Results

Age-adjusted mortality

The actual number of deaths and the age-standardised death rates for 2014 and the previous five years for the months February to June can be seen in Table 1 and for the months February to March can be seen in Table 2. For both February-March and February-June periods, the age standardised mortality rates were highest for 2014 and 2009 compared to the years 2010-2013. This is best seen in the comparison between February-March, 2009 and 2014, when the age-standardised rates are 1.5 deaths per 1000 person-years[3] and 1.6 deaths per 1000 person-years respectively (Table 2). Deaths in February-March, 2010–2013 were 1.1 to 1.2 per 1000 person-years. The results of the additional statistical analyses should be examined before concluding whether or not these differences in mortality rates are statistically significant and not due merely to annual random fluctuations, or other non-fire related factors.

Table 1. Age-standardised* mortality rates (ASR) in the Latrobe Valley per 1,000 person-years between February-June, 2009–2014**

Age category	2009 *n*	2009 *ASR*	2010 *n*	2010 *ASR*	2011 *n*	2011 *ASR*	2012 *n*	2012 *ASR*	2013 *n*	2013 *ASR*	2014 *n*	2014 *ASR*
< 50	24	0.3	18	0.4	12	0.3	18	0.2	29	0.3	18	0.4
50-64	22	0.4	24	0.4	34	0.4	32	0.5	27	0.3	32	0.3
≥ 65	225	2.4	189	2.1	184	2.0	157	2.3	170	2.4	188	2.8
All ages	**271**	**3.4**	**231**	**3.2**	**230**	**3.0**	**207**	**3.3**	**226**	**3.3**	**238**	**3.9**

*Directly age-standardised using the 2011 Australian standard population
**Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

Table 2. Age-standardised* mortality rates (ASR) in the Latrobe Valley per 1,000 person-years between February-March, 2009–2014**

Age category	2009 *n*	2009 *ASR*	2010 *n*	2010 *ASR*	2011 *n*	2011 *ASR*	2012 *n*	2012 *ASR*	2013 *n*	2013 *ASR*	2014 *n*	2014 *ASR*
< 50	7	0.1	6	0.2	4	0.1	8	0.1	13	0.1	8	0.1
50-64	10	0.2	9	0.1	10	0.2	14	0.1	9	0.1	16	0.1
≥ 65	94	1.1	63	0.7	68	0.7	59	0.9	59	0.8	84	1.2
All ages	**111**	**1.5**	**78**	**1.2**	**82**	**1.2**	**81**	**1.2**	**81**	**1.1**	**108**	**1.6**

*Directly age-standardised using the 2011 Australian standard population
**Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

3 The person-year is a measure of the estimated time-at-risk for the population under review.

Temperature and air quality

For the months of **February to June**, comparison of the mortality records with the environmental observations shows that there were more deaths occurring on days with mean temperatures at or over 30° C in 2009 and 2014 than in the years 2010–2013 (Table 3). There were 27 deaths that occurred on days with mean temperature at or over 30° C in the affected postcodes for these two years, 13 that occurred in 2009 and seven that occurred in 2014. In contrast, there were less deaths occurring on days with mean air quality at or over 50µg/m^3 PM_{10} in 2009 and 2014 than in the years 2010-2013 (Table 3). There were 93 deaths that occurred on days with mean air quality at or over 50µg/m^3 PM_{10} in the affected postcodes for 2009–14, 15 that occurred in 2013 and nine that occurred in 2014.

For the months of **February to March**, there were 27 deaths occurring on days with mean air quality at or over 50µg/m^3 PM_{10}, and more than half occurred in 2009 and 2014 (Table 4). For 2009 and 2014, 67% of the deaths on days with mean air quality at or over 50µg/m^3 PM_{10} occurred during the fire months of February-March, compared to deaths occurring with similar exposures at other times of the year. There were three deaths in 2011, and all were associated with mean air quality levels at or over 50µg/m^3 PM_{10} in the February-March period (100%).

We note that 68% of the total 93 deaths for February-June 2009–2014 deaths occurred on days of air quality at or over 50µg/m^3 PM_{10} in 2012 and 2013, with most occurring outside the months of February-March (compare Tables 3, 4). Overall for 2009–2014, most deaths during days with air quality at or over 50µg/m^3 PM_{10} in the affected postcodes occurred outside of the February-March period during the months April-June; 85% of these occurred in 2012 and 2013, during the months April-June.

Table 3. Latrobe Valley* number of deaths occurring on days with temperature or air quality exceedances, February-June, 2009–2014

	2009	2010	2011	2012	2013	2014	Total
Temperature ≥ 30° C	13	4	0	0	3	7	27
Air quality ≥ 50µg/m^3 PM_{10}	15	3	3	17	46	9	93

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

Table 4. Latrobe Valley* number of deaths occurring on days with air quality exceedances, February- March, 2009–2014.

	2009	2010	2011	2012	2013	2014	Total
Air quality ≥ 50µg/m^3 PM_{10}	10	2	3	0	8	6	27

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). Deaths on high temperature days are the same as for Table 3 and are not shown here.

Cause of death (Tables 5-8, Figure 1)
Analyses of cause of death are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

There were 10 deaths from *direct relationship with fire* between 2009 and 2014 in the Latrobe Valley; of these, six deaths occurred in February-June 2009 and one in February-June 2013. No deaths from *direct relationship with fire* occurred in February-June 2010–12 or 2014.

Table 5 provides the mortality rate for the months of February to June, and for February to March for 2009-2013 relative to the mortality rate in 2014. For the months **February-June** 2013, we found moderate statistical evidence for a 16% lower *all-cause* mortality rate compared to the same period in 2014 (Table 5, p=0.02). There was no statistical evidence for any differences in mortality between 2014 and any of the years 2009–2012. For the months **February-March**, the *all-cause* mortality rate was 31% lower in 2013 (p=0.01) and 24% lower in 2012 (p=0.05) compared to the same period in 2014 (Table 5). There was no statistical evidence for other differences in mortality for this period in the individual years 2009–2011. Figure 1 shows the data in Table 5 graphically. Caution should be used in interpreting these results, as the confidence intervals for these estimates are broad, and they overlap the 2014 reference rate, and each other.

Air quality ≥ 50μg/m^3 PM_{10} for the entire period was associated with *all-cause* mortality throughout this period (Table 5). Mortality in the **February-March** period was 2.13 times higher on days with air quality ≥ 50μg/m^3 PM_{10} compared to days with lower levels (p<0.01). Mortality in the **February-June** period was 1.83 times higher (p<0.01).

Temperature exceedances do not show statistical evidence of association with *all-cause* mortality in the **February-March** period 2009–2013 compared to February-March 2014. We note that for the months of **February to June**, there is moderate statistical evidence for the association of colder temperatures with mortality.

Cardiovascular mortality for all ages was 42% lower in 2009 compared to 2014, for the **February-March** period, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 7, p=0.05). This finding must be interpreted with caution due to the small number of deaths in this category. There was no statistical evidence for differences in mortality rates due to the other smoke exposure causes (*respiratory* and combined *cardiorespiratory* causes) for these time periods (Table 6, Table 8).

Table 5. Latrobe Valley* *all-cause* mortality in 2009–2013 compared to 2014 for the months February to June and the months February to March

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
Year						
2014	1	–	–	1	–	–
2013	**0.84**	**(0.74-0.97)**	**0.02**	**0.69**	**(0.52-0.90)**	**0.01**
2012	0.87	(0.76-1.00)	0.06	**0.76**	**(0.59-1.00)**	**0.05**
2011	0.89	(0.78-1.03)	0.13	0.86	(0.67-1.12)	0.29
2010	0.95	(0.83-1.09)	0.52	0.84	(0.65-1.09)	0.20
2009	0.93	(0.81-1.06)	0.30	1.01	(0.79-1.28)	0.91
Temperature						
< 30° C	1	–	–	1	–	–
≥ 30° C	**0.55**	**(0.34-0.89)**	**0.02**	1.24	(0.78-1.97)	0.35
PM_{10}						
< 50ug/m^3	1	–	–	1	–	–
≥ 50ug/m^3	**1.83**	**(1.57-2.14)**	**<0.01**	**2.13**	**(1.55-2.91)**	**<0.01**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Figure 1. All cause mortality rate ratios in the Latrobe Valley, 2009–2013 compared to 2014 (Reference rate 1.0)

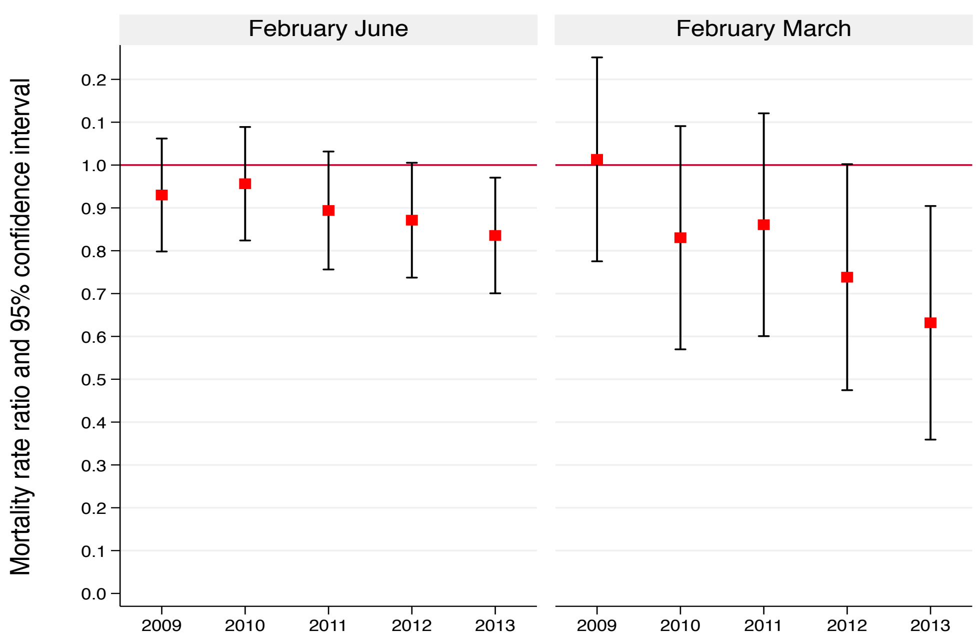

Table 6. Mortality due to respiratory causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

	February-June			February -March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
Year						
2014	1	-	-	1	-	-
2013	1.17	(0.78-1.76)	0.43	1.02	(0.49-2.15)	0.94
2012	1.04	(0.68-1.59)	0.84	1.61	(0.83-3.12)	0.16
2011	1.43	(0.96-2.13)	0.08	1.59	(0.82-3.07)	0.16
2010	1.43	(0.97-2.12)	0.07	1.27	(0.63-2.57)	0.49
2009	0.95	(0.61-1.47)	0.82	1.08	(0.54-2.17)	0.81

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 7. Mortality due to cardiovascular causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	
2013	0.80	(0.57-1.12)	0.21	0.77	(0.46-1.28)	0.32
2012	0.86	(0.62-1.20)	0.39	0.59	(0.34-1.05)	0.08
2011	0.79	(0.56-1.14)	0.22	0.65	(0.38-1.13)	0.14
2010	0.84	(0.60-1.19)	0.34	0.60	(0.34-1.07)	0.09
2009	0.70	(0.49-1.00)	0.06	**0.58**	**(0.34-0.99)**	**0.05**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 8. Mortality due to cardiorespiratory causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	-
2013	0.95	(0.74-1.22)	0.72	0.89	(0.60-1.33)	0.6
2012	0.97	(0.76-1.24)	0.83	0.94	(0.63-1.39)	0.77
2011	1.07	(0.84-1.37)	0.55	0.99	(0.67-1.45)	0.97
2010	1.06	(0.83-1.35)	0.63	0.84	(0.56-1.28)	0.44
2009	0.81	(0.62-1.05)	0.14	0.78	(0.52-1.15)	0.22

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Mortality in the vulnerable age group 65 years and older (Tables 9-12, Figure 2)
Analyses of cause of death in this age group are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

Table 9 provides the mortality rate for the months of February to June, and for February to March for 2009-2013 relative to the mortality rate in 2014. For the months **February-June**, we found moderate statistical evidence for a 15% lower *all-cause* mortality rate for February-June 2012 compared to the same period in 2014 (Table 9, p=0.04) for the vulnerable age group 65 years and older, after adjusting for age, sex, mean daily temperature and 24-hour air quality. The mortality rate for the **February-March** 2013 period was 32% lower for this age group compared to the same period in 2014 (Table 9, p=0.01). The ratio of the mortality rates for 2009–2013 to the mortality rates of 2014 has broad and overlapping associated 95% confidence intervals and must be interpreted with caution. Figure 2 shows the data in Table 9 graphically.

Air quality $\geq 50\mu g/m^3$ PM_{10} for the entire period was associated with *all-cause* mortality throughout this period for this age group (Table 9). Mortality in the **February-March** period was 2.0 times higher on days with air quality $\geq 50\mu g/m^3$ PM_{10} compared to days with lower levels (p<0.01). Mortality in the **February-June** period was 1.74 times higher (p<0.01).

Temperature exceedances do not show statistical evidence of association with *all-cause* mortality in the **February-March** period 2009–2013 compared to February-March 2014 for this age group. We note that there is moderate statistical evidence for the association of colder temperatures with **February-June** mortality for this age group.

Respiratory mortality for this age group was 57% higher in February-June 2011 compared to the same period in 2014, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 10, p=0.03).

Cardiovascular mortality for this age group was 36% lower in 2009 compared to 2014, for the February-March period, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 11, p=0.03). This finding must be interpreted with caution due to the small number of deaths in this category. There was no statistical evidence for differences in mortality rates due to combined *cardiorespiratory* causes for these time periods for this age group (Table 12).

Table 9. Latrobe Valley¶ all cause mortality in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

	February-June			February-March		
	Rate Ratio	**(95% CI)**	**p-value**	**Rate Ratio**	**(95% CI)**	**p-value**
Year						
2014	1	–	–	1	–	–
2013	0.86	(0.74-1.00)	0.06	**0.68**	**(0.50-0.92)**	**0.01**
2012	**0.85**	**(0.73-0.98)**	**0.04**	0.75	(0.56-1.00)	0.06
2011	0.88	(0.75-1.02)	0.11	0.79	(0.59-1.07)	0.14
2010	0.93	(0.80-1.09)	0.41	0.78	(0.58-1.05)	0.11
2009	0.95	(0.82-1.10)	0.5	1.01	(0.77-1.32)	0.92
Temperature						
< 30°C	1	–	–	1	–	–
≥ 30°C	**0.23**	**(0.07-0.79)**	**0.02**	0.55	(0.17-1.77)	0.32
PM_{10}						
< 50ug/m^3	1	–	–	1	–	–
≥ 50ug/m^3	**1.74**	**(1.46-2.09)**	**<0.01**	**2.00**	**(1.36-2.95)**	**<0.01**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Figure 2. All cause mortality rate ratios in the Latrobe Valley, 2009–2013 compared to 2014, *people age 65 years and older,* (Reference rate 1.0)

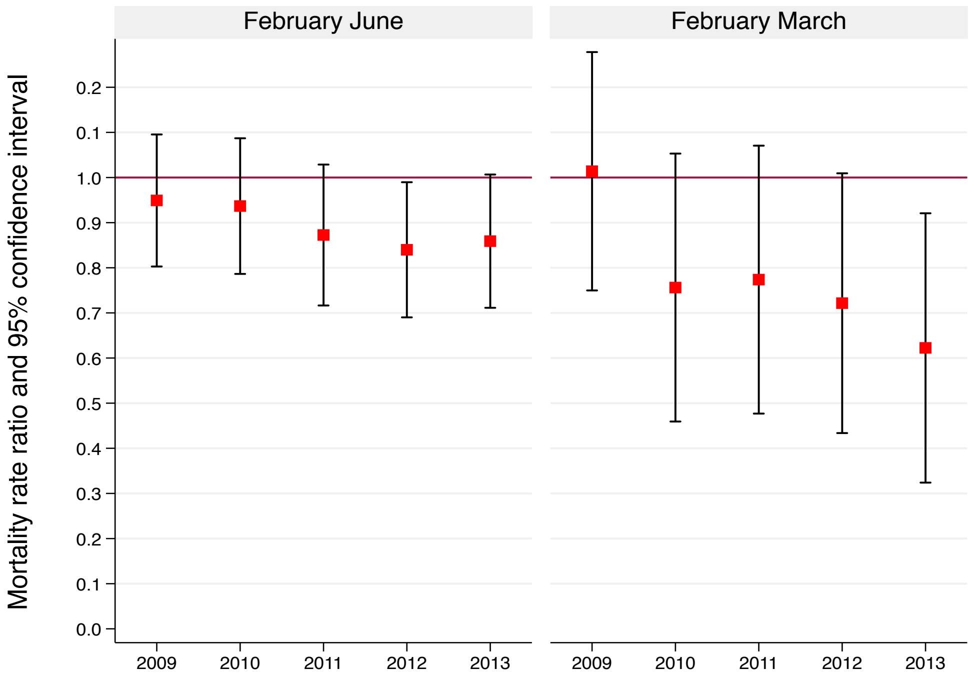

Table 10. Mortality due to respiratory causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	
2013	1.31	(0.87-1.98)	0.19	1.10	(0.53-2.28)	0.79
2012	1.10	(0.71-1.70)	0.67	1.50	(0.76-2.95)	0.23
2011	**1.57**	**(1.03-2.38)**	**0.03**	1.85	(0.94-3.63)	0.07
2010	1.38	(0.90-2.10)	0.13	1.02	(0.47-2.21)	0.95
2009	0.89	(0.56-1.43)	0.65	0.88	(0.41-1.84)	0.74

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 11. Mortality due to cardiovascular causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	-
2013	0.87	(0.61-1.24)	0.45	0.89	(0.53-1.50)	0.68
2012	0.84	(0.59-1.20)	0.36	0.64	(0.36-1.15)	0.14
2011	0.82	(0.56-1.21)	0.33	0.64	(0.34-1.19)	0.17
2010	0.83	(0.57-1.21)	0.36	0.74	(0.41-1.32)	0.31
2009	**0.64**	**(0.43-0.96)**	**0.03**	0.60	(0.34-1.05)	0.08

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 12. Mortality due to cardiorespiratory causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	-
2013	1.05	(0.82-1.35)	0.65	1.00	(0.68-1.48)	0.98
2012	0.99	(0.76-1.28)	0.94	0.96	(0.65-1.42)	0.85
2011	1.14	(0.88-1.47)	0.30	1.05	(0.70-1.57)	0.79
2010	1.04	(0.80-1.35)	0.73	0.84	(0.54-1.31)	0.46
2009	0.76	(0.57-1.02)	0.07	0.71	(0.47-1.09)	0.12

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Discussion

This analysis of the Latrobe Valley mortality data is in essence a comparison of the mortality in the region during the period of the Hazelwood mine fire with mortality in the same place and at the same season in previous years. The type of analysis best suited for this context is an ecological epidemiological analysis that compares data for regions across years. However, this analysis is limited with respect to explaining individual circumstances, and is thus one of the weakest methods for assigning cause of deaths. There are important caveats to note for this type of analysis, especially with respect to the limitations due to the small number of deaths for these comparisons.

