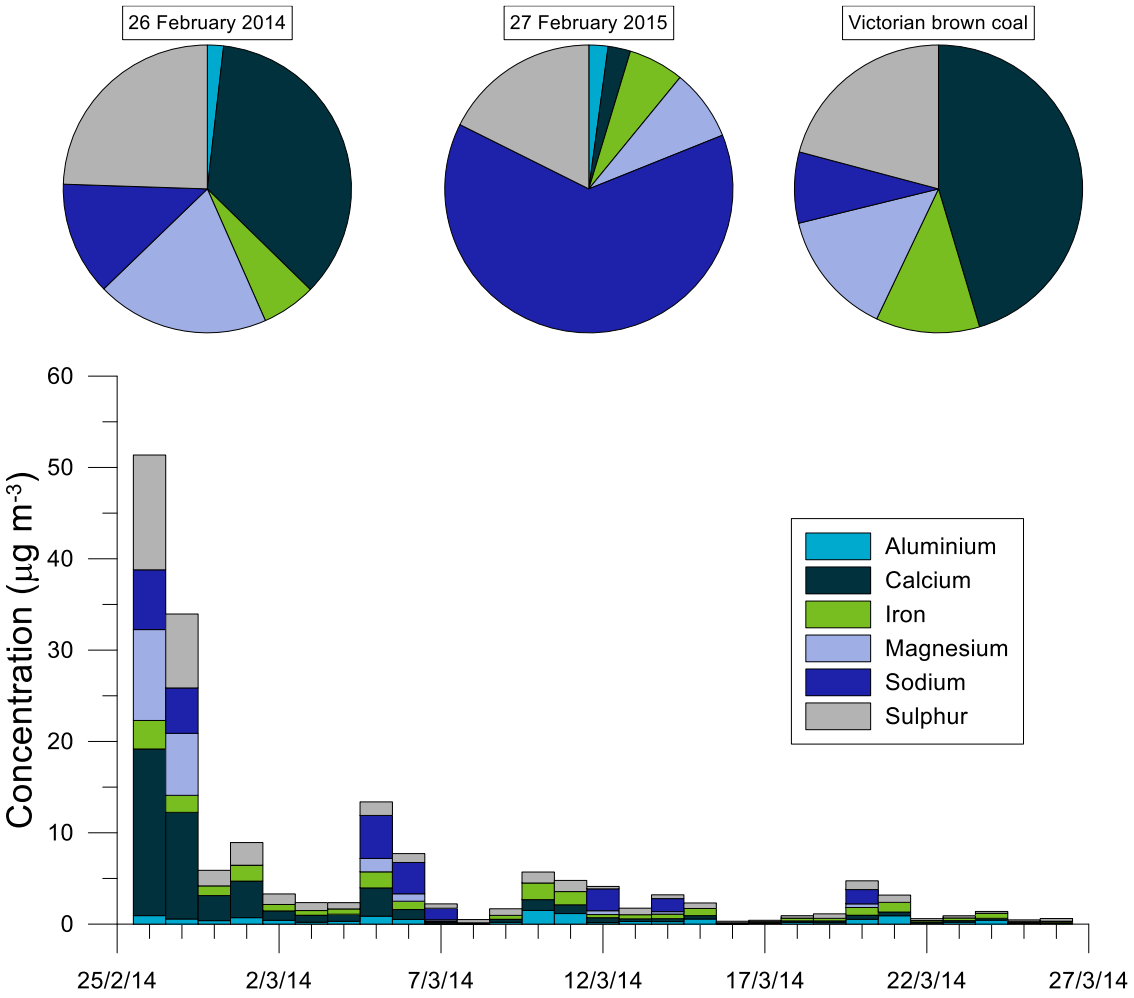

Figure 21 Time series of 24-hour concentrations of major elements measured on PM_{10} filters at Morwell South AMS (bottom); relative proportions of major elements measured on PM_{10} filters on 26 February 2014 and 27 February 2015 and in Victorian brown coal

Table 10 Averaged and 24-hour maximum concentrations (in µg m^{-3}) of inorganic compounds measured at Morwell South AMS

Compound	Annual average (02/14 – 02/15)	Incident (24-h max) (Feb-Mar2014)	Recovery (Feb-Mar2015)	24-hr guideline (µg/m^3) TCEQ	Annual guideline (µg/m^3) TCEQ
Aluminium	0.10	0.35 (0.93)	0.096	38.2	5
Arsenic	0.0005	0.0004 (0.001)	0.0003	1.28	0.21
Cadmium	0.00003	0.00002 (0.00004)	0.00003	0.19	0.046
Calcium	0.73	4.43 (18.2)	0.11	95.5	8.2
Chromium	0.0004	0.0005 (0.0011)	0.0013	0.78	0.041
Cobalt	0.0004	0.0014 (0.005)	0.0001	0.38	0.048
Copper	0.0011	0.0008 (0.0024)	0.0014	19.1	2.6
Iron	0.29	1.09 (3.12)	0.24	95.5	11.4
Lead	0.0011	0.0006 (0.0011)	0.0007	9.55	0.15
Magnesium	0.50	2.53 (9.95)	0.21	95.5	
Manganese	0.0054	0.022 (0.065)	0.0039	3.82	0.45
Nickel	0.0006	0.0011 (0.0026)	0.0010	1.13	0.14
Potassium	0.075	0.16 (0.26)	0.081	38.2	3.2
Selenium	0.0002	0.0006 (0.0015)	0.0001	3.82	0.65
Silicon[1]		1.91 (6.89)			
Sodium	1.36	3.29 (6.55)	1.46	19.1	0.94
Strontium	0.010	0.062 (0.26)	0.0016	38.2	7.2
Sulphur	0.96	3.07 (12.6)	0.47	95.5	6.6
Titanium	0.010	0.027 (0.060)	0.0094	95.5	9.8
Vanadium	0.0005	0.0006 (0.0016	0.0003	0.96	0.1
Zinc	0.0010	0.024 (0.087)	0.005	38.2	5.35

[1] Only measured during the Hazelwood mine fire

6 Discussion

The Hazelwood mine fire burned for 45 days, during which time the population was periodically exposed to elevated levels of air pollutants. The event was unprecedented not only due to the intensity of the event, but also due to the close proximity of the population to the Hazelwood mine fire. While bushfires can have a major impact on air quality (Figure 1), the primary pollutant of concern for population exposures is particulate matter. Most research studies have found that levels of fine particulate matter were consistently elevated downwind of bushfires, while levels of other pollutants varied little or showed increases that were much lower than NEPM air quality standards or guidelines *(Reisen and Brown 2006)*. This is likely due to dispersion in buoyant plumes and dilution during transport when clean air is entrained in the smoke plume resulting in lower concentrations downwind where populations are exposed.

In the case of the Hazelwood mine fire, there was no immediate fire threat to the Morwell community which meant that population exposure to smoke was at much closer proximity to the fire front than is usually the case for bushfires.

The air quality data showed that the smoke impact was localised with higher pollutant levels measured in Morwell South (approximately 500 m from the fire) than in Morwell East, located approximately 3 km from the fire. The spatial variability in particulate levels was also highlighted by the TravelBLANkET measurements. The air quality was especially impacted in February, with a significant decrease in pollutant concentrations observed in March.

Major air pollutants of concern included PM, CO, benzene and PAHs due to the elevated concentrations measured during the Hazelwood mine fire and will be further discussed below.

6.1 Particulate matter

During the Hazelwood mine fire $PM_{2.5}$ concentrations were very high and exceeded NEPM air quality standards on multiple occasions. While PM levels were elevated during the Hazelwood mine fire, the long-term air monitoring in Traralgon showed that this was not a unique event that caused elevated particle levels. As shown in Figure 1, elevated particle concentrations were previously observed during the 2006/07 Eastern Victorian Great Divide bushfires and during the 2009 bushfires, with higher daily and hourly PM concentrations than those observed in Traralgon AMS during the Hazelwood mine fire.

Since the biggest impact on particle levels was observed in Morwell South, the hourly $PM_{2.5}$ concentrations measured in Morwell South AMS during the Hazelwood mine fire are compared against those measured in Northeast Victoria during the 2006/07 Eastern Victoria Great Divide bushfires (Figure 22). Wangaratta and Ovens are towns located in Northeast Victoria that were severely impacted by the 2006/07 bushfires. In both instances monitoring started a few days after the fire clearly shown by the elevated concentrations at the start of the monitoring periods. Figure 22 shows that both events were of similar duration and magnitude. Analysis of $PM_{2.5}$ concentrations indicates that the impact of the Hazelwood mine fire on ambient particle concentrations was similar to that observed during major bushfires (Table 11). Maximum hourly and daily $PM_{2.5}$ concentrations were slightly higher at Ovens, VIC than at Morwell South AMS. However the number of hours at $PM_{2.5}$ concentrations greater than 250 µg m^{-3} was higher at Morwell South AMS.