The large confidence intervals demonstrate the uncertainties around interpretation of mortality comparisons between 2014 and the previous five years in the Latrobe Valley postcodes, as the numbers are small even with aggregating the four postcodes. Estimated mortality rate ratios for each year and cause of death category have broad and overlapping confidence intervals. Statistical evidence for or against associations with exposures to environmental factors must therefore be interpreted with caution. This means that we are not able to rule in or rule out evidence for excess regional deaths because of the coal fire in 2014.

All-cause and specific causes of death were considered separately, as *cardiovascular* and/or *respiratory* mortality are better indicators of the effects of exposure to smoke and particulate matter. However, in these data, there were insufficient numbers of such deaths to conduct any meaningful comparison between the periods of interest in 2009–2013 and 2014. Findings within the specific cause of death categories are to be interpreted with caution.

The same caveat exists for demonstrating the association of exposure to particulate matter from smoke on *all-cause* mortality in the Latrobe Valley. Whilst there were six deaths in the affected postcodes on days with air quality ≥ $50 \mu g/m^3$ PM_{10} during the 2014 mine fire, there were ten such deaths in 2009 during the same period and eight such deaths in 2013 during the same period. Overall for 2009–2014, most deaths associated with days of mean air quality ≥ 50μg/m^3 PM_{10} in the affected postcodes occurred outside of the February-March period; 85% of these occurred in 2012 and 2013. On average throughout the study period, *all-cause* mortality for all ages was increased by 83% for the months February-June and 113% for the months February-March (Table 5). For the vulnerable age group 65 years and older, *all-cause* mortality was increased by 74% for the months February-June and 100% for the months February-March (Table 9).

These observations mean that there is statistical evidence that air quality ≥ 50μg/m^3 PM_{10} is associated with mortality throughout the entire 2009–2014 study period, not just during the period of the Hazelwood mine fire. The small number of deaths restricts the analysis to air quality measures on the date of death; it is not possible to analyse each death in association with air quality on the day, week or month before that death.

We note in this regard that air quality records for monitoring stations in the affected postcodes show that the mean daily $PM_{2.5}$ level was exceeded during the February-March 2014 period except in Moe. Whilst we cannot compare these records with the same period in previous years, it does suggest that smoke exposure was variable throughout the Latrobe Valley and there may be associated differences in regional mortality that cannot be captured in our analysis.

Whilst extreme summer temperatures have been associated with increased mortality, we have no statistical evidence for this association with mortality in this dataset, once we have adjusted for the effects of air quality. The January 2014 Victorian heatwave may have affected vulnerable people in the Latrobe Valley who later died during the period of the coalmine fire. However, the small number of deaths in the affected postcodes restricts the analysis to temperatures on the date of death; it is not possible to analyse each death in association with temperatures on the day, week or month before that death.

We note that there is moderate statistical evidence for the association of colder temperatures with February-June mortality for all ages, and for the vulnerable age group 65 years and older. This may explain the 57% excess mortality due to *respiratory* causes in 2011 compared to 2014 in the vulnerable elderly. Statistical evidence of the association of colder temperatures and air quality ≥ 50μg/m^3 PM_{10} with mortality could not be demonstrated with these data; however, this lack of evidence does not rule out the possibility of such an effect.

There is moderate statistical evidence that *cardiovascular* mortality was higher during the period of the 2014 fire compared to the 2009 fire. This finding must be interpreted with caution due to the small number of deaths in these categories. There are not sufficient data to associate these excess deaths with specific extremes in air quality or temperature. However, the proposed prospective study that will track Latrobe Valley residents who were exposed during the Hazelwood fire may contribute useful information about the association of exposure to brown coal particulate matter with cardiovascular health.

Conclusion

Our results are based on an ecological epidemiological analysis that compares data for regions across years. It is therefore limited with respect to individual circumstances, and is one of the weakest methods for assigning cause of deaths. While deaths may have been higher in 2014 than some previous years, we are not able to attribute these deaths to the fire, as there was insufficient number of deaths and lack of personal level data and circumstances of deaths. This means that we are not able to rule in or rule out evidence for excess regional deaths because of the coal fire

The analysis of these data shows that 2014 mortality rates did not differ from comparable rates for the same months in 2009, a season similar to 2014 with respect to high temperatures and high particulate matter from bushfire smoke. However, the statistical uncertainty in these estimates, expressed by broad confidence intervals for each of the rate ratios for the years 2009–2013, shows the lack of statistical evidence for an overall higher rate of mortality in 2014.

Mortality in all age groups was 2.13 times higher on days with air quality over 50µg/ m^3 for PM_{10}, compared to days with lower levels for the period February-March, 2009–2014 ($p<0.01$). The mortality in the vulnerable age group 65 years and older was 2.0 times higher on days with air quality over 50µg/ m^3 for PM_{10} compared to days with lower levels for the same period ($p<0.01$). As mortality was associated with air quality over 50µg/ m^3 for PM_{10}, and the fire may have contributed to this measure of air quality, it is possible that a proportion of deaths in 2014 could have been due to the fire in February-March, 2014. However, as we do not know the source of the particulate matter nor the individual circumstances of deaths on days with air quality over 50µg/m^3 for PM_{10} we cannot offer specific conclusions on this matter.

Hazelwood Mine Fire Inquiry

Joint Expert Report – 31 August 2015

Attendees:

Emeritus Professor Bruce Armstrong	Epidemiologist and Public Health Physician
Associate Professor Adrian Barnett	Principal Research Fellow Faculty of Health, School - Public Health and Social Work Queensland University of Technology
Professor Ian Gordon	Director Statistical Consulting Centre, University of Melbourne
Dr. Louisa Flander (via Skype)	Senior Research Fellow, Centre for Epidemiology & Biostatistics, Melbourne School of Population and Global Health, University of Melbourne.
Monica Kelly	HMFI Secretariat – scribe

Conclusions relating to Term of Reference 6: Whether the Hazelwood Coal Mine Fire contributed to an increase in deaths, having regard to any relevant evidence for the period 2009 to 2014;

1. Was there an increase in mortality in Latrobe Valley during the coal mine fire in 2014?

1.1 There is moderate evidence for a higher mortality from all causes and from cardiovascular disease in Latrobe Valley in Feb-Jun 2014 than in the same period during 2009-13.

Agreed by all.

1.2 There is some evidence that the increase in mortality in Feb to Mar 2014 (the period of the mine fire) was greater than the increase in mortality during Feb to Jun 2014.

Additional consensus conclusions:

- The increase in mortality persisted beyond the period of the mine fire though there is weaker evidence for this.

Agreed by all.

1.3 Barnett (2015)[1] reported a 10% higher mortality in Latrobe Valley during February and March 2014 relative to that in the same months in 2004-13. This estimate is broadly consistent with other estimates in this report *(Armstrong's)* but probably attenuated and made statistically weaker by the inclusion of two additional Latrobe Valley postcodes in the analysis.

Agreed by all.

Note: GORDON, BARNETT have not yet had a chance to review the daily death data and noting that FLANDER only reviewed data from 2009 onwards in the four main postcodes.

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[1] Barnett A. *An updated analysis of death data during the Morwell mine fire* first published in 2015 (http://eprints.qut.edu.au/81685/)

[redacted]

- Based on my own analysis *(Gordon)*, in which the period of potentially different risk is assumed to extend beyond the actual time of the fire, (for example, to May 2014), the excess of deaths is statistically significant at conventional levels.

Agreed by all

2. What environmental exposures might have increased mortality in Latrobe Valley during the coal mine fire in 2014?

The associated bushfires?

2.1 Mortality from all causes in February and March and February to June 2014 was closer to that in the corresponding periods of 2009 than in those of 2009-13. This observation may suggest that bushfires, which occurred in Latrobe Valley in February in both 2014 and 2009, contributed to the probable increase in mortality from all causes in 2014. This was not evident for deaths from cardiovascular disease.

ARMSTRONG, FLANDER and GORDON agreed.

BARNETT: Not agreed. Have reservation given in 2014 there two sources of fire and the difficulty distinguishing between the impact of the two. Would like to see further air quality data available across the two time periods and expert opinion on the proportion that was due to the mine fire before agreeing.

Fine particle (smoke) air pollution from the coal mine fire or the bushfires?

2.2 Across the whole period from 2009 to 2014, mortality in Latrobe Valley in both February and March and February to June was higher on days when particulate air pollution was ≥ 50μg/m^3 of PM_{10} than when it was lower.

ARMSTRONG and FLANDER agreed.

GORDON: Qualified agreement: Have not yet had an opportunity to independently analyse the data.
BARNETT: Qualified agreement: Not the best way of analysing the impact of air pollution on health. Need to look at pollution as a linear variable rather than a threshold scale.

2.3 There was no evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher $PM_{2.5}$ levels than on days with lower $PM_{2.5}$ levels. This observation appears not to be consistent with the work of Flander and others (2015)[2], who found that mortality from all causes over the whole period 2009-14 was approximately two-fold higher in Latrobe Valley people exposed to PM_{10} at levels of 50 μG/m^3 or more on the day of death than in people not so exposed. *However, on the evidence of Flander, it is very likely that particulate air pollution during the mine fire caused an increase in mortality, realised, perhaps, more after the period of the fire than during it.

ARMSTRONG & FLANDER: Agreed
GORDON: Qualified agreement: Have not yet had an opportunity to independently assess the data.
BARNETT: Qualified agreement: Concerned about the use of PM_{10} as a threshold scale rather than a linear measure.

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[2] Flander L, Ouakrim DA, Dashti SG and Ugoni A. Age-standardised mortality and cause of death in the Latrobe Valley at the time of (and five years prior to) the Hazelwood coalmine fire in Morwell, Victoria. Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne, 2014.

Additional note: * Removed reference to Abramson reference (from ARMSTRONG's original paper) as all agreed concern about the use of the modelling adopted in this reference, in this circumstance. This is because the model is based on long term exposure for one pollutant, not short term exposure to multiple pollutants as experienced during the Hazelwood coal mine fire.

2.4 Crude mortality data suggest that mortality from all causes in Morwell in February and March and February to June 2014 was little if at all greater than that in the corresponding periods of 2009-13. In Churchill, Moe and Traralgon, however, crude mortality in these periods was greater than in 2009-13. Since Morwell was the most exposed of these populations to emissions from the mine fire, the comparative lack of greater mortality in Morwell in 2014 than 2009-13 is inconsistent with the mine fire being the cause of greater mortality in Latrobe Valley.

ADDED: However this conclusion does not take account of evacuation of some residents from Morwell during the period of the mine fire, which might explain the lack of observed increase in mortality.

Agreed by all

2.5 Barnett (2015)[3] also observed a lack of an increase in mortality in Morwell during February and March 2014 relative to that over the whole period 2004-14.

ADDED: It is acknowledged that due to the statistical uncertainty of this estimate, a large increase in mortality in Morwell cannot be ruled out.

Agreed by all

Carbon monoxide air pollution?

2.6 There was no consistent evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher carbon monoxide levels than on days with lower carbon monoxide levels.

Agreed by all

GORDON: Noted reservation: Have not yet had an opportunity to independently assess the data.
BARNETT: Noted reservation: Concerned about the use of CO as a threshold scale rather than a linear measure.

Very hot days?

2.7 Across the whole period from 2009 to 2014, mortality in Latrobe Valley in February to June was greater on days when the temperature was <30°C than on days when it was higher than this. This difference was not evident in February and March of these years.

Agreed by all

GORDON: Noted reservation: Have not yet had an opportunity to independently assess the data.
BARNETT: Noted reservation: Concerned about the use of temperature as a threshold measure rather than a linear measure.

2.8 There is no evidence that higher temperatures in Latrobe Valley during the period of the mine fire were associated with a higher mortality, whereas there is strong evidence that higher mortality was associated with lower temperatures. Lower temperatures, however, do not appear to explain the

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[3] Barnett A. *An updated analysis of death data during the Morwell mine fire* first published in 2015 (http://eprints.qut.edu.au/81685/)

higher mortality in February and March 2014 than in the same months in 2009-13 as the mean daily temperatures in these two period were nearly identical.

Agreed by all

3. Was there an increase in emergency admissions to hospital (for residents) in Latrobe Valley during the coal mine fire in 2014?

3.1 Emergency hospital admissions for all conditions in the Latrobe Valley during the period of the mine fire in 2014 were more frequent than they were for the same period in 2013. Hospital admission rates for respiratory and cardiovascular diseases, considered individually, were also greater in 2014 than in 2013, though the statistical evidence for these increases was weaker.

Agreed by all

GORDON: Noted reservation: Have not yet had an opportunity to independently assess the data.

3.2 There was strong evidence that emergency hospital admissions were greater in 2014 than 2009-13 in people 25-39 years of age. The causes of this increase should be investigated.

Agreed by all

GORDON: Noted reservation: Have not yet had an opportunity to independently assess the data.

4. Why might emergency admissions have increased?

4.1 Emergency hospital admissions were greater in infants and children (0-4 years of age), albeit with statistically weak evidence in 2014 than in 2009-13, and greater in older people (65-74 years of age and, less so, 75+ years of age). These are recognised vulnerable groups for health impacts of air pollution.

Agreed by all

GORDON: Noted reservation: Have not yet had an opportunity to independently assess the data.

Emeritus Professor Bruce Armstrong

Associate Professor Adrian Barnett

Cited & agreed via email 31/8/15

Dr. Louisa Flander

Professor Ian Gordon

From:	Bruce Armstrong
To:	Justine Stansen
Cc:	Monica Kelly
Subject:	RE: Hazelwood Mine Fire Inquiry
Date:	Friday, 18 September 2015 10:19:21 PM
Attachments:	image001.jpg

Justine

I have now read Adrian Barnett's Analysis of daily death data during the Morwell mine fire (version of September 2015).

His analysis of deaths is, from a technical point of view, an improvement on his previous analyses because it uses daily death data (referenced to the postcode of residence) and Australian Bureau of Statistics population data. It also restricts the analysis to the four postcode areas of greatest interest – Churchill, Moe, Morwell and Traralgon. From this analysis he reports a relative risk of death from the days of the fire (9th February 2015 to 26th March 2014) of 1.32 (95% credible interval of 1.03 to 1.66; p value 0.01). He also estimates the number of additional deaths in the four postcode areas from the period of the fire to be 23, 1 in Churchill, 8 in Moe, 6 in Morwell and 8 in Traralgon.

These estimates take account of the time trend in mortality in these four postcodes from 2009 to 2014, the underlying differences in mortality in the four postcodes, the seasonal variation in mortality, the weekly variation in mortality and the maximum daily temperature. Therefore, on the face of it, the observed relative increase in mortality risk during the period of the mine fire was independent of these other variables.

These results are reasonably coherent with, but suggest a greater increase in mortality in the period of the mine fire than, the other mortality analyses. For example, the table below compares Adrian Barnett's latest result with my result for the period February to March 2014 (Table 2 of my report) based on the Flander et al 2015 analysis.

Years	**February-June**			**February-March**			**Notes**
	Rate ratio	**95% CI**	**p-value**	**Rate ratio**	**95% CI**	**p-value**	
Deaths from all causes							
2014	1			1			
2009-2013[b]	0.90	0.80-1.00	0.04	0.83	0.68-1.02	0.08	As in Table 2 of my report
2009-2013				1.20	0.98-1.47	0.08	Inverted to be in the same form as Barnett's latest result
2009-2013				1.32	1.03-1.66	0.01	Barnett's latest result

The greater increase in mortality in the period of the mine fire could be due, perhaps, to the more precise definition of the period of the fire or to effects of one or more of the variables newly added to Barnett's statistical model for this analysis (time trend in mortality, weekly variation in mortality and maximum daily temperature). Whether it was any of the latter could be tested by removing each in turn from Barnett's statistical model and observing the change in the mine fire result consequent on the removal.

It is worth noting that Barnett's latest analysis shows an excess of deaths during the period of the mine fire in all four postcodes, Morwell included. In his second previous analysis there was an apparent deficit of deaths in Morwell (relative risk 0.8, 95% CI 0.55-1.28; Table 3 of the relevant report). Barnett does not describe how he arrived at the estimated number of extra deaths during the mine fire in the four postcodes.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Bruce Armstrong
Sent: Thursday, 17 September 2015 2:42 PM
To: 'Justine Stansen'
Subject: RE: Hazelwood Mine Fire Inquiry

Thanks Justine. I will be happy to give the Board my opinion. You should have it by Monday.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Justine Stansen [[redacted]]
Sent: Thursday, 17 September 2015 11:29 AM
To: Bruce Armstrong
Subject: Hazelwood Mine Fire Inquiry

Dear Bruce

I trust you are well. We have received some further analysis undertaken by Associate Professor

Adrian Barnett since the Hazelwood Inquiry hearings held earlier this month which is based on daily death data rather than monthly data. I was wondering whether you could consider the **attached** analysis and contact me to discuss your thoughts about it. The Board would be grateful for your additional input in relation to this issue.

I look forward to hearing from you.

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

Analysis of death data during the Morwell mine fire

Summary

The updated analyses gives a 79% to 82% probability of an increase in deaths during the two months of the fire. This is similar to the 80% to 89% probability from the previous analysis. The reduction in probability is because the two additional postcodes (3869 and 3870) showed a slight reduction in death risk.

Allowing the effect of the fire to vary by postcode gives a 94% probability of an increase in deaths in postcode 3844. The highest risks of death were in postcodes 3842 and 3844. There was little to choose statistically between a model with a fixed or varying fire effect across postcodes.

Introduction

This document contains my analysis of the Morwell mine fire data. This is an updated analysis using data from more postcodes for the years 2004 to 2014. Details on the methods can be found in my original analysis available here: `http://eprints.qut.edu.au/76230/`.

I am happy for this document to be freely shared. I am also happy to answer questions via e-mail: a.barnett@qut.edu.au.

Methods

Data

The data were monthly numbers of deaths from 2004 to 2014 for the months of January to December (December data were not available for 2014). The deaths were split by six postcodes (3840, 3842, 3825, 3844, 3869 and 3870) according to usual place of residence. The 11 years, 12 months (11 in 2014) and six postcodes gives 786 observations. There were 6,421 deaths in total.

The previous data were: from 2009 to 2014; only included the months January to June; only included 4 postcodes (3840, 3842, 3825 and 3844); and had 1,811 deaths in total.

Statistical methods

The statistical methods were as per the previous analysis (`http://eprints.qut.edu.au/76230/`) except for the following differences:

1. Fitting temperature as a non-linear effect using a linear and quadratic term. This is because the new data includes all 12 months (the previous data had just six months) and hence we need to model an increased risk of death during both high and low temperatures.

2. An additional analysis using a model that allowed the effect of the fire to vary over the six postcodes. This was based on qualitative evidence about some differences between postcodes in exposures and evacuations. Hence we might expect the effect of the fire to vary over the six postcodes.

3. Using the deviance information criterion (DIC) to compare the models. The DIC compares the fit of the model (that is, how well it explains the observed number of deaths) and includes a penalty for more complex models. Hence it will hopefully find the most simple explanation that best fits the data.

Results

Plots

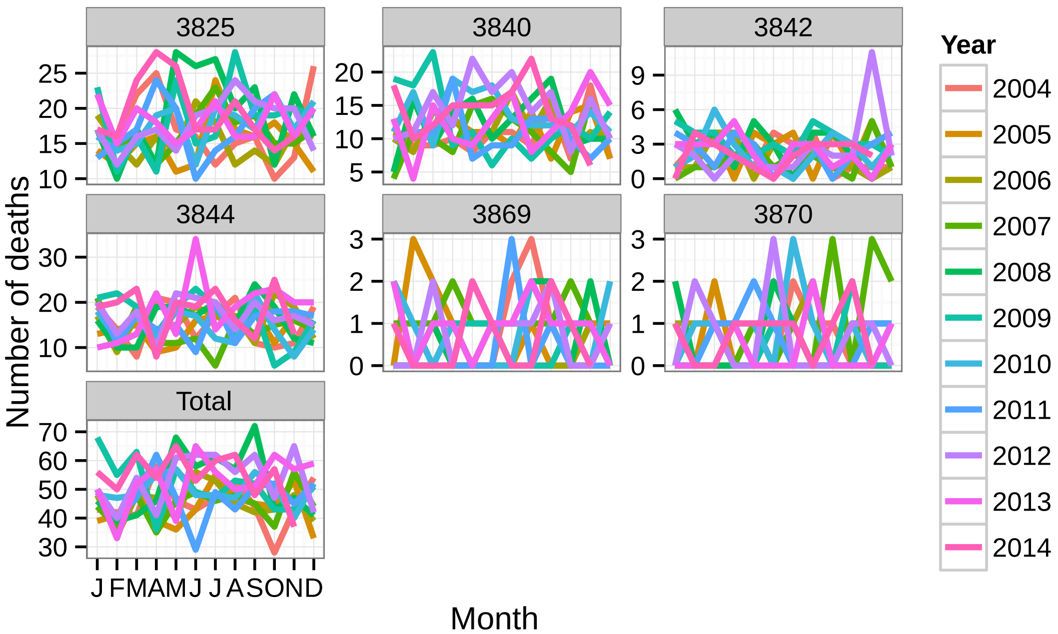

Figure 1: Death numbers by month and year in each postcode and the total number of deaths across the six postcodes. The scales on the y-axes differ between postcodes.

There were relatively large spikes in deaths in June 2013 in postcode 3844 and November 2012 in postcode 3842 (Figure 1). The differences in numbers on the y-axes between panels in Figure 1 are because some postcodes are larger than others.

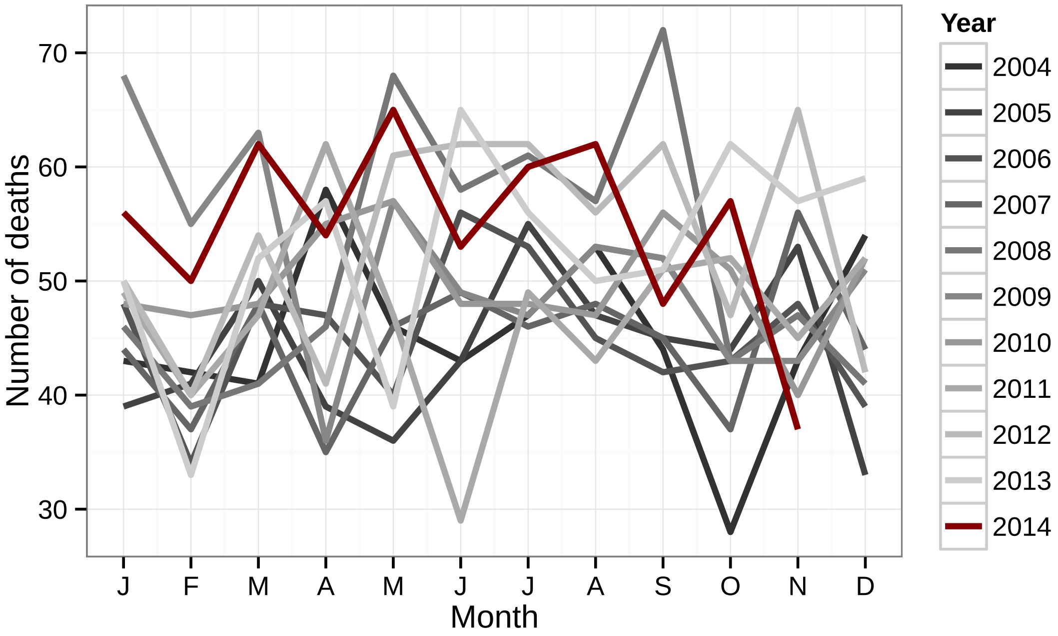

Figure 2: Total deaths across all six postcodes by month and year. The results for 2014 are highlighted in dark red.

Looking at the totals (Figure 2), the deaths in 2014 in February and April do appear to be high. Another year with high deaths rates is 2009 and this may be due to bushfires and extreme heat that summer.

Statistical model results

Table 1: Estimates without adjusting for temperature. Statistics are the mean and lower and upper 95% credible interval. For the effect of the fire the P-value column gives the probability that the risk of death was increased. Estimates are on a log scale except for the relative risks and absolute number of deaths.

	Mean	Lower	Upper	P-value
Intercept	−0.633	−0.691	−0.577	
Trend	0.016	0.008	0.024	
Postcode 3825	1.524	1.459	1.590	
Postcode 3840	1.162	1.093	1.231	
Postcode 3842	−0.504	−0.613	−0.396	
Postcode 3844	1.431	1.366	1.498	
Postcode 3869	−1.740	−1.922	−1.564	
Postcode 3870	−1.873	−2.070	−1.688	
Season, cos	−0.058	−0.093	−0.023	
Season, sin	0.005	−0.030	0.039	
Fire	0.082	−0.117	0.275	0.79
Fire, relative risk	1.090	0.890	1.316	
Absolute deaths	0.739	−0.899	2.583	

The probability that the death rate was higher than the average during the fire is 0.79. This means that the probability that the death rate was not higher than the average during the fire is 0.21. The mean increase in deaths is as a relative risk is 1.09, or 9 as a percentage. The absolute number of deaths per postcode per month is 0.7, which over 6 postcodes and 2 months is 8.4.

The results after adjusting for temperature are in Table 2. The probability that the death rate was higher than the average during the fire is 0.82. The mean increase in deaths is as a relative risk is 1.1, or 10 as a percentage. The absolute number of deaths per postcode per month is 0.8, which over 6 postcodes and 2 months is 9.6.

Table 2: Estimates after adjusting for monthly temperatures. Statistics are the mean and lower and upper 95% credible interval. For the effect of the fire the P-value column gives the probability that the risk of death was increased. Estimates are on a log scale except for the relative risks and absolute number of deaths.

	Mean	Lower	Upper	P-value
Intercept	−0.650	−0.717	−0.584	
Trend	0.016	0.008	0.024	
Postcode 3825	1.524	1.458	1.589	
Postcode 3840	1.161	1.093	1.230	
Postcode 3842	−0.503	−0.613	−0.397	
Postcode 3844	1.431	1.365	1.498	
Postcode 3869	−1.739	−1.924	−1.565	
Postcode 3870	−1.873	−2.066	−1.688	
Season, cos	0.010	−0.119	0.139	
Season, sin	0.005	−0.031	0.040	
Fire	0.093	−0.111	0.291	0.82
Fire, relative risk	1.103	0.895	1.337	
Absolute deaths	0.843	−0.857	2.754	
Temperature, linear	−0.010	−0.028	0.009	
Temperature, quadratic	0.001	−0.001	0.002	

Varying effect of the fire over postcodes

Table 3: Estimates of a varying effect of the fire. Including adjustment for monthly temperatures. Statistics are the mean and lower and upper 95% credible interval. For the effect of the fire the P-value column gives the probability that the risk of death was increased. Estimates are on a log scale except for the relative risks and absolute number of deaths.

	Mean	Lower	Upper	P-value
Intercept	−0.648	−0.714	−0.581	
Trend	0.016	0.008	0.024	
Postcode 3825	1.521	1.457	1.587	
Postcode 3840	1.163	1.095	1.232	
Postcode 3842	−0.509	−0.616	−0.399	
Postcode 3844	1.426	1.359	1.493	
Postcode 3869	−1.734	−1.916	−1.559	
Postcode 3870	−1.867	−2.062	−1.683	
Season, cos	0.008	−0.121	0.138	
Season, sin	0.005	−0.031	0.041	
Fire 3825	0.079	−0.253	0.386	0.69
Fire 3840	−0.157	−0.594	0.243	0.24
Fire 3842	0.228	−0.542	0.906	0.74
Fire 3844	0.246	−0.069	0.552	0.94
Fire 3869	−0.810	−3.057	0.573	0.16
Fire 3870	−0.766	−3.054	0.611	0.18
Fire, relative risk 3825	1.097	0.777	1.471	
Fire, relative risk 3840	0.874	0.552	1.275	
Fire, relative risk 3842	1.343	0.581	2.473	
Fire, relative risk 3844	1.295	0.933	1.737	
Fire, relative risk 3869	0.614	0.047	1.773	
Fire, relative risk 3870	0.642	0.047	1.843	
Absolute deaths 3825	1.687	−3.894	8.208	
Absolute deaths 3840	−1.528	−5.441	3.334	
Absolute deaths 3842	0.788	−0.962	3.385	
Absolute deaths 3844	4.693	−1.064	11.719	
Absolute deaths 3869	−0.256	−0.633	0.514	
Absolute deaths 3870	−0.207	−0.553	0.489	

The estimated risks of the fire in each postcode are in Table 3 and Figure 3. Three of the six postcodes had a decreased mean risk of death. Postcode 3844 had the largest probability that the death rate was increased of 0.94.

The relative risk was similar in postcodes 3842 and 3844 (Figure 3), but there was more certainty in postcode 3844 as the credible intervals were narrower. This is because 3844 has a larger population than 3842.

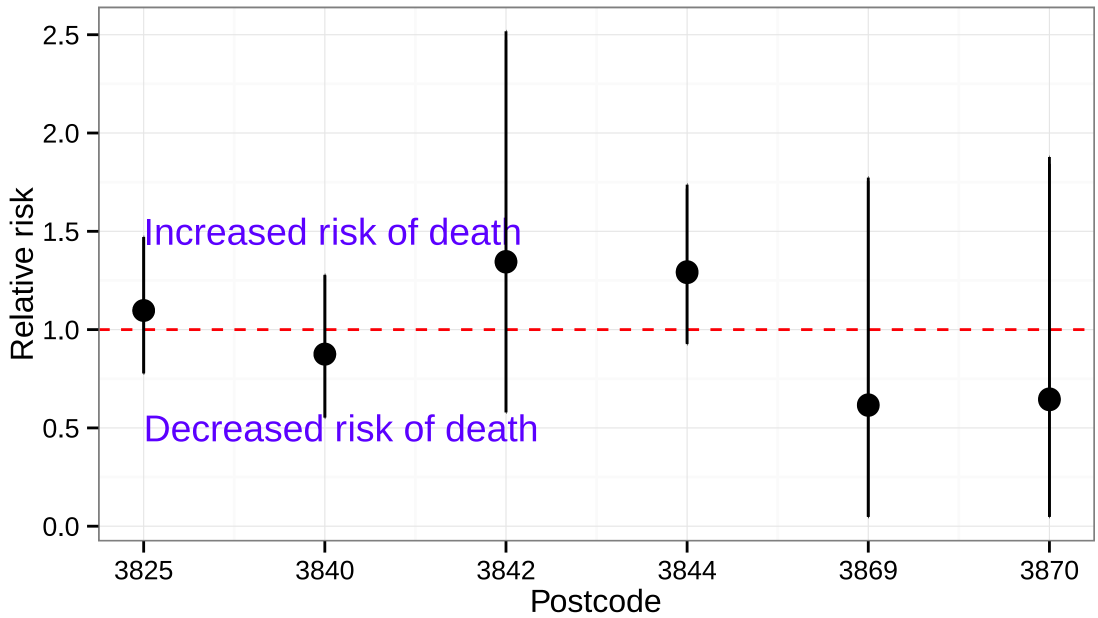

Figure 3: Mean relative risk of deaths due to fire and 95% credible intervals by postcode.

Choosing the best model (deviance information criterion)

Table 4: Deviance information criterion (DIC) and estimated number of parameters (pD). The lower the DIC the better the model.

model	pD	DIC
No weather adjustment, fixed effect of fire across postcodes	10.0	3253.1
Weather adjustment, fixed effect of fire across postcodes	11.9	3255.6
No weather adjustment, varying effect of fire across postcodes	13.5	3253.9
Weather adjustment, varying effect of fire across postcodes	15.6	3256.7

The best model according to the DIC is with no weather adjustment and with a fixed effect of the fire across postcodes (Table 4). However, a difference in the DIC of less than 1 is small, and hence there is little to choose between a model with a fixed and varying effect of the fire.