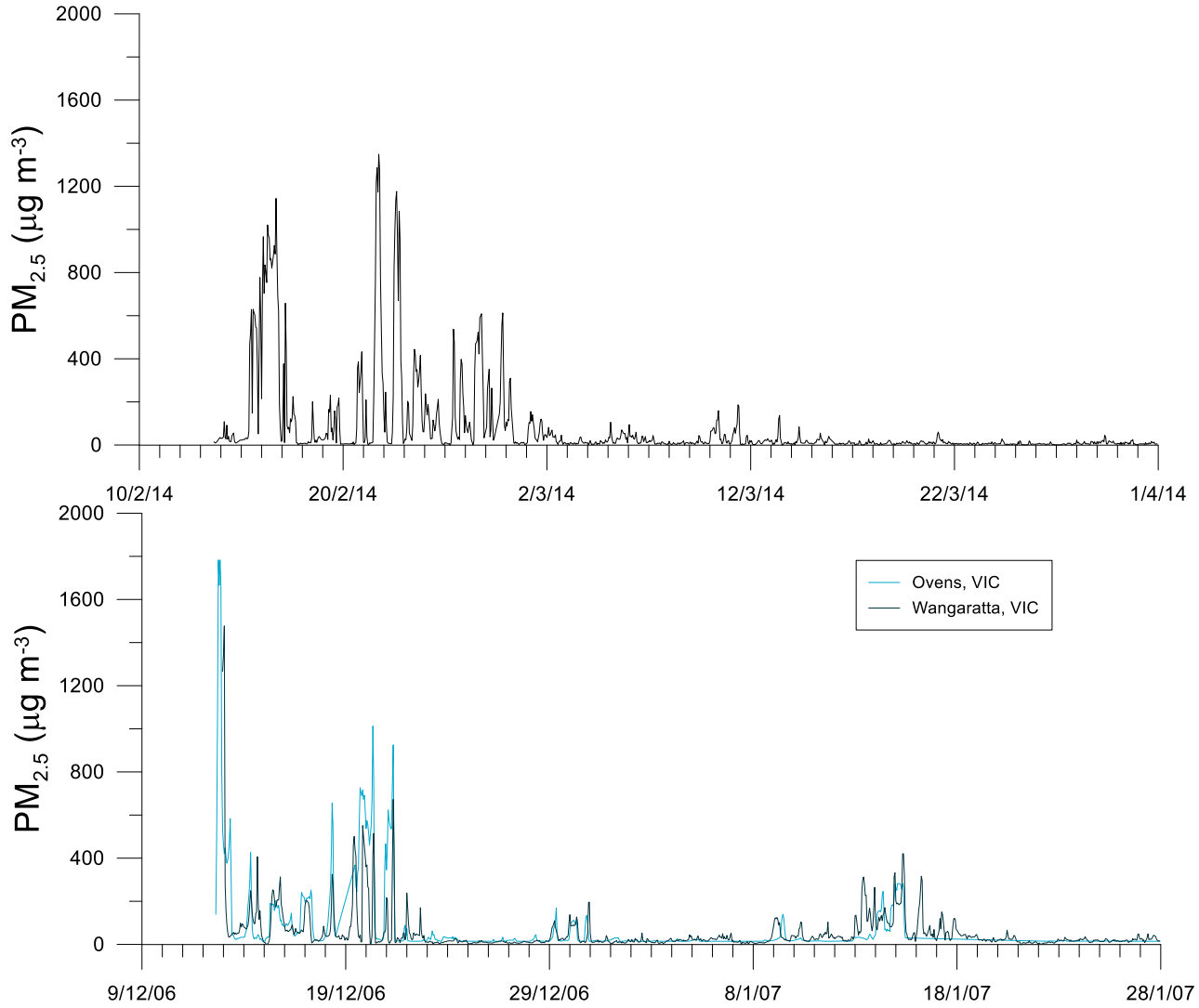

Figure 22 Time series of hourly $PM_{2.5}$ concentrations measured at Morwell South during the Hazelwood mine fire (top panel) and at Ovens, VIC and Wangaratta, VIC during the 2006/07 Eastern Victoria Great Divide bushfires (bottom panel). Measurements at Wangaratta were done by EPA Victoria (http://www.epa.vic.gov.au/~/media/Publications/1187.pdf). $PM_{2.5}$ was measured at Ovens by DustTrak calibrated with site specific gravimetric mass measurements (Reisen et al., 2011b).

Table 11 Comparative results of $PM_{2.5}$ measurements (in µg m^{-3}) collected between 13 February 2014 and 31 March 2014 at Morwell South, Morwell East, Traralgon and Melbourne and between 13 December 2006 and 31 January 2007 at Ovens, VIC and Wangaratta, VIC.

	Morwell South	Morwell East	Traralgon	Melbourne[1]	Ovens, VIC[2]	Wangaratta, VIC[1]
Ave ± stdev (µg m^{-3})	84 ± 196	21 ± 34	14 ± 16	20 ± 13	75 ± 175	54 ± 103
Median (µg m^{-3})	13.6	9.2	9.9	17.7	16.6	22.0
Hourly (min-max)	0 – 1349	0 – 328	5.1 – 211	0.2 – 108	14.5 – 1783	0 – 1477
Daily (min-max)	4.6 - 731	4.2 - 82	6.3 - 47	6.9 - 71	3.1 - 1111	7.8 - 213
# hours>25	351	200	111	277	299	483
# hours>100	170	41	8	4	136	143
# hours>250	94	3	0	0	70	41
# hours>500	52	0	0	0	34	7
# hours>1000	11	0	0	0	6	3
# days>25	21	15	5	8	17	25

[1] EPA Victoria

[2] *Reisen et al. (2011b)*

6.2 Carbon monoxide

One of the major differences between the Hazelwood mine fire and other major bushfire events was the fact that CO concentrations measured within the community were elevated (Table 12). During the event the highest ever 8-hour average CO concentrations measured by EPA Victoria was recorded. In general, concentrations of CO measured in downwind communities during wildfire smoke remain low. During the 2006/07 bushfires which had a significant impact on Melbourne, maximum hourly CO concentrations of 4.5 ppm were measured using infrared absorption spectrometry *(Keywood et al. 2015)*, in comparison to maximum hourly CO concentration of 39 ppm measured in Morwell also measured using infrared absorption spectrometry. At a staging area in Jamieson in Northeast Victoria, hourly concentrations of 17.3 ppm were measured during the 2006/07 bushfires, while CO concentrations on the fire ground were much higher in some instances. Based on a review of the scientific and technical literature, a few studies reported enhancements of CO concentrations above NEPM air quality guidelines resulting from impacts of plumes from wildfires *(Aditama 2000; Kunii et al. 2002; Konovalov et al. 2011)*.

Table 12 Comparative results of hourly carbon monoxide concentrations (in ppm) measured between 19 February 2014 and 31 March 2014 at Morwell South, Morwell East and Melbourne and hourly averaged concentrations measured on the fire ground.

	Average ± stdev	Median	Range (min-max)
Morwell South + CFA locations	2.5 ± 4.7	0.4	0 - 39.3
Morwell East	0.4 ± 0.7	0.1	0 - 5.2
Aspendale[1] (2006/07 fires)	0.73 ± 0.73	0.46	0.06 - 4.5
Melbourne[2] (summer 06/07)	0.2 ± 0.3	0.1	0 - 2.8
Fire ground (Prescribed burns)[3]	9.1	3.9	0.18 – 120
Fire ground (Bushfires)[3]	4.5	3.0	0.1 - 9.4
Staging area (2006/07 bushfires)[4]			0.01-17.3

[1] *Keywood et al. (2015)*
[2] *EPA Victoria*
[3] *Reisen et al. (2011a)* ; work shift average concentrations
[4] *Reisen et al. (2011a)* ; hourly concentrations

6.3 Air toxics

Measurements of air toxics only commenced on 26 February 2014, when concentrations of CO and $PM_{2.5}$ had already considerably subsided. As a result reported peak concentrations are likely not to be representative of the fire incident period.

6.3.1 Volatile organic compounds

Table 13 shows the weekly averaged concentrations of benzene and toluene measured at Morwell South AMS during the Hazelwood mine fire in comparison to weekly averaged concentrations measured in Ovens, VIC during the 2006/07 bushfires and in Melbourne in 2008/2009. Measured benzene concentrations were higher at Morwell South compared to those at Ovens, VIC and Melbourne, while toluene concentrations were higher in Melbourne. The lower benzene to toluene ratio observed in Melbourne is consistent with traffic related emissions. The benzene to toluene ratio at Morwell South was 2.2, which is higher than the ratio of 0.8 measured at Ovens, VIC during the 2006/07 *(Meyer et al. 2008)*, but similar to that observed during peat fires *(Blake et al. 2009)* and underground coal fires *(O'Keefe et al. 2011; Engle et al. 2012)*. Benzene to toluene ratios measured on the fire ground during prescribed burns ranged from 0.03 (recorded for lighting crews) to 4.5 (recorded for patrolling crews) *(Reisen and Brown 2009)*. After the Hazelwood mine fire the ratio of benzene to toluene was similar to that observed in Melbourne and consistent with traffic-related air pollution.

The annual averaged concentration of benzene calculated between February 2014 and February 2015 (which included the fire period) was about twice as high as the annual averaged concentration calculated between April 2014 and April 2015 (which excluded the fire period), but was still below the annual averaged concentration measured in Melbourne in 2006.

Table 13 Comparative results of weekly and annual averaged concentrations of benzene and toluene (average, range)

Event	Benzene (ppb)	Toluene (ppb)	Benzene:Toluene
Morwell South (Feb-Mar 2014) (weekly)	1.37 (0.38-3.4)	0.62 (0.29-1.3)	0.9-2.6
Bushfires (2006/07) (weekly)[1]	0.27 (0.03-1.1)	0.22 (0.05-0.62)	0.3-2.1
Melbourne 2008/09 (weekly)[2]	0.25 (0.06-0.72)	1.04 (0.4-2.7)	0.13-0.22
Morwell South (annual average)	0.25 (incl fire) 0.11 (excl fire)	0.28 (incl fire) 0.23 (excl fire)	
Melbourne 2006 (annual average)[3]	0.5-1.0	1.6-4.3	0.23-0.36
Fire ground (work shift exposures)[4]	18.8 (0.6-81.5)	45.2 (0.5-252)	0.03-4.6

[1] *Meyer et al. (2008)*
[2] *Cheng et al. (2015)*
[3] EPA Victoria
[4] *Reisen and Brown (2009)*

6.3.2 PAHs and dioxins/furans

24-hour sampling of PAHs was done using a Hi-Vol sampling technique that only captures particle bound compounds on filters and therefore concentrations of semi-volatile PAHs such as naphthalene, phenanthrene, anthracene, fluoranthene and pyrene are only estimates. The two PAH samples collected in March on PUFs have shown that the semi-volatile fraction contributes significantly to the total PAH concentrations (Figure 19).

Table 14 shows the average and maximum PAH concentrations measured during the Hazelwood mine fire in comparison to PAH concentrations measured near a busy road in Brisbane (sum of particle-bound and semi-volatile PAHs) and on the fire ground during prescribed burns. The results show that concentrations of particle bound PAHs (e.g. benzo(a)anthracene, benzofluoranthenes and benzo(a)pyrene (B(a)P)) were higher at Morwell South than in Brisbane, but much lower than those measured on the fire ground.

B(a)P is often used as a surrogate for total PAHs for the development of annual goals. Table 15 shows that measured concentrations of B(a)P and total PAHs were much higher at Morwell South than at other locations within Australia. The annual averaged concentration of B(a)P was especially affected by the fire and exceeded the annual NEPM air toxics guideline of 0.3 ng m^{-3}. The annual average concentrations measured at Morwell South AMS was approximately twice as high as the annual average concentration measured in Melbourne in 2006.

Table 14 Comparative results of PAH concentrations measured at Morwell South AMS, Brisbane and on the fire ground.

PAHs (ng m^{-3})	Morwell South Filter Ave (max)	Brisbane[1] (Filter + PUF) Ave (max)	Fireground[2] Filter Ave (max)	Fireground[2] PUF Ave (max)
Naphthalene	0.18 (0.38)		52.4 (512)	2984 (19,988)
Acenaphthene	0.21 (0.29)		2.6 (26.0)	243 (3226)
Fluorene	2.26 (3.8)		137 (1981)	648 (8971)
Anthracene	0.31 (1.4)	4.3 (8.8)	266 (4754)	1027 (5566)
Phenanthrene	0.82 (5.1)	36 (60)	70.9 (1190)	273 (2272)
Fluoranthene	1.51 (9.3)	7.6 (11.0)	230 (4671)	99.1 (850)
Pyrene	2.45 (14.4)	14 (31)	194 (2387)	98.9 (838)
Benzo(a)anthracene	4.44 (15.7)	1.2 (1.4)	80.7 (1777)	2.4 (25.2)
Chrysene	8.82 (31.4)		109 (3230)	42.5 (399)
Benzo(b)fluoranthene	2.29 (7.2)	4.1 (5.3)[3]	13.7 (112)	1.9 (39.9)
Benzo(k)fluoranthene	1.32 (4.7)		16.9 (423)	0.6 (9.3)
Benzo(a)pyrene	2.36 (8.2)	1.5 (2.0)	56.2 (1221)	1.3 (26.1)
Benzo(g,h,i)perylene	0.86 (2.6)	4.9 (6.6)	2.0 (56.9)	ND
Dibenz(a,h)anthracene	0.72 (2.6)		8.9 (167)	ND

[1] *Muller et al. (1998)*

[2] Unpublished data

[3] Sum of benzo(b)fluoranthene and benzo(k)fluoranthene

Table 15 Comparative results of B(a)P and total PAH concentrations measured at Morwell South AMS and other locations within Australia.

Site	B(a)P (ng m^{-3}) Ave (max)	Total PAHs (ng m^{-3}) Ave (max)
Morwell South (Feb-Mar 2014)	2.40 (8.25)	33.8 (123.2)
Morwell South (annual average)	0.39 (incl fire) 0.03 (excl fire)	
Melbourne 2006 (annual average)[1]	0.2	
Perth[2]	0.037 (summer) 0.084 (winter)	
Brisbane[2]	0.088 (summer) 0.16 (winter)	
Adelaide[2]	0.15 (summer) 0.33 (winter)	
Sydney[3]	0.03 (0.07) (summer) 0.46 (2.25) (winter)	0.62 (1.39) (summer) 4.47 (17.5) (winter)
Lower Hunter[3]	0.06 (0.40) (summer) 0.30 (1.92) (winter)	0.56 (2.82) (summer) 2.68 (13.0) (winter)
Fire ground (work shift exposures)[4]	9.3 (1600)	

[1] EPA Victoria
[2] *Kennedy et al. (2010)*
[3] *Department of Environment and Conservation (NSW) (2004)*
[4] *Reisen and Brown (2009)*

Similarly 24-hour sampling of dioxins/furans was done using a Hi-Vol sampling technique that only captures particle bound compounds on filters and therefore concentrations of semi-volatile congeners such as TCDD and TCDF are only estimates. For samples collected on both PUFs and filters, the sum of congeners was 684 fg m^{-3} for particle-bound congeners and 562 fg m^{-3} for semi-volatile congeners, the latter being dominated by TCDF and TCDD with a high TEQ. As a result, 24-hour measurements on filters may have significantly underestimated dioxin concentrations.

Table 16 shows TEQ values measured during the Hazelwood mine fire in comparison to TEQ values measured at Aspendale (VIC) in summer and winter and in Darwin during the dry and wet season. In February the TEQ values measured at Morwell South were significantly higher than those measured at Aspendale and Darwin. In March, measured dioxin concentrations at Morwell South have decreased to values similar to those observed at Aspendale in winter time. The higher dioxin levels in winter at Aspendale are due to domestic wood burning.

Table 16 Comparative results of dioxin TEQ values (in fg m^{-3}) measured at Morwell South AMS, Morwell South CSIRO site, Aspendale (VIC) and Darwin (NT)

	Filter (LB-UB)	PUF (LB-UB)	Filter + PUF (LB-UB)
Morwell South AMS (26&27 Feb)	35-37	NM	NM
Morwell South AMS (5-20 March)	2.0-6.0	NM	NM
Morwell South CSIRO site (3-18 March)	8.3-8.7	4.0-6.7	12.3-15.4
Aspendale (VIC) summer (2011-2013)	0.5-1.2	1.7-2.3	2.2-3.4
Aspendale (VIC) winter (2011-2013)	4.0-4.3	6.5-6.6	10.5-10.9
Aspendale (VIC) June 2013			35.8
Darwin (dry season)	0.3-1.0	1.2-2.1	1.5-3.1
Darwin (wet season)	0.1-1.0	0.0-0.8	0.1-1.8

NM: Not measured

6.4 Metals

Research has shown that elements contained within the coal can be mobilised during burning processes and be released into the environment *(Finkelman 2004)*. Some volatile elements that have been found to be enriched in coal deposits include arsenic, fluorine, mercury and selenium. These elements can be released into the environment during burning of coal beds. They can impact on human health, be adsorbed on crops and taken up by livestock *(Finkelman 2004)*. During the Hazelwood mine fire higher concentrations of cobalt, manganese, selenium, strontium, titanium, vanadium and zinc were measured. Although increased concentrations of these metals were measured during the Hazelwood mine fire, concentrations remained below TCEQ air quality guidelines.

6.5 Summary

Ambient measurements conducted in Morwell and surrounding areas have shown that the Hazelwood mine fire caused increased concentrations in a range of air pollutants especially $PM_{2.5}$, CO, benzene and other aliphatic and aromatic compounds, exceeding NEPM air quality guidelines. The air quality was significantly impacted in February with a decrease in pollutant levels recorded in March. Air quality concentrations dropped to background levels once the fire was declared safe at the end of March.

A summary of observed concentrations of air pollutants measured at Morwell during the Hazelwood mine fire is shown in Table 17 along with concentrations measured in the LaTrobe Valley and Melbourne during non-pollution events, in Ovens, VIC and Aspendale, VIC during the 2006/07 bushfires, during peat fires in WA and on the fire ground during prescribed burns. Results show that peak $PM_{2.5}$ concentrations were similar between the Hazelwood mine fire and the 2006/07 bushfires, but CO and benzene concentrations were higher during the Hazelwood mine fire. The CO levels remained lower than those observed on the fire ground.