Residual plots

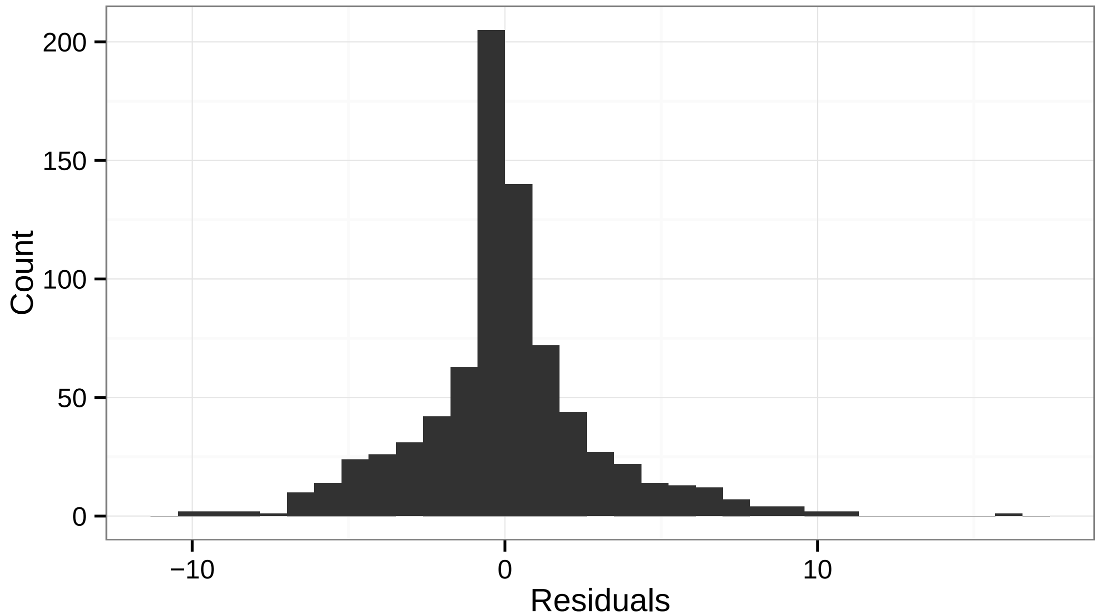

Figure 4: Residuals from the model with no weather adjustment and with a fixed effect of the fire across postcodes.

The residuals are approximately normally distributed (Figure 4). The was one large positive residual which was in postcode 3844 in June 2013 and was 34 deaths when the model predicted only 18. This large spike in deaths was identified in the plots and may have been due to a cold spell and/or flu outbreak.

Better data

A more accurate analysis could be provided by using more accurate data. This would include:

- Using daily death numbers rather than monthly numbers
- Knowing the cause of death
- Knowing the age of death

Having this information would increase the certainty of any association between the fire and death.

KING&WOOD MALLESONS

[redacted]

www.kwm.com

6 October 2015

Chris Fox
Partner
[redacted]

Emily Heffernan
Senior Associate
[redacted]

Dr Philip McCloud
Director and Principal Statistician
McCloud Consulting Group
[redacted]

By email: [redacted]

Dear Philip,

Second Board of Inquiry into Hazelwood Mine Fire – statistical advice

Please find enclosed the following materials:

(A) Statistical reports before the Board for the purposes of the hearings on Term of Reference 6 conducted on 1, 2, 3 and 9 September 2015

A1	Report of Associate Professor Barnett dated September 2014 entitled *Analysis of death data during the Morwell mine fire*
A2	Report of Associate Professor Barnett dated December 2014 entitled *An updated analysis of death data during the Morwell mine fire*
A3	Report of Emeritus Professor Bruce Armstrong dated August 2015 entitled *Expert Assessment and Advice Regarding Mortality Information as it relates to the Hazelwood Mine Fire Inquiry Terms of Reference – Final Report*
A4	Report of Professor Ian Gordon dated 11 August 2015 entitled *Commentary on the Hazelwood Mine Fire and Possible Contribution to Deaths*
A5	Report of Dr Louisa Flander and others dated 28 April 2015 entitled *Review of "Analysis of death data during the Morwell mine fire," A. Barnett, working paper, unpublished (2014, Queensland University of technology) and "An updated analysis of death data during the Morwell mine fire," A. Barnett, working paper, unpublished (2015, Queensland University of technology)"*
A6	Report of Dr Louisa Flander and others dated 4 June 2015 entitled *Age-Standardised Mortality and Cause of Death in the Latrobe Valley at the Time of (and Five Years Prior to) the Hazelwood Coal Mine Fire in Morwell, Victoria*

KWM

A7	Joint Report of Emeritus Professor Bruce Armstrong, Associate Professor Adrian Barnett, Professor Ian Gordon and Dr Louisa Flander dated 31 August 2015, entitled "*Consultations relating to Term of Reference 6: Whether the Hazelwood Mine Coal Mine Fire contributed to an increase in deaths, heaving regard to any relevant evidence for the period 2009 to 2014.*"

(B) Additional statistical reports received from the Board on 30 September 2015

B1	Report of Associate Professor Barnett dated 25 September 2015 entitled *Analysis of daily death data during the Hazelwood mine fire*
B2	Email of Emeritus Professor Bruce Armstrong dated 18 September 2015
B3	Report of Associate Professor Barnett dated 25 September 2015 entitled *Analysis of daily death data during the Hazelwood mine fire* (updated version of B1, produced in response to B2 above)

Request for advice

We would be grateful if you would please set out in a letter to us your comments and observations on the following:

1. <u>In relation to reports A1 – A7 (inclusive) above</u> – the:

   (a) statistical analyses; and

   (b) observations and conclusions,

   outlined of those reports; and

2. <u>In relation to reports B1 – B3 (inclusive) above</u> - the:

   (c) statistical analyses; and

   (d) observations and conclusions,

   outlined in those reports.

Should you have any questions, please contact Emily Heffernan of this office on (03) 9643 4208.

Yours faithfully,

King & Wood Mallesons

From: Heffernan, Emily (AU)
To: [redacted]
Cc: Fox, Chris (AU)
Subject: RE: Hazelwood Mine Fire Inquiry - KWM letter dated 6 October 2015 [KWM-Documents.FID1770821]
Attachments: Hazelwood Mine Fire Inquiry.msg

Dear Philip,

Further to our letter dated 6 October 2015 (below), please find **attached** an email received from the Solicitor to the Board this morning, enclosing:

1. A copy of KWM's letter dated 6 October 2015; and
2. An email from Associate Professor Barnett, together with its attachment, dated 8 October 2015.

Regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

From: Heffernan, Emily (AU)
Sent: Tuesday, 6 October 2015 7:42 PM
To: Philip McCloud [redacted]
Cc: Fox, Chris (AU)
Subject: Hazelwood Mine Fire Inquiry - KWM letter dated 6 October 2015 [KWM-Documents.FID1770821]

Dear Philip,

Please find attached:

1. Our letter dated 6 October 2015; and
2. A zip folder containing reports A1 – A7 and B1 – B3 referred to in the letter.

Please contact me should you wish to discuss.

Regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

This communication and any attachments are confidential and may be privileged.

King & Wood Mallesons in Australia is a member firm of the King & Wood Mallesons network.
See kwm.com for more information.

From: Justine Stansen
To: Heffernan, Emily (AU); Fox, Chris (AU); [redacted]
Robert Perry; Felicity Millner
Subject: Hazelwood Mine Fire Inquiry
Date: Thursday, 8 October 2015 11:57:20 AM
Attachments: image001.jpg
RE Hazelwood Inquiry.msg
4580_001.pdf

Dear all

I refer to the hearing in relation to Term of Reference 6, and in particular to the evidence of Associate Professor Barnett and my letters to you dated 30 September 2015.

The Board received a letter from King & Wood Mallesons dated 6 October 2015 seeking further information about the fourth report of Associate Professor Barnett. Associate Professor Barnett was requested to provide that information by email dated 7 October 2015 to which he responded today. Copies of the letter and emails are **attached**.

Please contact me if you have any queries about the above.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From: Adrian Barnett
To: Justine Stansen
Cc: Peter Rozen; Ruth Shann
Subject: RE: Hazelwood Inquiry
Date: Thursday, 8 October 2015 8:13:39 AM
Attachments: image001.jpg
Death.Analysis.4.pdf

Dear Justine

Please find attached my responses to the four queries. I'm happy to answer further queries.
Regards,

A/Prof Adrian Barnett BSc PhD
Senior Research Fellow
Institute of Health and Biomedical Innovation (IHBI) & School of Public Health and Social Work
Queensland University of Technology
[redacted]

From: Justine Stansen [redacted]]
Sent: Wednesday, 7 October 2015 10:28 AM
To: Adrian Barnett
Cc: Peter Rozen; Ruth Shann
Subject: Hazelwood Inquiry

Dear Adrian

I refer to your report dated 25 September 2015. The Board has received a request from one of the parties seeking further information. The Board would be grateful if you could provide the following:

1. the parameter estimates specified in the statistical model on page 2, together with their standard error and 95% credibility intervals;
2. full details of the "natural spline with three degrees of freedom" fitted with respect to daily maximum temperature, and temperature lag, referred to on page 2;
3. With respect to the results presented in Table 1 on page 3, the results for each individual year from 2009-2013 for the period of the Mine Fire, in comparison to 2014; and
4. the results for all 6 postcodes analysed (as was done in your earlier reports).

We would be grateful if you could provide this information as soon as possible (by 5pm, Thursday 8 October 2015 at the latest).

Kind regards,

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry

[redacted]

Analysis of daily death data during the Hazelwood mine fire

Purpose

The purpose of this document is to answer the four queries below received via e-mail on 7 October 2015.

1. the parameter estimates specified in the statistical model on page 2, together with their standard error and 95% credibility intervals;
2. full details of the "natural spline with three degrees of freedom" fitted with respect to daily maximum temperature, and temperature lag, referred to on page 2;
3. With respect to the results presented in Table 1 on page 3, the results for each individual year from 2009–2013 for the period of the Mine Fire, in comparison to 2014; and
4. the results for all 6 postcodes analysed (as was done in your earlier reports).

1. The parameter estimates

Here is the complete statistical model.

$$
\begin{aligned}
d_{i,t} &\sim \text{Poisson}(\mu_{i,t}), \qquad i = 1, \ldots, 4,\ t = 1, \ldots, 2191, \\
\log(\mu_{i,t}) &= \log(\text{pop}_{i,t}/10000) + \alpha_0 + \text{postcode}_i + \text{trend}_t + \text{season}_t + \text{weekday}_t \\
&+ \text{temperature}_t + \text{fire}_t, \\
\text{postcode}_i &\sim N(0, \sigma^2) \\
\text{trend}_t &= \text{ns}(\alpha_{1:2}, t, 2), \\
\text{season}_t &= \alpha_3 \cos\left[2\pi f(t)\right] + \alpha_4 \sin\left[2\pi f(t)\right], \\
\text{weekday}_t &= \alpha_{5:10}\mathbf{D}_t, \\
\text{temperature}_t &= \text{ns}(\alpha_{11:19}, \text{maximum temperature}_t, 3 \times 3), \\
\text{fire}_t &= \begin{cases} \alpha_{20}, & \text{if date}_t \in \{\text{9-Feb-2014}, \text{10-Feb-2014}, \ldots, \text{26-Mar-2014}\}, \\ 0, & \text{otherwise.} \end{cases}
\end{aligned}
$$

The parameter estimates are in Table 1. The 'Label' column is the label used in the equations above (Greek alpha). I have provided the standard deviation rather than the standard error of the mean. This is because Bayesian estimates are based on a large number of Markov chain Monte Carlo samples and use an entire distribution, hence the standard deviation is a better measure of spread [1]. Standard statistical methods to calculate confidence intervals use a formula that includes the standard error of the mean.

A minor point, the correct term is 'credible interval' not 'credibility interval'.

Table 1: Model of daily deaths. Statistics are the mean, standard deviation (SD) and lower and upper 95% credible interval. Estimates are on a log scale.

	Label	Mean	SD	Lower	Upper
Intercept	α_0	−1.601	0.065	−1.732	−1.475
Trend, 1	α_1	−0.125	0.113	−0.346	0.096
Trend, 2	α_2	0.137	0.062	0.016	0.258
Season, cos	α_3	0.105	0.083	−0.057	0.269
Season, sin	α_4	0.059	0.048	−0.033	0.153
Monday	α_5	−0.069	0.064	−0.196	0.056
Tuesday	α_6	−0.096	0.065	−0.223	0.031
Wednesday	α_7	−0.042	0.063	−0.165	0.083
Thursday	α_8	−0.060	0.064	−0.186	0.064
Friday	α_9	0.049	0.063	−0.074	0.172
Saturday	α_{10}	0.008	0.063	−0.114	0.131
Temperature, 1	α_{11}	0.103	0.068	−0.030	0.238
Temperature, 2	α_{12}	−0.046	0.169	−0.378	0.286
Temperature, 3	α_{13}	−0.097	0.116	−0.324	0.133
Temperature, 4	α_{14}	−0.104	0.044	−0.193	−0.018
Temperature, 5	α_{15}	0.030	0.104	−0.176	0.228
Temperature, 6	α_{16}	0.028	0.076	−0.123	0.175
Temperature, 7	α_{17}	0.029	0.057	−0.085	0.140
Temperature, 8	α_{18}	−0.177	0.136	−0.439	0.090
Temperature, 9	α_{19}	−0.187	0.094	−0.372	−0.004
Fire	α_{20}	0.281	0.120	0.033	0.504
Postcode, 3825	postcode_1	0.285	0.031	0.225	0.346
Postcode, 3840	postcode_2	0.129	0.034	0.062	0.194
Postcode, 3842	postcode_3	−0.310	0.059	−0.426	−0.196
Postcode, 3844	postcode_4	−0.104	0.031	−0.165	−0.042

2. Details of the spline

A spline is a method of fitting a non-linear association between an exposure and outcome. In this case the exposure is daily temperature and the outcome is daily deaths. Non-linear means that the association is not a straight line, and this is needed here because both low and high temperatures are often associated with an increased risk of death. This means the association is often J- or U-shaped [2].

Another important consideration is that there can be delay between exposure to temperature and death. For example, a person exposed to low temperatures may become sick, be hospitalised and then die, and this chain of events may take a week or longer. I assumed that the delayed association was also non-linear, because previous studies have often found a strong short-term association for high temperatures, and longer lasting effect for low temperatures [3, 4, 5]. The maximum lag (delay between exposure and death) was 21 days, and this was chosen based on recent published papers and biological plausibility.

The spline was fitted using the 'dlnm' package in R [6]. I used three degrees of freedom as this corresponds to two change-points in the association, and this matches the theory of a change in risk for low and high temperatures. More degrees of freedom would allow a bendier association with more change-points. The change-points are partly determined by the knots which act like pivot-points. The knots were at 16.5 and 22.3 degrees C, which are the 33rd and 66th percentiles of temperature. The knot for lag was at 10.5 days, half way between 0 and 21 days (the minimum and maximum lags). The knots were selected using the default settings in 'dlnm'. The reference temperature was 20.5 degrees which is the average daily maximum temperature. The relative risk will be 1 for 20.5 degrees and all other temperatures will be compared to this average temperature.

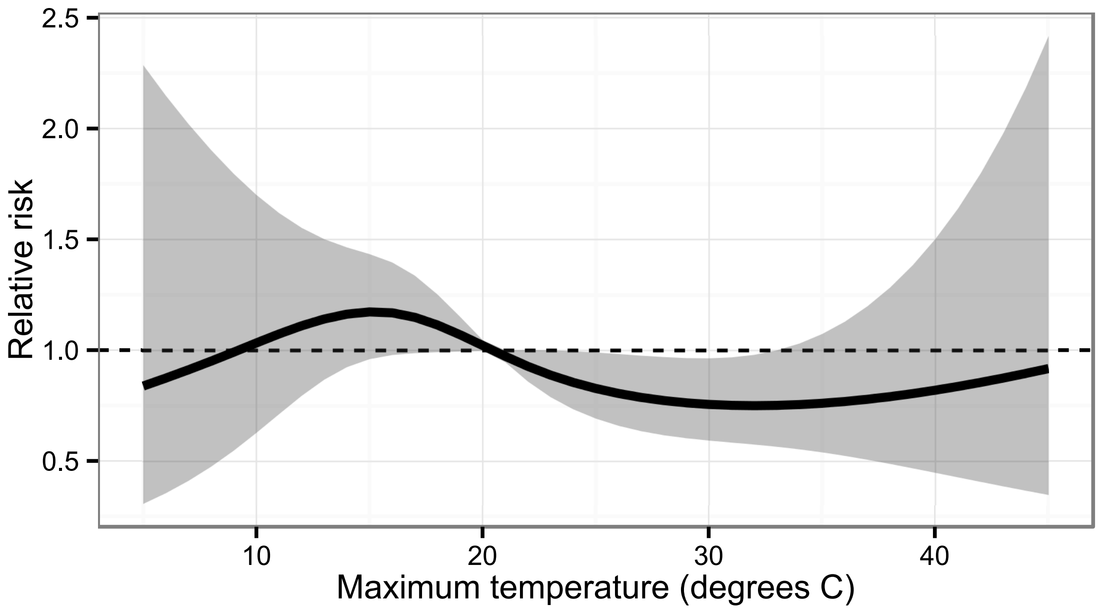

Figure 1: Estimated overall relative risk of maximum daily temperature (°C). The black line is the mean risk and the shaded areas are 95% credible intervals. The dotted horizontal line at a relative risk of 1 corresponds to no change in risk.

The overall effect of temperature is plotted in Figure 1. The lowest mean risk is around 32 degrees and the highest mean risk is around 15 degrees. The credible intervals are wider for very low and high temperatures due to the smaller number of days with extreme temperatures which increases the uncertainty.

Three estimates of the lagged effect of temperature are plotted in Figure 2. The relative risks were close to 1 for low temperatures of 10 degrees. The most notable feature is a short-term increase in risk for high temperatures (40 degrees) at lags 0 to 5 days, followed by a decrease in risk at 15 to 21 days. This decrease in risk may be due to 'harvesting' where some of the deaths caused by high temperatures were in already ill people who would have died soon after regardless of the temperature [2].

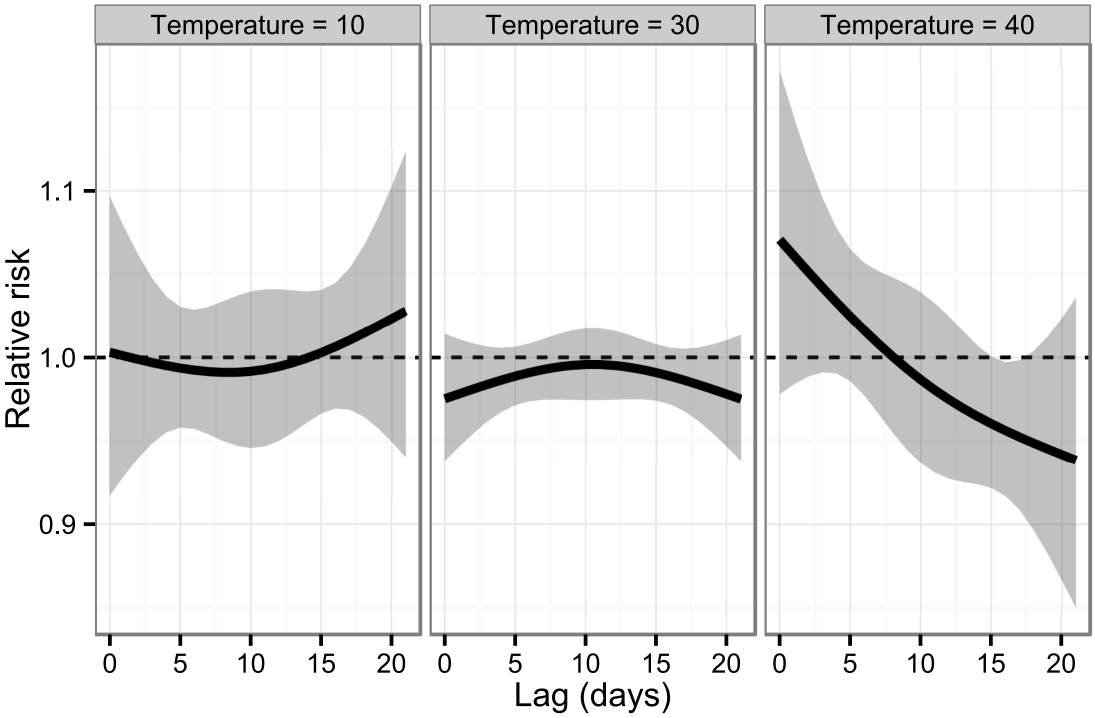

Figure 2: Estimated delayed relative risk of maximum daily temperature for three temperatures. The black line is the mean risk and the shaded areas are 95% credible intervals. The dotted horizontal line at a relative risk of 1 corresponds to no change in risk.

3. Results for individual years

The table below gives summary statistics on the daily number of deaths for the period of the fire (9 February to 26 March) in each year and postcode.

			Deaths			
Postcode	Year	N	Mean	SD	Min	Max
Churchill	2009	46	0.152	0.36	0	1
	2010	46	0.065	0.25	0	1
	2011	46	0.043	0.21	0	1
	2012	47	0.043	0.20	0	1
	2013	46	0.087	0.28	0	1
	2014	46	0.130	0.40	0	2
Moe	2009	46	0.391	0.49	0	1
	2010	46	0.500	0.75	0	2
	2011	46	0.500	0.62	0	2
	2012	47	0.511	0.66	0	2
	2013	46	0.522	0.69	0	2
	2014	46	0.717	0.81	0	3
Morwell	2009	46	0.652	0.87	0	3
	2010	46	0.261	0.49	0	2
	2011	46	0.348	0.60	0	2
	2012	47	0.426	0.50	0	1
	2013	46	0.370	0.71	0	3
	2014	46	0.413	0.62	0	2
Traralgon	2009	46	0.587	0.72	0	2
	2010	46	0.522	0.69	0	3
	2011	46	0.457	0.81	0	4
	2012	47	0.511	0.62	0	2
	2013	46	0.391	0.61	0	2
	2014	46	0.652	0.87	0	3

4. Results for all six postcodes

It is not possible to present the daily results for all six postcodes as the only daily data I have are for Moe (3825), Churchill (3842), Traralgon (3844) and Morwell (3840).

References

[1] A. Gelman, J.B. Carlin, H.S. Stern, D.B. Dunson, A. Vehtari, and D.B. Rubin. *Bayesian Data Analysis, Third Edition*. Chapman & Hall/CRC Texts in Statistical Science. Taylor & Francis, 2013.

[2] Ben Armstrong. Models for the relationship between ambient temperature and daily mortality. *Epidemiology*, 17(6):624–631, 2006.

[3] Jun Yang, Chun-Quan Ou, Yan Ding, Ying-Xue Zhou, and Ping-Yan Chen. Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. *Environmental Health*, 11:63, 2012.

[4] Marco Morabito, Alfonso Crisci, Marco Moriondo, Francesco Profili, Paolo Francesconi, Giacomo Trombi, Marco Bindi, Gian Franco Gensini, and Simone Orlandini. Air temperature-related human health outcomes: Current impact and estimations of future risks in central Italy. *Science of The Total Environment*, 441:28–40, 2012.

[5] Antonio Gasparrini and et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, 386(9991):369–375, 2015.

[6] Antonio Gasparrini. Distributed lag linear and non-linear models in R: the package dlnm. *Journal of Statistical Software*, 43(8):1–20, 2011.

KING&WOOD MALLESONS

[redacted]

www.kwm.com

6 October 2015

Chris Fox
Partner
[redacted]

Emily Heffernan
Senior Associate
[redacted]

Ms Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

By email

Dear Justine,

Hazelwood Mine Fire Inquiry – Term of Reference 6

We refer to your letter dated 30 September 2015.

Your letter encloses two further reports prepared by Associate Professor Barnett dated 15 and 25 September 2015 (**Proposed Additional Reports**), together with certain email correspondence between the Board's Solicitors / Secretariat and Associate Professor Barnett and Professor Armstrong, and advises that the Board will be holding a further hearing to consider this "*additional evidence*" on 15 October 2015.

Our client is extremely concerned with the manner in which this aspect of the Inquiry is proceeding.

Both of the Proposed Additional Reports have been prepared by Associate Professor Barnett after the public hearings in relation to TOR6 and the previous reports of the invited experts were concluded on 1, 2 and 3 September 2015, and after final submissions were made on 9 September 2015 in relation to the evidence of these experts by Counsel Assisting and by the parties in respect of whom leave to appear had been granted.

As stated by the Chairman at the conclusion of the hearing on 9 September 2015 (at Tr 716.25):

> "*There may or may not be further hearings but certainly not in respect of this matter*"

Nevertheless, it appears from your letter that the Proposed Additional Reports of Associate Professor Barnett are being admitted by the Board without any argument or consideration of whether that should occur at all, and further that there is to be a hearing to "*consider this additional evidence*" on 15 October 2015 next week without regard to whether this date is appropriate or convenient for the parties, including our client, or is sufficient to enable a proper and fair evaluation of the purported new material.

This apparent treatment of the Proposed Additional Reports must be assessed in light of (amongst other things):

(a) the previous difficulties that were raised in our client's Submissions (and by others) by reason of the significantly compressed timelines allowed for the consideration of the material that was utilised for

KWM

the purposes of the hearings on 1, 2 and 3 September 2015;

(b) the serious nature of the matter the subject of TOR6;

(c) the fact that the Proposed Additional Reports are by Associate Professor Barnett who, for the reasons set out in our client's Submissions, cannot be considered independent; and

(d) the fact that it is proposed to question the other three invited experts about the Proposed Additional Reports at the hearing on 15 October 2015 in circumstances where our client has no indication as to the evidence that they will give, and noting that that our client identified the belated introduction of oral evidence from these same witnesses on the issue of a possible causal correlation between any supposed increase in mortality and the Mine Fire as a particular mischief of the way evidence was led at the last public hearing.

For these reasons, our client respectfully submits that the Proposed Additional Reports, which have been prepared after the conclusion of the hearings in relation to this matter, should not be admitted.

If notwithstanding our client's position that the Proposed Additional Reports should not be admitted, the Board nevertheless intends to admit them, then our client notes the following.

It is readily apparent from an initial review of the Proposed Additional Reports in the limited time since they were received that further details and information are required in order for there to be any prospect of the Reports being meaningfully understood.

For example, it is plain that the modelling undertaken for the Proposed Additional Reports is different from that contained in the reports before the Board at the hearings on 1, 2 and 3 September 2015. Required details and information include:

1. for the statistical model described on page 2 - all parameter estimates specified in the model, together with their standard errors and 95% credibility intervals;

2. full details of the "*natural spline with three degrees of freedom*" fitted with respect to daily maximum temperature, and temperature lag, referred to on page 2;

3. for the results presented in Table 1 on page 3 – results for each individual year from 2009 – 2013 for the period of the Mine Fire, in comparison to 2014; and

4. results for all 6 postcodes analysed in Associate Professor Barnett's previous reports (instead of the 4 postcodes for which results have been included in the Proposed Additional Reports).

(note: all page references are to Associate Professor Barnett's report dated 25 September 2015).

If the Board is admitting the Proposed Additional Reports, we request that we be provided with the foregoing information and details as soon as possible.

Please note that even if this information and details are provided, it may not be possible to properly and fairly assess the new modelling and the Proposed Additional Reports by 15 October 2015.

Yours sincerely,

King & Wood Mallesons

From:	Heffernan, Emily (AU)
To:	Philip McCloud [redacted]
Subject:	FW: Hazelwood Mine Fire Inquiry [KWM-Documents.FID1770821]
Attachments:	image001.jpg RE Hazelwood Inquiry.msg RE Hazelwood Mine Fire Inquiry.msg

Dear Philip,

Further to our letter dated 6 October 2015, please see below further email correspondence received from the solicitor to the Board this morning, enclosing emails between the Board and Professor Bruce Armstrong.

Kind regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

From: Justine Stansen [[redacted]
Sent: Friday, 9 October 2015 11:56 AM
To: Heffernan, Emily (AU) <[redacted]
Subject: RE: Hazelwood Mine Fire Inquiry

Dear Chris/Emily

I refer to my letter sent yesterday. I **attach** emails to and from Professor Bruce Armstrong in relation to the fourth report of Associate Professor Adrian Barnett dated 7 and 8 October 2015 respectively I have also forward the email to Associate Professor Barnett. I will send you the response from Associate Professor Barnett when received.

Kind regards,

From: Justine Stansen
Sent: Thursday, 8 October 2015 3:28 PM
To: 'Heffernan, Emily (AU)'; 'Fox, Chris (AU)'
Subject: Hazelwood Mine Fire Inquiry

Dear Chris/Emily

Please see **attached** letter.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From: Justine Stansen
To: Bruce Armstrong
Subject: RE: Hazelwood Inquiry
Attachments: image003.jpg
image004.jpg

Dear Bruce

Further to my email below, could you provide to the Board a short report in relation to the fourth report of Associate Professor Barnett dated 25 September 2015. The Board is interested in your opinion as to whether the fourth report has taken into account your earlier observations and whether you agree or disagree with the methodology used and conclusions reached.

The Board would be grateful if you could provide your report by 4pm on Friday, 9 October 2015. Please let me know if you have any questions.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From: Justine Stansen
Sent: Wednesday, 30 September 2015 8:40 PM
To: 'Bruce Armstrong'
Subject: Hazelwood Inquiry

Dear Bruce

I refer to Term of Reference 6 and the recent public hearings held on 1-3 and 9 September 2015. During the course of those hearings two reports prepared by Associate Professor Barnett were tendered.

On 11 September 2015, Associate Professor Adrian Barnett contacted the Secretariat and indicated that he was undertaking further analysis of the daily death data provided to him prior to the hearing and that he intended to produce a further report that he wished to publish.

On 15 September 2015, Associate Professor Barnett provided that third report to the Board. On 17 September 2015, the Board sought your views concerning the third report of Associate Professor Barnett. Your comments in relation to the third report were provided to the Board on 18 September 2015 and were forwarded to Associate Professor Barnett by the Board in an email dated 24 September 2015. On 25 September 2015, Associate Professor provided a fourth report to the Inquiry.

Copies of the correspondence described above and the third and fourth reports of Associate Professor Barnett are **attached**. Copies of the reports and the correspondence will also be provided to all experts who gave evidence at the hearing in relation to Term of Reference 6.

The Board will holding a short further hearing to consider this additional evidence held on **15 October 2015 from 9.00 am** in Melbourne. The hearing will take place on level 11, 222 Exhibition St Melbourne. The Board requests that all experts who gave evidence in the early September hearing appear again as witnesses as a panel and will be questioned about this new material by Counsel Assisting and any other party.

I would be grateful if you could confirm that you are available to appear by skype on 15 October 2015.

If you have any questions about the above, please contact me.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]:[redacted]

From:	Bruce Armstrong
To:	Justine Stansen
Cc:	Monica Kelly
Subject:	RE: Hazelwood Mine Fire Inquiry
Date:	Thursday, 8 October 2015 10:54:22 PM
Attachments:	image002.jpg

Justine

Thank you for asking me to comment on Associate Professor Adrian Barnett's fourth report, which was attached as file Death.Analysis.3.pdf to an email he sent you on 25th September 2015. Barnett states that this fourth report was an expansion on his original (I assume immediately previous) analysis to answer [my] questions.

His further analysis responds effectively to these of my observations about the previous report:

"The greater increase in mortality in the period of the mine fire could be due, perhaps, to the more precise definition of the period of the fire or to effects of one or more of the variables newly added to Barnett's statistical model for this analysis (time trend in mortality, weekly variation in mortality and maximum daily temperature). Whether it was any of the latter could be tested by removing each in turn from Barnett's statistical model and observing the change in the mine fire result consequent on the removal."

His further results in Table 5 on page 11 show that the relative risk of death during the mine fire was sensitive to the (appropriate) inclusion of temperature in the model, and that this inclusion partly explains the higher relative risk of death during the mine fire that he observed in this model. I agree with him that adjustment for the effects of temperature is appropriate and thus that temperature should be in the model.

It does not appear to me that his further analysis has fully responded to these of my observations about the previous report:

"It is worth noting that Barnett's latest analysis shows an excess of deaths during the period of the mine fire in all four postcodes, Morwell included. In his second previous analysis there was an apparent deficit of deaths in Morwell (relative risk 0.8, 95% CI 0.55-1.28; Table 3 of the relevant report). Barnett does not describe how he arrived at the estimated number of extra deaths during the mine fire in the four postcodes."

Barnett now describes how the numbers of additional deaths due to the fire in each postcode were calculated. This explanation, however, is not clear to me. There are two variables in the expression that Barnett offers on page2, 4th line up from the bottom of the page:

1. The mean number of deaths per day for each postcode.
   The period over which this average has been calculated is not stated; It should be. As I see it, the period should (a) be relatively recent so that it can provide a reasonably unbiased estimate of the expected number of deaths in the four postcode areas over the period of the fire, (b) not include the observed deaths during the period of the mine fire and (c) be based on a period long enough to remove most of the effect of day to day variation in daily numbers on the calculated mean numbers. All these may be true, but it is not clear that they are.

2. Exp (a_{20}), the relative risk of death during the fire. As far as I can tell this is the relative risk across all four postcodes. If this is true, postcode specific relative risks have not been used when estimating the excess deaths and, therefore, previously apparent variation between postcodes in relative risk of death during the period of the mine fire is not taken into account when calculating the numbers of excess deaths. If this is correct, a deficit of deaths in Morwell during the period of the mine fire would be obscured in this analysis.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Bruce Armstrong
Sent: Friday, 18 September 2015 10:18 PM
To: Justine Stansen ([redacted])
Cc: Monica Kelly
Subject: RE: Hazelwood Mine Fire Inquiry

Justine

I have now read Adrian Barnett's Analysis of daily death data during the Morwell mine fire (version of September 2015).

His analysis of deaths is, from a technical point of view, an improvement on his previous analyses because it uses daily death data (referenced to the postcode of residence) and Australian Bureau of Statistics population data. It also restricts the analysis to the four postcode areas of greatest interest – Churchill, Moe, Morwell and Traralgon. From this analysis he reports a relative risk of death from the days of the fire (9th February 2015 to 26th March 2014) of 1.32 (95% credible interval of 1.03 to 1.66; p value 0.01). He also estimates the number of additional deaths in the four postcode areas from the period of the fire to be 23, 1 in Churchill, 8 in Moe, 6 in Morwell and 8 in Traralgon.