Table 17 Concentrations of key air pollutants measured during the Hazelwood mine fire in comparison to background air, urban air and other major air pollution events

Event	Hourly $PM_{2.5}$ ($\mu g\ m^{-3}$)	Daily $PM_{2.5}$ ($\mu g\ m^{-3}$)	Hourly CO (ppm)	Benzene (ppb)	Formaldehyde (ppb)	B(a)P ($ng\ m^{-3}$)
Hazelwood mine fire	0-1349	5.4-731	0-39.3	1.3-14.0 (24h) 0.4-3.4 (7day)	1.4-7.6	0.01-8.2
LaTrobe Valley (Sep-Nov 2014)	0-27.6	1.9-14.1	0-2.1	0.02-0.15 (7day)	NM	<0.006
Melbourne[1] (Feb/March 2013)	0-27.6	0-13.1	0-0.7	NM	NM	NM
Melbourne 2008/09[2]				0.06-0.72	0.5-3.8	NM
Ovens VIC 2006/07[3]	14.5-1783	14.6-1102	NM	0.03-1.1 (7day)	NM	NM
Aspendale[4] (Fires 2006/07)	12-556		0.06-4.5	NM	NM	NM
Fire ground[5] (work shift exposure)		20-16,000	0.18-120	0.63-81.5	ND-665	ND-1600 (mean of 9.3)
Peat fires (WA)[7]	0.3-106	7.3-17.1		16.9-30.5 (1h)		

[1] EPA Victoria
[2] *Molloy et al. (2012)*; *Cheng et al. (2015)*
[3] *Meyer et al. (2008)*
[4] *Keywood et al. (2015)*
[5] *Reisen and Brown (2009)* ; *Reisen et al. (2011a)*
[6] *Blake et al. (2009)*

6.6 Research gap

A literature search on coal fire emissions has provided few results with only a limited number of research studies available. The research studies focused primarily on underground mine shafts and often measured mainly greenhouse gases or other volatile organic gases but no particulate matter.

Currently there are no available data in the literature on emission characterisation from open-cut coal mine fires. Our understanding of the combustion of solid fuels such as Victorian brown coal has been focused on burning in furnaces and industrial processes and open combustion is a relatively recent area of concern. Experience with open burning of biomass (vegetation) suggests that the combustion process itself has a larger influence on emissions than the composition of the fuel. In particular there is a significant difference between emissions from biomass fuel burned in laboratory conditions to fuel burned in more field-like conditions. Therefore application of laboratory-derived emission factors in the modelling activities may result in significant uncertainties in emissions of particles and air toxics.

7 Conclusion

On 9 February 2014, embers from nearby bushfires spotted into an unused part of the Hazelwood mine and started a fire that spread rapidly and extensively under strong south-westerly winds and burned over a period of 45 days. Smoke levels during the initial period of the fire were elevated and impacted nearby towns particularly under south-westerly winds.

Air quality monitoring undertaken on-site showed that smoke from the Hazelwood mine fire affected a wide area, with particle NEPM air quality guidelines exceeded in Traralgon located ~13 km from the mine. Pollutant levels were significantly elevated in February and decreased in March returning to background levels once the fire was declared safe at the end of March. The highest pollutant concentrations were recorded at Morwell South AMS, with lower concentrations observed at Morwell East AMS.

The ambient particle concentrations related to the Hazelwood mine fire were of similar magnitude than those recorded during the 2006/07 Eastern Victoria Great Divide bushfires. However measured concentrations of CO and benzene were higher than those measured during the extensive bushfire event.

While PM and CO monitoring started approximately 4 days after the fire when smoke levels were very high, targeted monitoring of air toxics only began on 26 February when smoke levels had subsided. Limited research on emission factors from open-cut coal mine fires make it difficult to assess the likely concentrations of air toxics emitted during the initial more intense period of the fire.

Appendix A Measurement and analysis methods

A.1 Instruments

A.1.1 Particle instruments

- The e-sampler (E-sampler-9800, Met One Instruments Inc., USA) provides both continuous real-time particulate measurements through near-forward light-scattering and collection of sample on a 47mm filter substrate that can be used for subsequent measurements of gravimetric mass and for chemical composition. Air was sampled at a constant flow rate of 2 l min^{-1} through a sharp-cut $PM_{2.5}$ cyclone. The samples were collected on Teflon filters 47 mm in diameter with 2 µm pore size. Continuous real-time measurements were calibrated against gravimetric filter measurements (Australian reference method). Uncertainty ± 10%
- The DustTrak (TSI Inc., USA) is a laser photometer that provides real-time measurements based on 90 degree light scattering. The particle mass concentration is determined by the amount of light scatter, based on a calibration factor. The relationship between light scattering and particle mass concentrations varies with particle source and particle size distribution. DustTrak produces data that is considered indicative of levels of PM2.5 in an area. If calibrated with a site specific mass calibration factor determined gravimetrically uncertainty ± 10%. The site specific mass calibration factor is determined by collecting a sample of particles on a filter, weighing the filter and relating that mass to the light scattering integrated over the period the filter sample was collected.
- BAM (Model 4014*i* Beta, Thermo Fisher Scientific Inc.) is a standard beta attenuation monitor that automatically measures and records airborne particles. This instrument works by collecting particles on a filter tape and measuring the reduction in beta rays travelling through the particles. From this, the concentration of airborne particles is calculated. BAMs meet the Australian National Standard (AS 3580.9.12–2013). Uncertainty ±10%
- The nephelometer measures the amount of particles in the air using very sensitive, light-scattering sensors and calculates a visibility reduction index.
- The Tapered Element Oscillating Micro-balance (TEOM) continually measures the concentration of airborne particles. It does this by collecting and weighing the particles using a very sensitive balance. TEOMs are standard across EPA's network and meet the Australian National Standard (AS 3580.9.8–2008). Uncertainty ±10%
- A High-Volume Air Sampler (HiVol) samples large volumes of air and collects the contained particulate matter by filtration. Air was sampled at a flow rate of 1.1 m^3 min^{-1} through a 10 µm size-selective inlet. AS/NZ 3850.9.6:2015 or AS/NZ 3850.9.14:2013. Uncertainty ±10%.
- The Partisol is a gravimetric sampler that employs a sequential system of 47 mm filters that enables several 24-hour period samples to be collected automatically. The Partisol operates at a flow rate of 10-19 L min^{-1}. AS/NZ 3850.9.9:2006. Uncertainty ±10%
- The MOUDI (Model 110-R, MSP Corporation) is a 10 stage cascade impactor with the stages having 50% cut-points ranging from 0.056 µm to 18 µm in aerodynamic diameter. The HiVol MOUDI

(Model 131, MSP Corporation) is a 6-stage impactor with the stages having 50% cut-points ranging from 0.25 µm to 10 µm in aerodynamic diameter. The MOUDI works by inertial impaction using multi-nozzle stages in series. The MOUDI and HiVol MOUDI samples were taken at the designed flow rate of 30 L min^{-1} and 100 L min^{-1} respectively.

A.1.2 CO measurements

CO was measured by two methods

- Ecotech trace CO analyser which utilises infrared absorption spectrometry. Australian Standard AS3580.7.1:2011. Uncertainty of approx. 2% Operated in AMS.
- The CFA used AreaRAE portable personal monitors which use electrochemical sensors to detect CO.These monitors are traditionally used to assess occupational exposure so that the CO sensor is less sensitive than the NDIR method employed by EPAV to measure ambient levels of CO.

A.1.3 VOC measurements

Different methods were used to collect VOCs: canister sampling over a 24-hour period, passive sorbent tube sampling using Radiello tubes and active sampling on sorbent tubes and DNPH cartridges and are summarised in Tables A1 and A2.

- Canister samples were collected over a 24- hour period in stainless steel fused silica-coated canisters and transported to analytical laboratory for chemical analysis.
- Radiello tubes are adsorbent tubes that absorb VOCs in the air. They are a stand-alone, passively sampling tube that were deployed at different sites in Morwell and sampled over a 7-day period.
- VOC samples were also collected by drawing air through two Markes Carbograph 1TD / Carbopack X adsorbent tubes at a flow rate of 20 ml min^{-1} for 25-minutes per hour over a 24 hour period, giving a typical volume of 6 L. The absorbent tubes were placed in sequence, with a back-up tube to assess sample break-through. Sampling was conducted according to USEPA Compendium method TO-17 (USEPA TO-17).
- Samples for the analysis of carbonyl compounds (including formaldehyde) were collected by drawing air through Supelco LpDNPH s10 air monitoring cartridges at a flow rate of 500 ml min^{-1} over a 24-hour period. Carbonyls were trapped on high purity silica adsorbent coated with 2,4-dinitrophenylhydrazine(2,4-DNPH), where they are converted to the hydrazone derivatives. An ozone scrubber was placed in front of the LpDNPH cartridge. Sampling was conducted according to USEPA method TO-11A.