These estimates take account of the time trend in mortality in these four postcodes from 2009 to 2014, the underlying differences in mortality in the four postcodes, the seasonal variation in mortality, the weekly variation in mortality and the maximum daily temperature. Therefore, on the face of it, the observed relative increase in mortality risk during the period of the mine fire was independent of these other variables.

These results are reasonably coherent with, but suggest a greater increase in mortality in the period of the mine fire than, the other mortality analyses. For example, the table below compares Adrian Barnett's latest result with my result for the period February to March 2014 (Table 2 of my report) based on the Flander et al 2015 analysis.

Years	February-June			February-March			Notes
	Rate ratio	95% CI	p-value	Rate ratio	95% CI	p-value	
Deaths from all causes							
2014	1			1			
2009-2013[b]	0.90	0.80-1.00	0.04	0.83	0.68-1.02	0.08	As in Table 2 of my report
2009-2013				1.20	0.98-1.47	0.08	Inverted to be in the same form as Barnett's latest result
2009-2013				1.32	1.03-1.66	0.01	Barnett's latest result

The greater increase in mortality in the period of the mine fire could be due, perhaps, to the more precise definition of the period of the fire or to effects of one or more of the variables newly added to Barnett's statistical model for this analysis (time trend in mortality, weekly variation in mortality and maximum daily temperature). Whether it was any of the latter could be tested by removing each in turn from Barnett's statistical model and observing the change in the mine fire result consequent on the removal.

It is worth noting that Barnett's latest analysis shows an excess of deaths during the period of the mine fire in all four postcodes, Morwell included. In his second previous analysis there was an apparent deficit of deaths in Morwell (relative risk 0.8, 95% CI 0.55-1.28; Table 3 of the relevant report). Barnett does not describe how he arrived at the estimated number of extra deaths during the mine fire in the four postcodes.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

[redacted]

From: Bruce Armstrong
Sent: Thursday, 17 September 2015 2:42 PM
To: 'Justine Stansen'
Subject: RE: Hazelwood Mine Fire Inquiry

Thanks Justine. I will be happy to give the Board my opinion. You should have it by Monday.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Justine Stansen [[redacted]
Sent: Thursday, 17 September 2015 11:29 AM
To: Bruce Armstrong
Subject: Hazelwood Mine Fire Inquiry

Dear Bruce

I trust you are well. We have received some further analysis undertaken by Associate Professor Adrian Barnett since the Hazelwood Inquiry hearings held earlier this month which is based on daily death data rather than monthly data. I was wondering whether you could consider the **attached** analysis and contact me to discuss your thoughts about it. The Board would be grateful for your additional input in relation to this issue.

I look forward to hearing from you.

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From: Heffernan, Emily (AU)
To: "Philip McCloud ([redacted]"
Cc: Fox, Chris (AU)
Subject: Hazelwood Mine Fire Inquiry #2 [KWM-Documents.FID1770821]
Attachments: 22407956_1.pdf

Dear Philip,

We refer to our letter dated 6 October 2015.

We have received a copy of data supplied to the Board by the Victorian Registry of Births, Deaths and Marriages (**BD&M**), concerning deaths recorded in 2014 and part of 2015, with respect to the following (eight) postcode areas: 3844, 3840, 3825, 3842, 3870, 3854, 3856, and 3869.

Please find **attached** a table prepared by King & Wood Mallesons, summarising the deaths recorded by BD&M for each individual postcode area (where Usual Place of Residence) in the period 9 February – 25 March.

Kind regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted] 9643 5999
[redacted]

Hazelwood Mine Fire Inquiry - Term of Reference 6

Summary of deaths recorded by Births Deaths & Marriages in the period 9 February – 25 March (Postcode of Usual Place of Residence)

Postcode	2014	2015
3840	18	22
3842	6	6
3825	32	29
3844	27	20
4 postcode total	**83**	**77**
3869	0	3
3870	0	1
6 postcode total	**83**	**81**
3854	1	0
3856	2	0
8 postcode total	**86**	**81**

From:	Heffernan, Emily (AU)
To:	"Philip McCloud [redacted]"
Cc:	Fox, Chris (AU)
Subject:	FW: Hazelwood Mine Fire Inquiry [KWM-Documents.FID1770821]
Attachments:	image001.jpg image003.jpg RE Hazelwood Mine Fire Inquiry.msg

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Dear Philip,

Further to our letter dated 6 October 2015, please see below and attached further information received from the Board this afternoon.

Kind regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

From: Justine Stansen [redacted]
Sent: Saturday, 10 October 2015 2:08 PM
To: Heffernan, Emily (AU); Fox, Chris (AU)
Subject: RE: Hazelwood Mine Fire Inquiry

Dear Emily/Chris

Further to my email below, please see attached email from Assoc Prof Barnett received last night.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

cid:image001.jpg@01D0BF00.FDC13FB0

From: Justine Stansen
Sent: Friday, 9 October 2015 11:55 AM
To: 'Heffernan, Emily (AU)'; 'Fox, Chris (AU)'
Subject: RE: Hazelwood Mine Fire Inquiry

Dear Chris/Emily

I refer to my letter sent yesterday. I **attach** emails to and from Professor Bruce Armstrong in relation to the fourth report of Associate Professor Adrian Barnett dated 7 and 8 October 2015 respectively I have also forward the email to Associate Professor Barnett. I will send you the response from Associate Professor Barnett when received.

Kind regards,

From: Justine Stansen
Sent: Thursday, 8 October 2015 3:28 PM
To: 'Heffernan, Emily (AU)'; 'Fox, Chris (AU)'
Subject: Hazelwood Mine Fire Inquiry

Dear Chris/Emily

Please see **attached** letter.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From:	Adrian Barnett
To:	Justine Stansen
Subject:	RE: Hazelwood Mine Fire Inquiry
Date:	Friday, 9 October 2015 8:42:14 PM
Attachments:	image001.jpg image002.jpg Death.Analysis.5.pdf

Dear Justine

Please find attached my responses to Prof Armstrong's queries. Regards,

Adrian

From: Justine Stansen [redacted]
Sent: Friday, 9 October 2015 10:55 AM
To: Adrian Barnett
Subject: FW: Hazelwood Mine Fire Inquiry

Dear Adrian

Please see email below received from Professor Bruce Armstrong. I would be grateful if you could provide any comment on the matters raised below as soon as possible.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

From: Bruce Armstrong [[redacted]
Sent: Thursday, 8 October 2015 10:47 PM
To: Justine Stansen
Cc: Monica Kelly
Subject: RE: Hazelwood Mine Fire Inquiry

Justine

Thank you for asking me to comment on Associate Professor Adrian Barnett's fourth report, which was attached as file Death.Analysis.3.pdf to an email he sent you on 25th September 2015. Barnett states that this fourth report was an expansion on his original (I assume immediately previous) analysis to answer [my] questions.

His further analysis responds effectively to these of my observations about the previous report:

"The greater increase in mortality in the period of the mine fire could be due, perhaps, to the more precise definition of the period of the fire or to effects of one or more of the variables newly added to Barnett's statistical model for this analysis (time trend in mortality, weekly variation in mortality and maximum daily temperature). Whether it was any of the latter could be tested by removing each in turn from Barnett's statistical model and observing the change in the mine fire result consequent on the removal."

His further results in Table 5 on page 11 show that the relative risk of death during the mine fire was sensitive to the (appropriate) inclusion of temperature in the model, and that this inclusion partly explains the higher relative risk of death during the mine fire that he observed in this model. I agree with him that adjustment for the effects of temperature is appropriate and thus that temperature should be in the model.

It does not appear to me that his further analysis has fully responded to these of my observations about the previous report:

"It is worth noting that Barnett's latest analysis shows an excess of deaths during the period of the mine fire in all four postcodes, Morwell included. In his second previous analysis there was an apparent deficit of deaths in Morwell (relative risk 0.8, 95% CI 0.55-1.28; Table 3 of the relevant report). Barnett does not describe how he arrived at the estimated number of extra deaths during the mine fire in the four postcodes."

Barnett now describes how the numbers of additional deaths due to the fire in each postcode were calculated. This explanation, however, is not clear to me. There are two variables in the expression that Barnett offers on page2, 4th line up from the bottom of the page:

1. The mean number of deaths per day for each postcode.
   The period over which this average has been calculated is not stated; It should be. As I see it, the period should (a) be relatively recent so that it can provide a reasonably unbiased estimate of the expected number of deaths in the four postcode areas over the period of the fire, (b) not include the observed deaths during the period of the mine fire and (c) be based on a period long enough to remove most of the effect of day to day variation in daily numbers on the calculated mean numbers. All these may be true, but it is not clear that they are.
2. Exp (a_{20}), the relative risk of death during the fire. As far as I can tell this is the relative risk across all four postcodes. If this is true, postcode specific relative risks have not been used when estimating the excess deaths and, therefore, previously apparent variation between postcodes in relative risk of death during the period of the mine fire is not taken into account when calculating the numbers of excess deaths. If this is correct, a deficit of deaths in Morwell during the period of the mine fire would be

obscured in this analysis.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Bruce Armstrong
Sent: Friday, 18 September 2015 10:18 PM
To: Justine Stansen [redacted])
Cc: Monica Kelly
Subject: RE: Hazelwood Mine Fire Inquiry

Justine

I have now read Adrian Barnett's Analysis of daily death data during the Morwell mine fire (version of September 2015).

His analysis of deaths is, from a technical point of view, an improvement on his previous analyses because it uses daily death data (referenced to the postcode of residence) and Australian Bureau of Statistics population data. It also restricts the analysis to the four postcode areas of greatest interest – Churchill, Moe, Morwell and Traralgon. From this analysis he reports a relative risk of death from the days of the fire (9th February 2015 to 26th March 2014) of 1.32 (95% credible interval of 1.03 to 1.66; p value 0.01). He also estimates the number of additional deaths in the four postcode areas from the period of the fire to be 23, 1 in Churchill, 8 in Moe, 6 in Morwell and 8 in Traralgon.

These estimates take account of the time trend in mortality in these four postcodes from 2009 to 2014, the underlying differences in mortality in the four postcodes, the seasonal variation in mortality, the weekly variation in mortality and the maximum daily temperature. Therefore, on the face of it, the observed relative increase in mortality risk during the period of the mine fire was independent of these other variables.

These results are reasonably coherent with, but suggest a greater increase in mortality in the period of the mine fire than, the other mortality analyses. For example, the table below compares Adrian Barnett's latest result with my result for the period February to March 2014 (Table 2 of my report) based on the Flander et al 2015 analysis.

Years	**February-June**			**February-March**			
	Rate	**95%**	**p-**	**Rate**	**95%**	**p-**	

	ratio	CI	value	ratio	CI	value	Notes
Deaths from all causes							
2014	1			1			
2009-2013[b]	0.90	0.80-1.00	0.04	0.83	0.68-1.02	0.08	As in Table 2 of my report
2009-2013				1.20	0.98-1.47	0.08	Inverted to be in the same form as Barnett's latest result
2009-2013				1.32	1.03-1.66	0.01	Barnett's latest result

The greater increase in mortality in the period of the mine fire could be due, perhaps, to the more precise definition of the period of the fire or to effects of one or more of the variables newly added to Barnett's statistical model for this analysis (time trend in mortality, weekly variation in mortality and maximum daily temperature). Whether it was any of the latter could be tested by removing each in turn from Barnett's statistical model and observing the change in the mine fire result consequent on the removal.

It is worth noting that Barnett's latest analysis shows an excess of deaths during the period of the mine fire in all four postcodes, Morwell included. In his second previous analysis there was an apparent deficit of deaths in Morwell (relative risk 0.8, 95% CI 0.55-1.28; Table 3 of the relevant report). Barnett does not describe how he arrived at the estimated number of extra deaths during the mine fire in the four postcodes.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY
Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Bruce Armstrong
Sent: Thursday, 17 September 2015 2:42 PM
To: 'Justine Stansen'
Subject: RE: Hazelwood Mine Fire Inquiry

Thanks Justine. I will be happy to give the Board my opinion. You should have it by Monday.

Bruce

BRUCE ARMSTRONG
Emeritus Professor, School of Public Health
THE UNIVERSITY OF SYDNEY

Senior Adviser
THE SAX INSTITUTE
Chairman
BUREAU OF HEALTH INFORMATION

CONTACT INFORMATION
[redacted]

From: Justine Stansen [[redacted]]
Sent: Thursday, 17 September 2015 11:29 AM
To: Bruce Armstrong
Subject: Hazelwood Mine Fire Inquiry

Dear Bruce

I trust you are well. We have received some further analysis undertaken by Associate Professor Adrian Barnett since the Hazelwood Inquiry hearings held earlier this month which is based on daily death data rather than monthly data. I was wondering whether you could consider the **attached** analysis and contact me to discuss your thoughts about it. The Board would be grateful for your additional input in relation to this issue.

I look forward to hearing from you.

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

Analysis of daily death data during the Hazelwood mine fire

Purpose

The purpose of this document is to answer two queries from Professor Bruce Armstrong:

1. The mean number of deaths per day for each postcode. The period over which this average has been calculated is not stated; It should be. As I see it, the period should (a) be relatively recent so that it can provide a reasonably unbiased estimate of the expected number of deaths in the four postcode areas over the period of the fire, (b) not include the observed deaths during the period of the mine fire and (c) be based on a period long enough to remove most of the effect of day to day variation in daily numbers on the calculated mean numbers. All these may be true, but it is not clear that they are.
2. Exp(α_{20}), the relative risk of death during the fire. As far as I can tell this is the relative risk across all four postcodes. If this is true, postcode specific relative risks have not been used when estimating the excess deaths and, therefore, previously apparent variation between postcodes in relative risk of death during the period of the mine fire is not taken into account when calculating the numbers of excess deaths. If this is correct, a deficit of deaths in Morwell during the period of the mine fire would be obscured in this analysis.

Summary response

1. I tried a few alternative methods for calculating the mean number of deaths based on Professor Armstrong's suggestions. The estimated number of deaths during the fire were similar regardless of which mean was used.
2. A model using postcode specific relative risks was not as good a fit to the data as a model with a common relative risk. Hence the previous results using a common relative risk should be preferred. However, even for a model with a varying risk across postcodes, there is an increased relative risk of death during the fire in Morwell.

More detailed analyses that address the two queries are given in the sections below.

1. The mean number of deaths per day for each postcode

The estimated additional number of deaths during the fire in each postcode were calculated using:

$$45 \times \overline{d}_i \times [\exp(\alpha_{20}) - 1],$$

where $\overline{d}_i$ is the mean number of daily deaths in postcode i and $\exp(\alpha_{20})$ is the relative risk of death during the fire. The daily estimate is multiplied by 45 days to give an estimate for the period of the fire.

Prof Armstrong queried the time period used to calculate the mean number of deaths ($\bar{d}_i$). This was based on the entire period of available data, from 1 January 2009 to 31 December 2014 and hence includes the period of the fire. My reasoning for using the entire period was that the influence of the fire would be relatively small given the large sample size.

However, I agree with Prof Armstrong's reasoning that the baseline mean should exclude the period of the fire, I therefore show some alternative calculations below.

Table 1: Mean number of additional deaths during the fire and 95% credible intervals using alternative versions of the baseline mean number of deaths in each postcode ($\bar{d}_i$).

Postcode	Period used to calculate the baseline mean	Baseline mean	Mean	Lower	Upper
3825	All data	0.56	8.2	0.9	16.5
3825	Period of fire in previous years (2009–2013)	0.48	7.1	0.7	14.3
3825	Period of fire in previous two years (2012–2013)	0.52	7.5	0.8	15.2
3840	All data	0.40	5.8	0.6	11.7
3840	Period of fire in previous years (2009–2013)	0.41	6.0	0.6	12.1
3840	Period of fire in previous two years (2012–2013)	0.40	5.8	0.6	11.7
3842	All data	0.08	1.1	0.1	2.2
3842	Period of fire in previous years (2009–2013)	0.08	1.1	0.1	2.3
3842	Period of fire in previous two years (2012–2013)	0.06	0.9	0.1	1.9
3844	All data	0.52	7.6	0.8	15.5
3844	Period of fire in previous years (2009–2013)	0.49	7.2	0.7	14.6
3844	Period of fire in previous two years (2012–2013)	0.45	6.6	0.7	13.3
Total	All data	1.56	22.7	2.4	46.0
Total	Period of fire in previous years (2009–2013)	1.47	21.4	2.2	43.3
Total	Period of fire in previous two years (2012–2013)	1.43	20.9	2.2	42.2

The results in Table 1 show that the alternative calculations for the baseline mean have only a minor impact on the estimated additional number of deaths. The 'period of the fire' is 9 February to 26 March.

2. Postcode specific relative risks

Prof Armstrong is correct in stating that $\exp(\alpha_{20})$ is the relative risk common to all four postcodes. My reasoning for using a common relative risk is that the previous analysis found little evidence for a postcode-specific effect (Table 4 in December 2014 analysis [1]). However, we can revisit this issue given that we are now examining daily data.

Given the time constraints of providing these analyses I could not use a Bayesian approach as these take time to run. Instead I used a standard statistical approach, and I show the similarity of the Bayesian and standard models below. The major differences between the two approaches are: i) how they estimate the model parameters, and ii) the interpretation of the parameters. Both approaches used the same model structure (e.g., same variables to control for daily temperature).