Apx Table A.1 VOC sampling and measurement details

SITE	SAMPLING DATE	SAMPLING PERIOD	SAMPLING METHOD	COLLECTED BY	ANALYSIS METHOD	ANALYSED BY
Morwell South AMS; Maryvale Crescent Preschool; Morwell East AMS	26-27 February 27-28 February 5-6 March 6-7 March 13-14 March	24-hours	Canister	EPA Victoria	USEPA Method TO-15	NMI
Morwell South AMS; Maryvale Crescent Preschool; Morwell East AMS	From 4 February	7-days	Radiello sorbent tubes (passive)	EPA Victoria	USEPA Method TO-17	SGS-Leeder Consulting
Morwell South (cnr of Chapel and Elgin st)	3 -19 March	25min per hour over 24h period	Sorbent tubes (active)	CSIRO	USEPA Method TO-17	CSIRO

Apx Table A.2 Carbonyl sampling and measurement details

SITE	SAMPLING DATE	SAMPLING PERIOD	SAMPLING METHOD	COLLECTED BY	ANALYSIS METHOD	ANALYSED BY
Morwell South AMS; Maryvale Crescent Preschool; Morwell East AMS	26-27 February 27-28 February 5-6 March 6-7 March 13-14 March	24h	Radiello (passive)	EPA Victoria	USEPA Method TO-11	SGS-Leeder Consulting
Morwell South (cnr of Chapel and Elgin st)	3 -19 March	24h	DNPH cartridges (active)	CSIRO	USEPA Method TO-11	CSIRO

Table A3 summarises the collection and analysis methods for PAHs and dioxins.

Apx Table A.3 PAHs and dioxins sampling and measurement details

SITE	SAMPLING DATE	SAMPLING PERIOD	SAMPLING METHOD	COLLECTED BY	ANALYSIS METHOD	ANALYSED BY
Morwell South AMS	26-27 February 27-28 February 5-6 March 6-7 March 7-8 March 12-13 March 14-15 March 20-21 March	24-hours	HiVol PM10 filters	EPA Victoria	USEPA Method (Isotope dilution)	NMI
Morwell South (cnr of Chapel and Elgin st)	3 -18 March 18-28 March	15 days 10 days	Quartz filters and PUFs	CSIRO	USEPA Method TO9A	Asure Quality

Table A4 summarises the collection and analysis methods for metals.

Apx Table A.4 Metals sampling and measurement details

SITE	SAMPLING DATE	SAMPLING PERIOD	SAMPLING METHOD	COLLECTED BY	ANALYSIS METHOD	ANALYSED BY
Morwell South AMS	26-27 February 27-28 February 5-6 March 6-7 March 7-8 March 12-13 March 14-15 March 20-21 March	24-hours	HiVol PM10 filters	EPA Victoria	ICP	SGS-Leeder Consulting
Morwell South AMS	28 February-26 March	24-hours	Partisol PM10	EPA Victoria	PIXE	ANSTO
Morwell South (cnr of Chapel and Elgin st)	3 -7 March 7-14 March 14-21 March 21-28 March	weekly	E-sampler PM2.5	CSIRO	PIXE	ANSTO
Morwell East AMS	28 Feb-7 March 7-14 March 14-28 March	weekly weekly 2-weeks	E-sampler PM2.5	CSIRO	PIXE	ANSTO
Traralgon	28 Feb-7 March 7-14 March 14-28 March	weekly weekly 2-weeks	E-sampler PM2.5	CSIRO	PIXE	ANSTO

Appendix B Results of air pollutant measurements

Apx Table B.1 24-hour concentrations (in ppbv) of volatile organic compounds collected at Morwell South AMS (canister samples)

COMPOUND	27/02/14	28/02/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14	3/04/14
1,3-Butadiene	2.5	1.6	<0.5	<0.5	<0.5	<2	<0.5	<0.5
2-Butanone(MEK)	1.1	0.92	<0.3	<0.3	<0.3	<0.3	4.4	0.54
Acetone	8	7.2	3	2.1	3	3.1	14	3.2
Benzene	14	9.7	3.1	1.3	2.3	1.1	1.3	<0.9
Ethanol	7.4	8.5	4.8	5.2	5.8	7.4	40	8
Ethylbenzene	<0.5	0.58	<0.5	<0.5	<0.5	<0.5	0.6	<0.5
Heptane	0.9	0.71	<0.5	<0.5	<0.5	<0.5	1	<0.5
Hexane	1.2	0.88	<0.6	<0.6	<0.6	<0.6	11	<0.6
Naphthalene	0.97	1.6	<0.6	<0.6	<0.6	<0.1	<0.6	<0.6
Propene	42	28	8.1	2.7	4.9	2.8	<0.5	<0.5
Toluene	4.8	3.5	1.1	<0.5	0.9	0.64	3.7	<0.5

Apx Table B.2 24-hour concentrations (in ppbv) of volatile organic compounds collected at Maryvale Crescent Preschool (canister samples)

COMPOUND	27/02/14	28/02/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14	3/04/14
1,3-Butadiene	1.6	0.68	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2-Butanone(MEK)	0.75	0.81	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Acetone	5.9	6.3	2.8	1.8	2	2.8	2.7	1.4
Benzene	9.1	6	2	1.1	1.2	<0.9	1.1	<0.9
Ethanol	5.3	5.3	5	5.8	5.8	9	6.4	4.7
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Heptane	0.61	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Hexane	0.77	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Naphthalene	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6

Apx Table B.3 24-hour concentrations (in ppbv) of volatile organic compounds collected at Morwell East AMS (canister samples)

COMPOUND	27/02/14	28/02/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14	3/04/14
1,3-Butadiene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2-Butanone(MEK)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Acetone	1.9	2.2	2.9	1.5	2.9	2.4	2.7	2.4
Benzene	1.7	2.1	2.5	<0.9	1.2	<0.9	<0.9	<0.9
Ethanol	2.9	4.9	5.8	5.8	14	7.4	7.4	4
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	<0.6	<0.6	<0.6	<0.6	0.76	<0.6	<0.6	<0.6
Propene	4.8	5.7	5.7	0.87	3.1	0.81	<0.5	<0.5
Toluene	0.69	0.93	1.1	<0.5	0.96	<0.5	0.98	<0.5

Apx Table B.4 Weekly concentrations (in ppbv) of volatile organic compounds collected at Morwell South AMS (Radiello tubes)

COMPOUND	26/02/14	5/03/14	12/03/14	19/03/14	26/03/14	2/04/14	9/04/14	16/04/14
2-Methylpentane	0.22	0.25	0.15	0.15	0.22	0.17	0.24	0.28
3-Methylpentane	0.051	0.079	<0.04	0.048	0.071	0.048	0.094	0.094
Benzene	3.4	1.9	0.75	0.41	0.38	0.13	0.15	0.2
Carbon tetrachloride	0.078	0.087	0.084	0.062	0.075	0.043	0.073	0.08
Ethylbenzene	0.14	0.085	<0.032	0.15	0.06	0.035	0.039	0.06
m&p-Xylenes	0.39	0.21	0.14	0.22	0.15	0.081	0.14	0.2
Methyl ethyl ketone	0.078	<0.04	<0.04	0.085	<0.04	<0.04	<0.04	0.075
n-decane	0.14	<0.04	<0.04	0.064	0.055	<0.04	<0.04	0.05
N-Dodecane	2.6	1.9	1.2	0.43	0.56	0.4	0.34	0.86
n-Heptane	0.27	0.15	<0.04	<0.04	0.059	<0.04	<0.04	0.066
n-Hexane	0.48	0.25	<0.04	0.14	0.14	0.068	0.12	0.14
N-Nonane	0.072	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.042
N-Octane	0.16	0.1	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
N-Undecane	0.2	0.15	<0.064	0.066	<0.064	<0.064	<0.064	0.13
o-Xylene	0.17	0.1	<0.035	0.071	0.055	0.037	0.041	0.062
Toluene	1.3	0.74	0.37	0.29	0.42	0.21	0.29	0.45

Apx Table B.5 Carbonyl concentrations (in ppbv) measured at Morwell South CSIRO site

Date/Time ON	3/3/14 15:15		5/3/14 12:00		7/3/14 15:01		11/3/14 17:01	12/3/14 17:25	14/3/14 18:06	16/3/14 6:41	19/3/14 9:00	
Date/Time OFF	5/3/14 10:30		7/3/14 13:50		8/3/14 15:00		12/3/14 14:14	13/3/14 17:01	15/3/14 18:01	17/3/14 6:00	20/3/14 0:00	
Formaldehyde	4.07	4.89	1.58	1.45	0.48	0.65	1.40	1.63	1.72	0.97	0.95	0.94
Acetaldehyde	0.91	0.91	1.15	1.02	0.09	0.10	0.75	1.17	0.80	0.46	0.42	0.36
Acrolein	0.002#	0.03	0.001#	0.01	0.003#	0.004	0.01	0.003#	0.02	0.01	0.02	0.01
Acetone	0.47	0.67	0.02	0.01	0.17	0.14	0.23	0.19	0.50	0.05	0.45	0.24
Propionaldehyde	0.04	0.09	0.22	0.22	0.007#	0.007#	0.02	0.09	0.05	0.04	0.04	0.03
Crotonaldehyde	0.005	0.005	0.002#	0.007	0.003#	0.003#	0.004#	0.003#	0.003#	0.003#	0.10	0.09
Methacrolein	0.06	0.06	0.014	0.013	0.004	0.009	0.02	0.02	0.04	0.01	0.02	0.02
MEK	0.02	0.03	0.001#	0.005	0.001#	0.002#	0.002#	0.001#	0.002#	0.002#	0.001#	0.001#
Butyraldehyde	0.07	0.08	0.07	0.06	0.003#	0.02	0.02	0.06	0.03	0.03	0.04	0.03
Benzaldehyde	0.05	0.07	0.04	0.03	0.01	0.02	0.05	0.04	0.07	0.03	0.03	0.02
Glyoxal	0.15	0.19	0.10	0.04	0.06	0.05	0.13	0.05	0.18	0.03	0.009#	0.04
Valeraldehyde	0.04	0.04	0.04	0.04	0.01	0.01	0.02	0.05	0.04	0.01	0.02	0.02
m-Tolualdehyde	0.03	0.05	0.02	0.02	0.01	0.01	0.05	0.02	0.06	0.01	0.03	0.01
Methyl glyoxal	0.51	0.57	0.15	0.12	0.16	0.13	0.40	0.13	0.49	0.05	0.13	0.08
Hexaldehyde	0.07	0.07	0.04	0.03	0.02	0.007	0.003	0.04	0.05	0.03	0.03	0.02