The estimates in Figure 1 are very similar for both the means and 95% intervals. The only noticeable difference is for the intercept, where the Bayesian credible interval is narrower

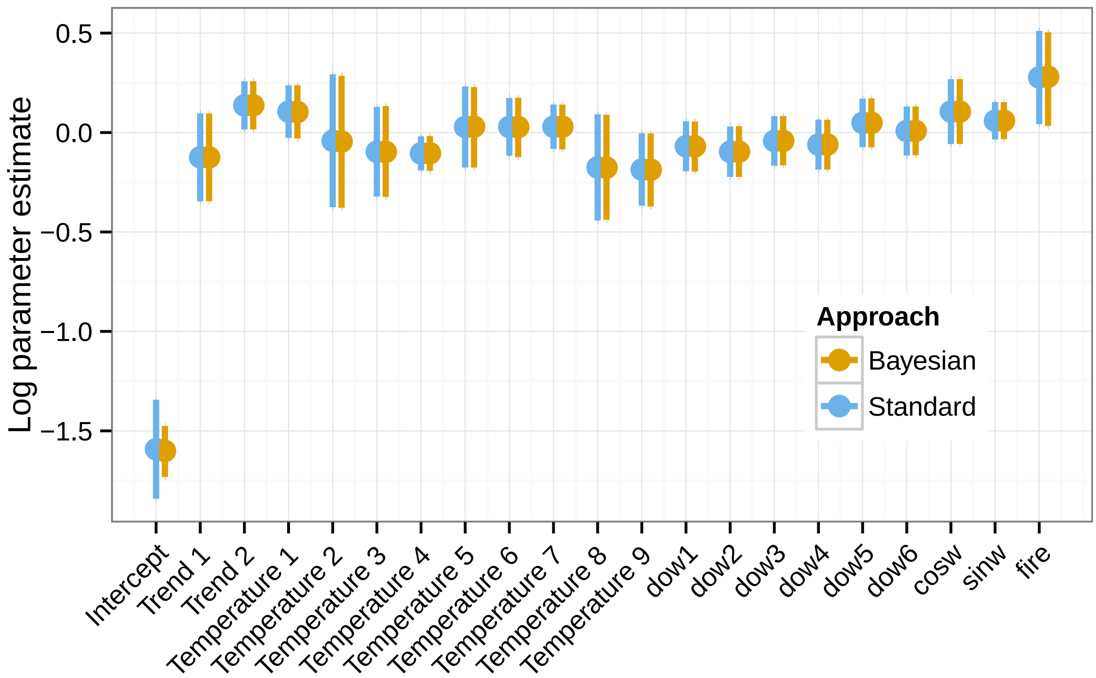


Figure 1: Comparison of parameter estimates using a standard statistical and Bayesian approach. The dots show the mean and the vertical lines are the 95% confidence/credible intervals.

than the standard confidence interval.

Table 2: Akaike information criterion (AIC) and degrees of freedom (df) comparing the two models using a standard statistical approach. The lower the AIC the better the model.

Relative risk of fire	df	AIC
Common across postcodes	22	13301
Varying across postcodes	24	13305

To compare the model fit we can use the Akaike Information Criterion (AIC) [2] as shown in Table 2. The fit was somewhat worse for the model with the varying relative risk, therefore the model with a common risk should be preferred. The degrees of freedom is essentially the number of model parameters, so the model with a varying relative risk had two extra parameters. The varying model was more complex, but did not give a better fit to the data.

The relative risks assuming a varying model are shown in Table 3. The lowest risk was in 3825 (Moe) and the highest in 3842 (Churchill), but the range in relative risks was relatively narrow and all mean risks were increased (i.e., greater than 1).

Table 3: Estimates of the mean relative risk assuming a common and varying effect of the fire across the four postcodes.

Model	Postcode	Mean relative risk
Common effect of fire		1.32
Varying effect of fire	3825	1.29
Varying effect of fire	3840	1.31
Varying effect of fire	3842	1.38
Varying effect of fire	3844	1.35

References

[1] Adrian Barnett. An updated analysis of death data during the morwell mine fire. Technical report, Queensland University of Technology, `http://eprints.qut.edu.au/81685/`, 2 2015.

[2] K.P. Burnham and D.R. Anderson. *Model Selection and Inference: A Practical Information-Theoretic Approach*. Springer New York, 2013.

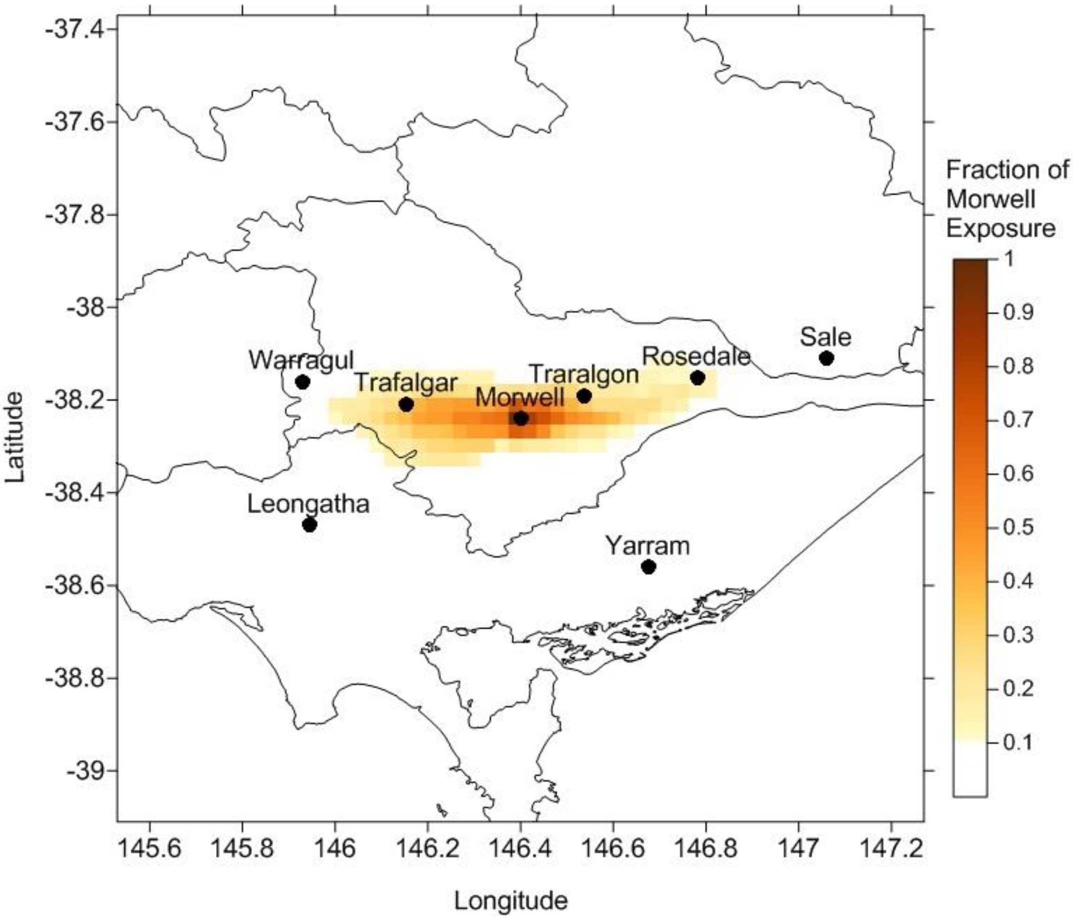
From:	Heffernan, Emily (AU)
To:	"Philip McCloud ([redacted])"
Cc:	Fox, Chris (AU)
Subject:	Hazelwood Mine Fire Inquiry [KWM-Documents.FID1770821]
Attachments:	Attachment 1 - CSIRO Morwell Exposure Levels Map.pdf Attachment 2 - Updated_literature_review_final.pdf Witness statement of Michael Abramson.pdf

Dear Philip,

Further to King & Wood Mallesons' letter dated 6 October 2015, please find **attached** the Witness Statement of Professor Michael Abramson, together with its attachments.

Kind regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]



The variation in smoke exposure (relative to the exposure experienced across Morwell) in the Latrobe Valley and beyond, as estimated by the CSIRO model.

MONASH University

M8 Alliance

Medicine, Nursing and Health Sciences

School of Public Health & Preventive Medicine

Updated Literature Review on Mortality and Morbidity associated with Environmental Smoke Events

Prepared for the Department of Health and Human Services

05 May, 2015

Authors: Dr Diogenes S. Ferreira, Dr Martine Dennekamp, Professor Michael J. Abramson

Contents

GLOSSARY OF TERMS

AOD: Aerosol optical depth (measured by remote satellite sensing)

AQI: Air quality index

BMI: Body mass index

CF: Cardiac failure

CO: Carbon monoxide

COPD: Chronic obstructive pulmonary disease

CVD: Cardiovascular diseases

ED: Emergency department

ICU: Intensive care unit

ICD: International Classification of Diseases

IQR: Interquartile range is a measure of dispersion calculated as the difference between the upper and lower quartiles (75^{th} and 25^{th} percentiles) of the data

Lag: An interval of time between two related phenomena. In studies investigating the effects of air pollution on health, lag day 0, 1, 2, 3, etc. refer to the interval in days between exposure to a pollutant or pollution event and the outcome of interest (eg mortality or hospitalisations). Lag day 0 refers to exposure and outcome on the same day, lag day 1 to exposure 24 hours before the outcome, and so on.

LFS: Landscape fire smoke

OHCA: Out-of-hospital cardiac arrest

O_3: Ozone

OR: Odds ratio

$PM_{2.5}$: The concentrations (expressed in $\mu g/m^3$) of particles of less than 2.5 µm diameter in the air

PM_{10}: The concentrations (expressed in $\mu g/m^3$) of particles of less than 10 µm diameter in the air

r: Correlation coefficient

RR: Relative risk

SO_2: Sulphur dioxide

WHO: World Health Organization

µm: Abbreviation for micrometre or micron (a unit of length). 1µm = one thousandth of a millimetre

95% Confidence interval (95%CI): The degree of uncertainty associated with a sample statistic, i.e. 95% CI means that there is a 95% chance that the true value lies between the two bounds

EXECUTIVE SUMMARY

This updated literature review addresses the question of whether increased mortality could be attributed to an environmental smoke event, in the absence of any observed increase in morbidity. We searched the Medline, EMBASE and Scopus databases from 2013 to 2015 for peer-reviewed original articles reporting on human health outcomes associated with outdoor biomass smoke exposure. We also checked the references of earlier literature reviews. The strongest available epidemiological designs are time series and case-crossover studies.

We identified and summarised 4 studies of bushfire smoke that reported both mortality and morbidity data. One good quality Australian study did not find any increase in all-cause, cardiovascular or respiratory mortality associated with PM_{10} exposure from bushfires. On the other hand, bushfire PM_{10} was associated with respiratory admissions, particularly from COPD and asthma. There were also 3 lower quality studies of health effects associated with the Borneo and Sumatra forest fires in 1997. All found increased morbidity and one reported increased pulmonary mortality. However these findings must be interpreted cautiously because of limited statistical analysis.

We identified and summarised a further 15 studies that only examined mortality in relation to bushfire smoke exposure. Twelve studies reported increased mortality due either to all non-traumatic, cardiovascular or respiratory causes associated with bushfires. The most ambitious study estimated global all-cause mortality attributable to landscape fire smoke using published concentration response relationships for $PM_{2.5}$. The estimate of the associated average annual mortality was 339,000 worldwide.

We identified and summarised 44 studies that only examined morbidity in relation to bushfire smoke exposure. There were 20 studies reporting hospitalisations, 19 Emergency Department visits, 1 ambulance call outs and 9 outpatient physician visits. Some studies reported more than one outcome. Time series or case-crossover designs were utilised in 24 studies. Adverse effects of bushfire smoke were found in 22 of 23 respiratory studies and 7 of 11 cardiovascular studies. A large number of studies around the world show clear associations between bushfire smoke exposure and hospitalisations, ED and outpatient visits.

Whilst it is not possible to definitely conclude from these studies whether increased mortality attributable to environmental smoke events could ever occur in the absence of an observed increase in morbidity, we consider this possibility unlikely.

INTRODUCTION

This updated Literature Review was commissioned by the Department of Health and Human Services to determine whether increased mortality attributable to environmental smoke events could occur in the absence of an observed increase in morbidity.

The specific points requested to be addressed in this Review were:

1. Update the literature review provided previously as part of the rapid health risk assessment.
2. Specifically investigate whether there are credible literature reports in which the mortality rate rises, but there is no accompanying change in morbidity.

The Hazelwood mine fire commenced when a grass fire entered the coal mine. Vegetation fires are an important source of biomass burning smoke occurring in all continents and are associated with high levels of pollutants such as particulate matter smaller than 2.5 µm diameter ($PM_{2.5}$), smaller than 10 µm diameter (PM_{10}) and other by-products of combustion. As brown coal originates from organic material including plants, it is expected that pollutants from vegetation fire smoke would be relatively similar to those from brown coal mine fire smoke.

Mortality displacement / harvesting

A relevant public health question related to the association between health and air pollution is: Would the people who have died from air pollution, have died in a few days anyway? If the answer would be yes the public health impact would be considerably less than if this would not be the case.

Sophisticated statistical analyses investigating this issue have concluded that the deaths as a result of air pollution are not mainly those that would have occurred a few days or weeks later anyway (1-5). The same was observed for hospital admissions (3). This lack of evidence of short term compensatory reduction in deaths in combination with generally larger estimated particulate matter effects for longer exposure periods further supports the conclusion that the short term exposure studies observe more than just short-term mortality displacement (6).

METHODOLOGY

Search strategy

An initial literature search for peer-reviewed publications about health effects of smoke from fires in open cut brown coal mines did not identify any such study. An underground black coal mine fire in Centralia, Pennsylvania, USA, has been burning since 1962 and is described in a book (7). However, we have not identified any scientific investigations into possible health effects of this fire. For this reason, we searched for studies of outdoor biomass burning of similar short duration as the Hazelwood mine fire.

A search was performed on the bibliographic databases MEDLINE (via Ovid), EMBASE (via Ovid) and Scopus for peer-reviewed original articles reporting on human health outcomes associated with outdoor biomass smoke exposure. We searched for the exposure words bushfire, wildfire, forest fire, vegetation fire, peat fire, biomass fire and sugar cane fire. We have focused this review on the outcomes at the tip of the air pollution health effects pyramid (figure 1), i.e. mortality, hospital admissions, emergency department visits and outpatient visits to a physician (8).

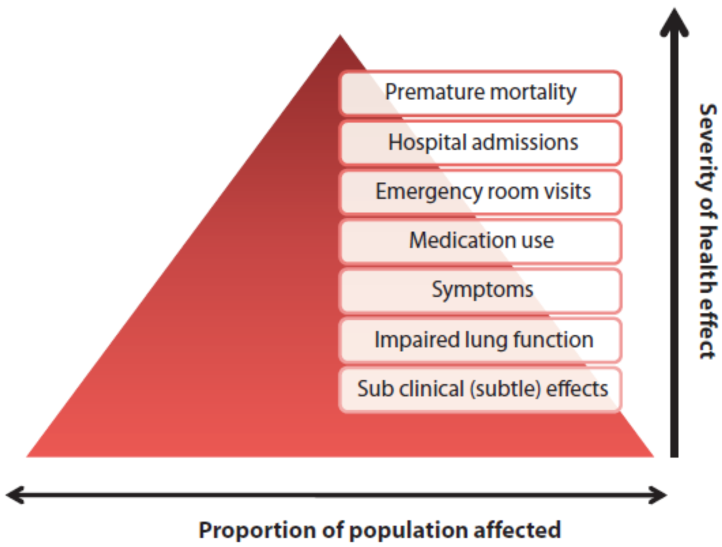


Figure 1. The air pollution health effects pyramid (8).

On MEDLINE and EMBASE, the search involved title and abstract text words and subject headings, while in Scopus only title and abstract text words were used.

The following text words were used for searching all 3 databases: bushfire*, (bush* adj3 fire*) (the proximity search term "adj3" searches for both words – bush* and fire* – separated by up to 3 intervening words), wildfire*, (wild adj3 fire*), (forest* adj3 fire*), (vegetation adj3 fire*), peat fire*, (biomass adj3 fire*), (biomass adj3 combust*), (biomass adj3 burn*), (sugarcane adj3 burn*), (sugar cane adj3 burn*) OR sugar cane fire* AND any of the outcome words mortality, hospital*, emergenc*, emergency department, emergency room, ambulance*, physician visit* OR outpatient*.

The subject headings 'Fires', 'Smoke' and 'Particulate matter' were not included as search terms for exposures because a very large number of articles retrieved with them were related to background urban air pollution from gasoline/diesel combustion and industry, not relevant to our current review. The subject headings used in the MEDLINE search for the relevant outcomes were 'Mortality', 'Hospitalisation', 'Hospitals', 'Emergencies', 'Emergency Service, Hospital', 'Ambulances', 'Cardiovascular Diseases' OR 'Respiratory tract diseases'. Minor amendments were made for the EMBASE search.