All values are blank corrected; ½ MDL was used for blank concentrations below the MDL

Concentrations below the MDL presented as ½ MDL

Apx Table B.6 24-hour concentrations (in ng m^{-3}) of polycyclic aromatic hydrocarbons collected at Morwell South AMS using a High Volume PM_{10} sampler

COMPOUND	26/02/14	27/02/14	5/03/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14
Naphthalene	0.38	0.22	0.08		0.01	0.12	0.27	
Acenaphthylene	0.24	0.24			0.01			
Acenaphthene	0.22	0.26	0.29	0.29	0.13	0.09	0.22	
Fluorene	0.41	0.19	3.59	3.62	1.63	2.53	3.84	
Anthracene	1.41	0.24	0.18	0.25	0.01	0.18	0.08	0.11
Phenanthrene	5.08	0.55	0.29	0.08	0.01	0.17	0.11	0.28
Fluoranthene	9.27	0.98	0.98	0.06	0.01	0.29	0.09	0.37
Pyrene	14.37	1.93	1.67	0.12	0.01	0.53	0.20	0.73
Benz(a)anthracene	15.68	12.52	3.38	0.58	0.01	1.28	0.11	1.96
Chrysene	31.39	24.80	5.99	1.19	0.01	3.10	0.38	3.68
Benzo(b)fluoranthene	7.17	5.85	2.33	0.74	0.01	0.94	0.40	0.89
Benzo(k)fluoranthene	4.69	3.24	1.14	0.30	0.01	0.49	0.20	0.45
Benzo(a)pyrene	8.22	6.38	1.81	0.50	0.01	0.77	0.20	0.99
Benzo(e)pyrene	8.22	5.98	3.38	1.04	0.01	1.41	0.86	1.43
Perylene	8.71	5.43	0.69	0.11	0.01	0.21	0.04	0.72
Indeno(1,2,3-cd)pyrene	2.59	2.59	0.47	0.17	0.01	0.20	0.06	0.21
Benzo(ghi)perylene	2.59	2.59	0.73	0.29	0.01	0.30	0.13	0.21
Dibenz(ah)anthracene	2.59	2.59	0.26	0.07	0.01	0.09	0.02	0.10

Apx Table B.7 Concentrations (in ng m^{-3}) of semi-volatile and particle-bound polycyclic aromatic hydrocarbons measured over a 2-week sampling period at Morwell South CSIRO site

COMPOUND	FILTER 3-18 MARCH	FILTER 18-28 MARCH	PUF 3-18 MARCH	PUF 18-28 MARCH
Naphthalene	0.09	0.05	54.19	44.58
Acenaphthylene	0.00	0.00	1.02	0.38
Acenaphthene	0.00	0.00	2.86	1.54
Fluorene	0.02	0.01	20.83	8.54
Anthracene	0.06	0.02	5.11	1.78
Phenanthrene	0.14	0.05	34.20	12.58
Fluoranthene	0.13	0.04	6.41	1.96
Pyrene	0.19	0.06	5.87	2.38
Benz(a)anthracene	0.66	0.05	0.93	0.43
Chrysene	1.87	0.11	2.32	1.10
Benzo(b)fluoranthene	0.69	0.12	0.07	0.07
Benzo(k)fluoranthene	0.65	0.10	0.06	0.06
Benzo(a)pyrene	0.69	0.06	0.02	0.01
Indeno(1,2,3-cd)pyrene	0.24	0.05	0.00	0.00
Benzo(ghi)perylene	0.33	0.07	0.00	0.00
Dibenz(ah)anthracene	0.13	0.02	0.00	0.00

Apx Table B.8 24-hour concentrations (in fg m^{-3}) of dioxins collected at Morwell South AMS using a High Volume PM_{10} sampler

COMPOUND	26/02/14	27/02/14	5/03/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14
2378 TCDF	18	13	3.4	*<0.63*	*<0.56*	*<1.4*	*<0.54*	2.5
2378 TCDD	7.1	5	*<1.3*	*<0.63*	*<0.7*	*<2.7*	*<0.81*	*<1.3*
12378 PeCDF	3.5	4.3	1.7	<0.76	<0.7	<1.4	<1.2	4
23478 PeCDF	4.7	3.8	*<1.3*	*<0.88*	*<0.7*	*<1.4*	*<1.4*	1.2
12378 PeCDD	18	16	4.8	*<1.3*	*<0.85*	*<2.7*	*<4.1*	*<2.6*
123478 HxCDF	<3.8	<5.3	<1.3	<0.76	<0.42	<0.68	<0.81	5
123678 HxCDF	*<3.8*	*<3.9*	*<1*	*<0.63*	*<0.28*	*<0.82*	*<0.95*	2.8
234678 HxCDF	*<2.5*	*<2.6*	*<0.92*	*<0.63*	*<0.42*	*<0.68*	*<1.1*	*<2.6*
123789 HxCDF	*<1.3*	*<2.6*	*<0.39*	*<0.25*	*<0.42*	*<0.95*	*<0.81*	*<1.1*
123478 HxCDD	22	14	4.7	1.4	*<0.56*	1	*<1.4*	1.6
123678 HxCDD	23	16	5.2	1.4	*<0.56*	2	*<1.4*	1.9
123789 HxCDD	32	24	8.4	*<2.5*	*<0.56*	*<2.7*	*<1.4*	2.1
1234678 HpCDF	8.7	18	2.5	1.8	<0.85	1.8	2.4	13
1234789 HpCDF	*<1.3*	2.5	*<0.39*	*<0.38*	*<0.42*	*<2.7*	*<1.4*	2.1
1234678 HpCDD	250	180	60	19	*<1.4*	19	14	17
OCDF	4.6	13	<2.6	<0.76	<0.7	<1.4	<1.4	6.1
OCDD	1800	1200	590	200	*<9.9*	220	200	210
Total TCDF congeners	7400	4900	690	48	<4.2	50	5.7	61
Total TCDD congeners	7300	4900	840	81	*<4.2*	120	16	130
Total PeCDF congeners	89	70	20	<6.3	<5.6	<9.5	<9.5	13
Total PeCDD congeners	950	720	170	44	*<5.6*	50	*<27*	34
Total HxCDF congeners	51	51	11	5.3	<2.8	<4.1	<5.4	19
Total HxCDD congeners	1100	830	210	61	*<1.4*	61	31	45
Total HpCDF congeners	11	26	2.5	2.5	<1.3	6.7	2.4	20
Total HpCDD congeners	860	610	170	56	*<2.8*	54	37	44
Total 210 congeners LB	20000	13000	2700	500	0	560	300	590
Total 210 congeners MB	20000	13000	2700	500	19	570	320	590
Total 210 congeners UB	20000	13000	2700	510	39	580	340	590
WHO-05 TEQ LB	39	31	7.9	0.55	0	0.58	0.22	2.5
WHO-05 TEQ MB	39	32	8.9	1.9	1.1	3.9	3.3	4.6
WHO-05 TEQ UB	40	33	9.9	3.3	2.2	7.2	6.4	6.8

Apx Table B.9 Concentrations (in fg m^{-3}) of semi-volatile and particle-bound dioxins measured over a 2-week sampling period at Morwell South CSIRO site

COMPOUND	FILTER 3-18 MARCH	FILTER 18-28 MARCH	PUF 3-18 MARCH	PUF 18-28 MARCH
2378 TCDF	*<1.77*	*<1.54*	6.61	6.28
2378 TCDD	1.57	*<2.00*	2.35	*<2.18*
12378 PeCDF	3.15	*<1.67*	2.94	4.85
23478 PeCDF	3.1	*<1.57*	2.33	4.19
12378 PeCDD	2.8	*<2.41*	*<1.86*	3.76
123478 HxCDF	9.04	*<2.64*	2.16	5.27
123678 HxCDF	4.4	*<2.75*	*<0.923*	2.63
234678 HxCDF	3.1	*<2.54*	*<0.86*	*<1.31*
123789 HxCDF	*<2.43*	*<3.53*	*<1.17*	*<1.83*
123478 HxCDD	2.22	*<3.37*	*<1.53*	*<1.34*
123678 HxCDD	1.53	*<3.61*	*<1.59*	*<1.49*
123789 HxCDD	3.09	*<3.37*	*<1.53*	*<1.34*
1234678 HpCDF	15.6	6.85	1.32	2.43
1234789 HpCDF	3.17	*<2.98*	*<1.23*	*<1.72*
1234678 HpCDD	29.6	11.3	*<1.00*	*<1.24*
OCDF	25.5	6.32	*<2.25*	*<3.84*
OCDD	314	165	*<2.30*	*<2.91*
Total TCDF congeners	39.7	7.88	261	122
Total TCDD congeners	46.6	*<2.00*	263	75.2
Total PeCDF congeners	24.3	3.72	16.8	25.8
Total PeCDD congeners	40.6	*<2.41*	10.3	3.76
Total HxCDF congeners	16.5	*<3.53*	2.16	7.88
Total HxCDD congeners	76.8	*<3.61*	*<1.59*	*<1.49*
Total HpCDF congeners	18.8	6.85	1.32	2.43
Total HpCDD congeners	81.2	11.3	*<1.00*	*<1.24*
Total 210 congeners LB	684	201	555	237
Total 210 congeners MB	684	207	559	242
Total 210 congeners UB	684	213	562	247
WHO-05 TEQ LB	8.32	0.233	4.03	6.6
WHO-05 TEQ MB	8.53	3.88	5.35	8.08
WHO-05 TEQ UB	8.74	7.52	6.67	9.55

Apx Table B.10 24-hour concentrations (in µg m^{-3}) of metals and elements collected at Morwell South AMS on PM_{10} High Volume samples

COMPOUND	26/02/14	27/02/14	5/03/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14
Aluminium	9.30E-01	5.62E-01	3.80E-01	2.09E-01	6.04E-03	1.46E-01	1.19E-01	4.38E-01
Antimony	1.18E-04	1.05E-04	6.40E-06	6.40E-06	6.40E-06	1.54E-04	2.35E-04	2.65E-04
Arsenic	9.95E-04	6.01E-04	3.14E-04	2.64E-04	6.40E-05	6.40E-05	2.70E-04	3.98E-04
Barium	1.81E-01	1.23E-01	3.46E-02	1.75E-02	1.94E-03	6.09E-03	7.39E-03	1.12E-02
Beryllium	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05
Bismuth	6.40E-05	1.31E-04	6.40E-05	6.40E-05	6.40E-05	6.40E-05	1.35E-04	6.40E-05
Boron	9.27E-02	3.76E-02	2.46E-02	7.12E-03	8.14E-03	3.90E-03	7.29E-03	1.03E-02
Cadmium	4.19E-05	3.92E-05	1.31E-05	6.40E-06	1.31E-05	2.08E-05	1.89E-05	6.40E-06
Calcium	1.82E+01	1.17E+01	2.79E+00	1.18E+00	1.31E-01	5.67E-01	2.91E-01	5.25E-01
Cerium	2.62E-03	1.72E-03	1.26E-03	7.12E-04	6.40E-05	4.68E-04	4.59E-04	1.33E-03
Chromium	9.43E-04	4.70E-04	6.80E-04	4.22E-04	2.36E-04	1.82E-04	2.70E-04	1.11E-03
Cobalt	4.97E-03	3.40E-03	9.42E-04	4.48E-04	6.40E-05	2.34E-04	2.16E-04	5.30E-04
Copper	1.81E-03	7.32E-04	3.93E-04	1.58E-04	6.40E-05	2.60E-04	2.97E-04	2.36E-03
Gallium	2.44E-02	1.96E-02	6.02E-03	2.48E-03	5.78E-04	9.89E-04	1.11E-03	2.39E-03
Gold	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	2.60E-04	2.16E-03	6.40E-05
Iron	3.12E+00	1.86E+00	1.34E+00	6.67E-01	2.34E-02	3.72E-01	3.86E-01	9.62E-01
Lanthanum	6.40E-05	6.40E-05	5.23E-04	2.64E-04	6.40E-05	2.60E-04	2.70E-04	5.30E-04
Lead	7.86E-04	6.79E-04	6.02E-04	3.69E-04	6.30E-04	3.38E-04	6.21E-04	1.06E-03
Lithium	1.28E-03	1.10E-03	6.40E-05	6.40E-05	6.40E-05	6.40E-05	5.13E-04	6.40E-05
Magnesium	9.95E+00	6.79E+00	1.47E+00	8.17E-01	1.63E-01	4.16E-01	2.70E-01	3.98E-01
Manganese	6.51E-02	4.41E-02	3.10E-02	1.07E-02	4.46E-04	6.66E-03	6.91E-03	1.39E-02
Mercury	1.57E-04	1.05E-04	1.31E-05	2.37E-05	6.40E-06	5.73E-05	4.32E-05	6.40E-06
Molybdenum	2.36E-04	1.83E-04	3.66E-04	6.40E-05	6.40E-05	1.30E-04	1.35E-04	2.65E-04
Nickel	2.59E-03	1.44E-03	1.75E-03	5.01E-04	6.40E-05	6.51E-04	5.40E-04	1.03E-03
Phosphorus	4.45E-02	2.87E-02	4.45E-02	5.01E-02	2.63E-02	2.34E-02	2.02E-02	3.98E-02
Potassium	2.62E-01	2.22E-01	1.39E-01	2.29E-01	6.04E-02	1.22E-01	8.63E-02	1.40E-01
Rubidium	6.40E-05	6.40E-05	5.23E-04	5.01E-04	6.40E-05	1.30E-04	1.89E-04	5.30E-04
Selenium	1.52E-03	6.01E-04	5.50E-04	5.54E-04	4.73E-04	8.07E-04	5.67E-04	6.40E-05
Silver	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05
Sodium	6.55E+00	4.96E+00	4.71E+00	3.43E+00	1.26E+00	2.39E+00	1.43E+00	1.56E+00
Strontium	2.62E-01	1.67E-01	3.40E-02	1.40E-02	1.26E-03	5.47E-03	3.24E-03	5.04E-03
Sulphur	1.26E+01	8.10E+00	1.26E+00	1.08E+00	2.36E-01	6.40E-05	6.40E-05	1.33E+00
Tellurium	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05
Thallium	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05
Thorium	6.81E-04	1.18E-03	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	2.65E-04
Tin	3.14E-04	9.41E-04	3.14E-04	5.27E-04	6.40E-05	1.82E-04	3.24E-04	7.95E-04
Titanium	6.00E-02	4.42E-02	2.59E-02	1.95E-02	5.78E-04	1.30E-02	1.19E-02	4.22E-02
Tungsten	1.41E-03	1.23E-03	1.23E-03	3.43E-04	8.93E-04	6.40E-05	5.94E-04	6.40E-05
Uranium	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05	6.40E-05
Vanadium	1.31E-03	6.40E-05	1.57E-03	1.05E-03	2.63E-04	6.40E-05	5.40E-04	6.40E-05
Yttrium	8.12E-04	5.23E-04	3.66E-04	1.85E-04	6.40E-05	1.30E-04	6.40E-05	2.65E-04
Zinc	1.41E-02	8.88E-03	8.74E-02	1.95E-02	3.78E-02	1.15E-02	1.19E-02	6.40E-05
Zirconium	3.43E-03	2.38E-03	6.40E-05	6.40E-05	6.40E-05	5.21E-04	1.73E-03	9.04E-03

Apx Table B.11 24-hour concentrations (in µg m^{-3}) of metals and elements collected at Morwell South AMS on PM_{10} Partisol samples

	AL	BR	CA	CL	CR	CO	CU	FE	PB	MN	NI	P	K	SE	SI	SR	S	TI	V	ZN
28/02/14	0.381	0.006	2.745	4.954	0.001	0.001	0.002	1.059	0.001	0.018	0.001	0.001	0.142	0.009	1.776	0.032	1.706	0.094	0.001	0.009
1/03/14	0.709	0.035	3.999	5.736	0.004	0.001	0.001	1.740	0.001	0.027	0.001	0.001	0.193	0.001	3.551	0.025	2.483	0.180	0.001	0.006
2/03/14	0.419	0.011	1.027	4.055	0.001	0.001	0.001	0.704	0.001	0.011	0.001	0.001	0.121	0.001	2.022	0.010	1.156	0.095	0.001	0.004
3/03/14	0.209	0.001	0.762	1.668	0.001	0.001	0.001	0.515	0.001	0.006	0.001	0.001	0.088	0.003	1.014	0.001	0.870	0.049	0.001	0.001
4/03/14	0.308	0.005	0.779	0.878	0.001	0.001	0.001	0.576	0.007	0.010	0.001	0.001	0.113	0.001	1.450	0.004	0.686	0.059	0.001	0.003
5/03/14	1.368	0.009	3.381	4.294	0.005	0.002	0.001	2.181	0.012	0.042	0.001	0.001	0.263	0.001	6.892	0.029	1.713	0.285	0.001	0.002
6/03/14	0.820	0.017	0.990	5.839	0.001	0.001	0.001	1.143	0.001	0.015	0.001	0.001	0.215	0.002	3.701	0.002	0.868	0.169	0.001	0.001
7/03/14	0.068	0.003	0.237	3.423	0.001	0.001	0.001	0.168	0.001	0.003	0.001	0.001	0.148	0.003	0.396	0.001	0.719	0.017	0.001	0.002
8/03/14	0.005	0.007	0.088	2.972	0.001	0.001	0.001	0.053	0.001	0.001	0.001	0.001	0.073	0.001	0.058	0.001	0.353	0.004	0.001	0.001
9/03/14	0.201	0.016	0.329	1.935	0.001	0.001	0.001	0.426	0.007	0.005	0.001	0.001	0.112	0.001	0.803	0.001	0.725	0.030	0.002	0.001
10/03/14	1.498	0.009	1.183	2.255	0.002	0.001	0.003	1.820	0.001	0.025	0.001	0.001	0.264	0.001	6.496	0.001	1.202	0.289	0.001	0.010
11/03/14	1.158	0.022	0.956	1.834	0.004	0.001	0.001	1.449	0.005	0.019	0.001	0.001	0.023	0.003	4.736	0.001	1.222	0.214	0.001	0.130
12/03/14	0.188	0.130	0.506	4.892	0.002	0.001	0.001	0.319	0.001	0.006	0.001	0.001	0.130	0.001	0.930	0.001	0.533	0.034	0.001	0.002
13/03/14	0.286	0.160	0.293	4.203	0.002	0.001	0.001	0.452	0.001	0.005	0.001	0.001	0.135	0.004	1.434	0.001	0.716	0.059	0.001	0.003
14/03/14	0.430	0.001	0.358	2.572	0.002	0.001	0.001	0.609	0.001	0.008	0.001	0.001	0.158	0.004	1.915	0.001	0.825	0.082	0.001	0.004
15/03/14	0.561	0.005	0.370	1.708	0.003	0.001	0.002	0.780	0.007	0.012	0.001	0.001	0.156	0.003	2.319	0.001	0.606	0.097	0.001	0.004
16/03/14	0.024	0.002	0.054	1.609	0.001	0.001	0.006	0.068	0.003	0.001	0.001	0.001	0.046	0.004	0.095	0.003	0.170	0.005	0.001	0.001
17/03/14	0.082	0.001	0.072	1.129	0.002	0.001	0.001	0.119	0.001	0.001	0.001	0.001	0.048	0.001	0.436	0.001	0.147	0.019	0.001	0.001
18/03/14	0.197	0.001	0.159	1.861	0.001	0.001	0.001	0.298	0.001	0.006	0.001	0.001	0.091	0.004	0.849	0.001	0.262	0.039	0.001	0.006
19/03/14	0.153	0.001	0.202	5.307	0.002	0.001	0.001	0.277	0.001	0.005	0.001	0.001	0.137	0.007	0.827	0.001	0.493	0.040	0.001	0.002
20/03/14	0.625	0.001	0.357	2.431	0.003	0.001	0.005	0.737	0.005	0.009	0.001	0.001	0.177	0.005	2.512	0.001	0.592	0.121	0.001	0.051
21/03/14	0.918	0.010	0.404	1.465	0.003	0.001	0.001	1.061	0.002	0.017	0.001	0.001	0.210	0.001	3.561	0.001	0.796	0.162	0.001	0.008
22/03/14	0.100	0.004	0.140	3.022	0.001	0.001	0.001	0.157	0.001	0.001	0.001	0.001	0.073	0.002	0.460	0.001	0.204	0.023	0.001	0.001
23/03/14	0.210	0.001	0.174	2.278	0.001	0.001	0.001	0.287	0.001	0.002	0.001	0.001	0.072	0.008	0.880	0.001	0.235	0.038	0.001	0.001
24/03/14	0.438	0.002	0.195	1.129	0.001	0.001	0.001	0.556	0.001	0.008	0.001	0.001	0.095	0.001	1.700	0.007	0.198	0.079	0.001	0.010
25/03/14	0.102	0.001	0.081	1.152	0.002	0.001	0.001	0.119	0.001	0.001	0.001	0.001	0.040	0.001	0.361	0.001	0.164	0.017	0.001	0.001
26/03/14	0.072	0.003	0.128	3.325	0.001	0.001	0.001	0.118	0.008	0.001	0.001	0.001	0.078	0.006	0.495	0.001	0.294	0.019	0.001	0.005

Apx Table B.12 Concentrations (in µg m^{-3}) of metals and elements collected on $PM_{2.5}$ filter samples over an approximately 1-week sampling period at Morwell South CSIRO site, Morwell East AMS and Traralgon AMS.

SITE	START DATE	END DATE	AL	CA	CR	CO	CU	FE	PB	MN	NI	K	SE	SR	S	TI	V	ZN
Morwell South	3/03/14	7/03/14	0.129	0.131	0.004	0.004	0.067	0.120	0.020	0.002	0.007	0.079	0.008	0.031	0.588	0.005	0.005	0.053
	7/03/14	14/03/14	0.062	0.049	0.007	0.007	0.617	0.010	0.003	0.010	0.005	0.004	0.148	0.691	0.003	0.002	0.013	0.119
	14/03/14	21/03/14	0.034	0.037	0.002	0.002	0.001	0.033	0.012	0.003	0.001	0.031	0.005	0.020	0.394	0.003	0.002	0.002
	21/03/14	28/03/14	0.038	0.015	0.002	0.002	0.001	0.023	0.010	0.002	0.001	0.018	0.004	0.017	0.168	0.008	0.002	0.001
Morwell East	28/02/14	7/03/14	0.101	0.164	0.001	0.003	0.001	0.172	0.006	0.005	0.001	0.066	0.003	0.011	0.699	0.019	0.002	0.003
	7/03/14	14/03/14	0.108	0.113	0.001	0.003	0.001	0.168	0.007	0.004	0.001	0.067	0.003	0.011	0.504	0.020	0.002	0.003
	14/03/14	28/03/14	0.048	0.052	0.001	0.002	0.002	0.078	0.005	0.002	0.001	0.046	0.002	0.009	0.274	0.010	0.001	0.002
Traralgon	28/02/14	7/03/14	0.033	0.023	0.002	0.002	0.001	0.026	0.008	0.001	0.001	0.040	0.003	0.012	0.580	0.002	0.002	0.001
	7/03/14	14/03/14	0.027	0.025	0.002	0.001	0.001	0.018	0.009	0.001	0.001	0.023	0.004	0.014	0.362	0.003	0.002	0.001
	14/03/14	21/03/14	0.052	0.035	0.002	0.002	0.001	0.043	0.012	0.002	0.001	0.043	0.005	0.019	0.400	0.003	0.003	0.006
	21/03/14	28/03/14	0.010	0.013	0.002	0.002	0.001	0.016	0.011	0.002	0.001	0.024	0.005	0.018	0.175	0.003	0.003	0.002

Apx Table B.13 24-hour concentrations (in µg m^{-3}) of water-soluble ions collected at Morwell South AMS on PM_{10} HiVol samples

COMPOUND	26/02/14	27/02/14	5/03/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14
Na^+	8.043	6.741	4.409	3.689	1.704	3.239	2.004	1.593
NH_4^+	2.339	1.893	0.743	0.987	0.110	0.905	0.457	1.361
K^+	0.355	0.315	0.200	0.275	0.076	0.164	0.127	0.132
Mg^{2+}	6.761	5.565	1.603	0.797	0.199	0.497	0.298	0.282
Ca^{2+}	10.294	6.898	3.305	1.055	0.099	0.556	0.318	0.321
Cl^-	11.364	10.067	7.797	6.741	2.494	6.179	1.521	2.029
NO_2^-	0.079	0.058	0.028	0.013	0.005	0.017	0.018	0.023
Br	0.071	0.050	0.025	0.017	0.006	0.016	0.008	0.011
NO_3^-	0.846	0.870	0.582	1.676	0.397	0.809	1.433	2.651
SO_4^{2-}	35.473	24.455	6.606	4.222	1.009	2.450	2.878	2.944
$C_2O_4^{2-}$	0.095	0.101	0.087	0.108	0.056	0.057	0.257	0.243
PO_4^{3-}	0.016	0.011	0.013	0.009	0.006	0.013	0.034	0.034
Acetate	0.774	0.552	0.181	0.090	0.058	0.132	0.126	0.143
Formate	1.275	1.040	0.375	0.152	0.086	0.179	0.147	0.174
MSA-	0.089	0.146	0.078	0.095	0.044	0.089	0.096	0.125

Apx Table B.14 24-hour concentrations (in µg C m^{-3}) for PM_{10} samples collected at Morwell South AMS

CARBON FRACTION	26/02/14	27/02/14	5/03/14	6/03/14	7/03/14	12/03/14	14/03/14	20/03/14
OC1	52.04	42.15	17.12	4.39	0.32	6.56	2.84	5.10
OC2	52.36	41.21	9.75	2.33	0.40	3.30	2.12	2.21
OC3	30.14	17.90	8.47	3.77	1.03	5.92	4.66	4.86
OC4	1.75	5.65	2.43	2.83	0.46	2.54	2.48	2.79
OC pyro	31.66	20.88	7.36	0.44	0.08	3.61	0.31	3.78
EC1	50.49	27.64	10.75	2.76	0.42	6.55	4.15	7.40
EC2	0.60	0.12	0.17	0.07	0.01	0.07	0.04	0.17
EC3	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
OC	167.94	127.79	45.13	13.76	2.29	21.93	12.75	18.74
EC	19.46	6.88	3.57	2.39	0.35	3.01	3.53	3.78
TC	187.40	134.68	48.70	16.14	2.64	24.93	16.29	22.52

OC (organic carbon fraction) is defined as OC1+OC2+OC3+OC4+OCpyro

EC (elemental carbon fraction) is defined as EC1+EC2+EC3-OCpyro

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