The searches in these 3 databases were restricted to articles published between 2013 and the 3rd week of February 2015. All these searches were completed on 27 February 2015. No restrictions were imposed on language of publication.

A MEDLINE search on PubMed was performed to find additional articles recently published online ahead of print in January and February 2015 which might not have been available in the previous searches. The text words described above were included in this MEDLINE via PubMed search.

To obtain relevant articles for our review published before 2013 we relied on the list of references from the "Evidence Review: Health surveillance for wildfire smoke events" published online by the British Columbia Centre for Disease Control (9). Additional papers were obtained from the list of references of: (A) the review by Dennekamp and Abramson (8) focusing on "the effects of bushfire smoke on respiratory health", (B) the systematic review by Liu et al. (10) on "the physical impacts from non-occupational exposure to wildfire smoke" and (C) an as yet unpublished systematic review about "the cardiorespiratory health impacts of particulate matter exposure from wildfire smoke" which has been written by Anjali Haikerwal, a PhD student in the School of Public Health and Preventive Medicine, Monash University.

We excluded studies which focused on dust storms, volcanic ash, indoor smoke from black coal fires, open cut coal mining dust exposure, coal-fired power plant pollution, fire-fighters and police exposed on duty. We also excluded studies which reported only morbidity and mortality caused by skin burns or physical trauma directly associated with fires (such as those from car accidents due to smoke reducing visibility or falling walls/roofs from burning homes/buildings) and animal studies.

Types of studies

Two epidemiological study designs are particularly suitable to investigate the effects of air pollution on health: time series analyses and case-crossover studies. However it has been shown that the two approaches yield generally similar results (11, 12).

Time series analyses follow a given community or region through time. Exposure variables such as pollutant concentrations are measured at regular (usually daily) time intervals and the outcomes are often rates of binary events, such as death or hospital admission. Thus the comparison of "exposed" and "non-exposed" involves the same population evaluated at different times, rather than different groups of persons being compared as in longitudinal studies.

An advantage of the time series approach is that it reduces confounding by factors which vary between subjects but not over time (e.g. genetic factors), or whose day to day variation is unrelated to the main exposure of interest. Confounding however can occur as a result of infectious agents, correlated pollutants, time trends in mortality and meteorological factors. Temperature, humidity and seasonal fluctuations may be associated with both pollution and health outcomes (13, 14).

The ***case-crossover design*** is primarily used for studying the aetiology of acute outcomes such as myocardial infarct or deaths from acute events in situations where the suspected exposure is transient and its effect occurs over a short time. This type of design has been used in studying exposures such as air pollution events characterised by rapid and transient increases in particulate matter. In this type of study, a case is identified (for example, a person who has suffered a myocardial infarct) and the level of the environmental exposure, such as concentration of particulate matter, is ascertained for a short time period preceding the event (the at-risk period). This level is compared with the level of exposure in control time periods that are more remote from the event. Thus, each person who is a case serves as his/her own control, with the period immediately before the adverse outcome being compared with "control" periods at other times when no adverse outcome occurred. The question being asked is: Was there any difference in exposure between the time period immediately preceding the outcome and another time period which was not immediately followed by any adverse health effect? (15)

RESULTS

We have included in this review, 19 studies reporting on mortality associated with wildfires (16-34). Among these, 4 also reported morbidity results (16-18, 25) and are summarised in table 1. All studies presenting mortality data only are summarised in table 2. In addition, 44 manuscripts have been included that presented only morbidity associated with wildfires (35-78). The numbers of studies presenting results for the following morbidity outcomes were: hospitalisations 20, Emergency Department (ED) visits 19, ambulance call outs 1, outpatient physician visits 10. Some studies investigated more than one of these morbidity outcomes. These studies are summarised in tables 3 to 7 sorted by geographical area of the affected population (Victoria, Australian states other than Victoria, Southeast Asia and Europe, North America and South America).

DISCUSSION

In this section, we will discuss the most relevant studies with results for both mortality and morbidity, mortality only and morbidity only.

Studies reporting both mortality and morbidity

Among the four articles (16-18, 25) reporting on mortality and morbidity associated with wildfires and summarised in table 1, one Australian study stands out with appropriate methodology and clear reporting of results (25). Morgan et al. (25) investigated the effect of bushfires on daily mortality and hospital admissions in Sydney using a time series analysis of data from January 1994 to June 2002. They defined bushfire days as those with city-wide daily average PM_{10} concentrations greater than the 99th percentile for the study period (PM_{10} > 42 µg/m^3) and calculated PM_{10} on bushfire days as the difference between total PM_{10} and estimated urban "background" PM_{10}. The authors assumed that PM_{10} on nonbushfire days was derived from miscellaneous urban sources, including vehicles, industry, domestic wood smoke and crustal particles and defined this as "background PM_{10}". Analyses were adjusted for temperature, humidity, day of week and influenza epidemics. During the study period (8.5 years) there were 32 bushfire days with a daily median PM_{10} concentration of 62 µg/m^3 (IQR 47-80 µg/m^3).

Bushfire PM_{10} was <u>not</u> significantly associated with mortality. For a same-day 10 µg/m^3 increase in bushfire PM_{10} the change (95%CI) in all-cause mortality was 0.80% (-0.24%, 1.86%), 0.76% (-0.76%, 2.30%) in cardiovascular mortality and -0.32% (-3.70%, 3.18%) in respiratory mortality. Up to a lag of 3 days no significant effects were found on any of these outcomes. However background PM_{10} was associated with 1.35% (95%CI: 0.38%, 2.32%) increase in all-cause mortality at lag 1 and 1.07% (95%CI: 0.14%, 2.00%) at lag 2.

On the other hand, both bushfire and background PM_{10} were associated with respiratory admissions on the same day (lag 0). When the analysis was restricted to respiratory admissions of people over 65 years of age, bushfire PM_{10} showed a more consistent association than background PM_{10}. Bushfire, but not background PM_{10} was associated with hospital admissions for COPD among those over 65 years old and asthma admissions by those aged 15-64 years. For cardiovascular admissions, there were associations with background PM_{10} but not with bushfire $PM_{10.}$

Although this study presents results of both mortality and morbidity (hospital admissions) in relation to bushfires, it is not possible to calculate a summary mortality : morbidity ratio because no absolute numbers of deaths and hospital admissions associated with bushfires were provided. Nevertheless, this study reports increased morbidity associated with bushfires in the absence of a significant increase in mortality.

Additional inferences can be drawn from this study. Looking at figure 1, one can see that bushfire PM_{10} has a weak positive effect on CVD mortality at lag 0, but no apparent effect on CVD admissions. Quite a different effect is shown for PM_{10} on respiratory outcomes in figure 2: no association with mortality yet a clear increase in respiratory admissions at lag 0 in addition to a positive trend at lags 1 and 2.

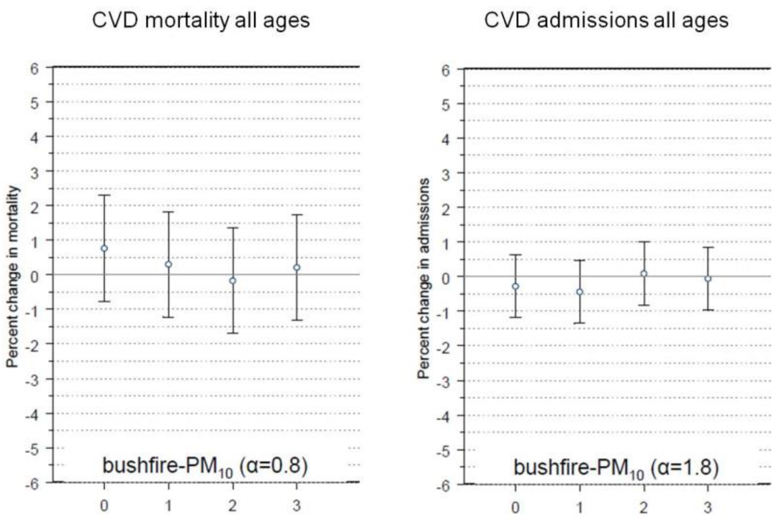


Figure 1. Percent change in cardiovascular (CVD) mortality and hospital admissions, all ages, per 10 $\mu g/m^3$ change in daily PM_{10}, Sydney 1994 to 2002. Lag days are shown on horizontal axis (25).

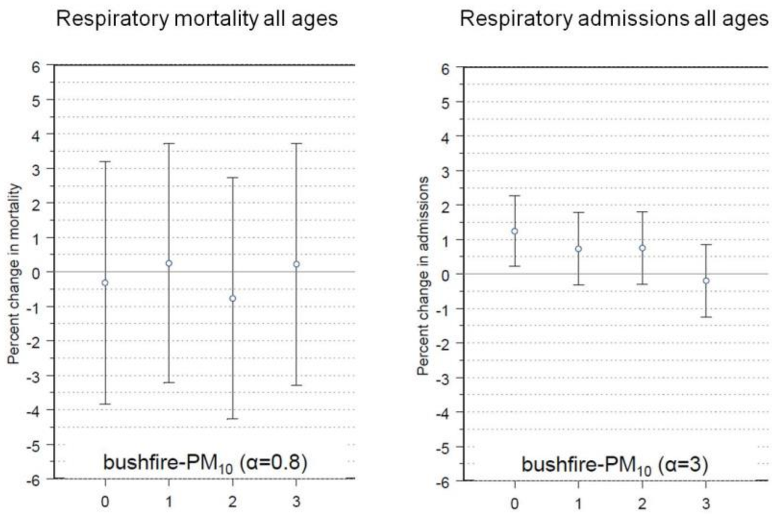


Figure 2. Percent change in respiratory mortality and hospital admissions, all ages, per 10 μg/m^3 change in daily PM_{10}, Sydney 1994 to 2002. Lag days are shown on horizontal axis (25).

There were 3 additional reports of mortality and morbidity in relation to the large 1997 Indonesian forest fires that produced severe smoke haze affecting several neighbouring countries in South East Asia (16-18). Awang et al. (17) and Emmanuel (18) stated that there was no increase in mortality during the fire events, however no numerical results were published. Aditama (16) reported increased mortality rate in the pulmonary ward of Jambi Hospital, Indonesia compared with the previous month, however again no numerical data were provided and no statistical tests performed. These 3 studies (16-18) describe increased morbidity during the forest fire period. The mortality results of these studies must be interpreted with caution, because subsequent publications with clear and more sophisticated analytical approaches (19, 24) have estimated increased mortality related to the Indonesian fires in 1997, which will be commented on in the next section.

Studies reporting mortality

A summary of these studies is presented in table 2. Twelve (19, 22-24, 26-33) of 15 studies have identified increased mortality due either to all non-traumatic causes, cardiovascular or respiratory causes associated with forest fires. A time series or case-crossover approach was employed in 9 studies. Two studies performed large population estimations of mortality using previously published equations reporting the association between pollutant and mortality (23, 24). One study was essentially descriptive relying on comparison of data without formal statistical testing (20). Among 5 studies of short wildfire duration, including single or multiple fire events taking place over a few days up to 2 months (20, 21, 27, 32, 34), only two (27, 32) found an association between wildfire smoke pollution and mortality. One investigation about out-of-hospital cardiac arrests (76) summarised in table 3 will also be discussed in this section.

The largest study to date aimed to estimate the annual global all-cause mortality attributable to landscape fire smoke, LFS (23). Exposure to $PM_{2.5}$ from fire emissions was estimated globally for 1997 through 2006 by combining outputs from a chemical transport model with satellite-based observations of aerosol optical depth. In World Health Organization (WHO) subregions classified as sporadically affected, the daily burden of mortality was estimated using previously published concentration–response coefficients for the association between short-term elevations in $PM_{2.5}$ from LFS and all-cause mortality. In subregions classified as chronically affected, the annual burden of mortality was estimated using the American Cancer Society study coefficient for the association between long-term $PM_{2.5}$ exposure and all-cause mortality. Strong La Niña and El Niño years were compared to assess the influence of climatic variability.

The estimate for the average annual mortality associated with exposure to LFS was 339,000 worldwide, including 157,000 in sub-Saharan Africa and 110,000 in Southeast Asia. All models tested had a median of 379,000 annual deaths and interquartile range of 260,000-600,000 annual deaths. The estimates for a strong El Niño year (September 1997-August 1998) and La Niña year (September 1999-August 2000) were 532,000 and 262,000 annual deaths, respectively. These analyses provide evidence for an effect of landscape fire smoke exposure on all-cause mortality, which although lower than estimates for urban air pollution (800,000)(79), disproportionately affect low-income regions.

Marlier et al. (24) combined satellite-derived fire estimates and atmospheric modelling to quantify cardiovascular mortality from fire emissions in 10 Southeast Asian countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam) from 1997 to 2006. Fires in this region predominated on the Indonesian islands of Sumatra and Borneo. The mortality estimates combined modelled pollutant-concentration changes from fires with published epidemiological relationships between exposure to $PM_{2.5}$ and cause-specific mortality. During a high fire year with strong El Niño system (1997), fire emissions were associated with an increased adult cardiovascular disease mortality burden of approximately 10,800 (6,800-14,300) annual deaths from $PM_{2.5}$ exposure. During a La Niña year (2000), these estimates were 1,600 (800-2,800) deaths annually. As these analyses included the 1997 Indonesian fire season and several affected countries in Southeast Asia, we must consider this as supporting evidence for increased mortality in the region when interpreting the apparent lack of an effect on mortality in previous reports (17, 18).

Johnston et al. (26) have analysed mortality associated with bushfire events in Sydney and their study has similarities with that of Morgan et al. (25). Johnston et al. (26) analysed non-accidental, cardiovascular and respiratory mortality for an extended period of time (1994-2007) which included the years studied by Morgan et al. (25) (1994-2002), using a case-crossover study design. A bushfire smoke event was defined in the same way as the previous study, ie. any day with PM_{10} concentration exceeding the 99th percentile of the study period (47.3 μg/m^3). With this definition, the authors identified 46 bushfire event days during the 13.5-year study period, 14 additional event days in comparison with the 8.5-year study. In the analyses adjusted for temperature, humidity and influenza epidemics, there was increased risk of non-accidental mortality associated with smoke events (OR 1.05, 95%CI: 1.00, 1.10) at lag 1. This risk was estimated for exposure to a smoky day with PM_{10} > 47.3 μg/m^3. No associations with respiratory or cardiovascular mortality were found. Taken together, these Sydney studies (25, 26) suggest that detecting a significant small increase in mortality associated with moderate levels of bushfire PM_{10} exposure would depend on studying a large enough population over an extended period of time.

Study reporting out-of-hospital cardiac arrests

Dennekamp et al. (76) investigated the association between out-of-hospital cardiac arrests (OHCA) attended by ambulance personnel with presumed cardiac aetiology in Melbourne and bushfire smoke exposure for one severe bushfire season (summer of 2006/2007). We discuss this study separately as it does not strictly fall under mortality or morbidity; 84% of ambulance call-outs for out-of-hospital cardiac arrests result in a patient not making it to hospital alive, and about half of those who make it alive will not survive to hospital discharge. The study used a case-crossover design adjusting for temperature and humidity. Hourly observed air pollutant data were available, and several short term averages (1, 2, 4, 8 and 12 hours) were investigated, but the strongest association was found for the 24 and 48 hour moving averages (i.e. average $PM_{2.5}$ concentrations 24 and 48 hours prior to the emergency call), e.g. during the fire season a significant increased risk of OHCA was observed with an IQR increase in $PM_{2.5}$ both overall (5.4%; 95% CI: 0.9, 10,2%) and among men (8.1%; 95% CI (2.3,14.1%). This study also estimated that due to the bushfire smoke exposure in Melbourne during the 2006/2007 summer, 24 to 29 excess OHCAs were estimated to have occurred.

Studies reporting morbidity

A summary of these studies is presented in tables 3-7. The number of studies per geographical area were: 2 in Victoria (54, 76), 10 in other Australian states (37, 39, 42, 48, 50, 52, 59, 61, 63, 78), 3 in Asia (38, 40, 44), 1 in Europe (46), 19 in North America (35, 36, 41, 43, 45, 47, 49, 51, 53, 55-58, 60, 62, 64-66, 77) and 9 in South America (67-75). There were 20 studies reporting hospitalisations (40, 41, 44, 48, 50, 51, 54-56, 59, 61, 66, 67, 70-72, 74, 75, 78), 19 Emergency Department (ED) visits (35-39, 41, 42, 47, 49, 54, 55, 57, 58, 60, 63, 65, 66, 68, 69) , one about ambulance call outs (76) (discussed under mortality) and 9 with outpatient physician visits (43, 45, 46, 52, 53, 56, 62, 64, 77). Only 3 (37, 38, 66) of 44 studies did not show a deleterious effect of wildfire exposure on health outcomes. Twenty-four investigations used a time series (38, 42, 44, 50, 51, 54, 57-59, 62, 64, 67-72, 74, 75, 78) or case-crossover design (48, 61, 63, 76). The following disease outcomes were reported: respiratory diseases, cardiovascular diseases, all non-traumatic causes of hospitalisation or ED visit, headache, ophthalmological problems, otitis media, diabetes and panic disorder.

Focusing just on the 24 time series and case-crossover studies of the most commonly reported outcomes (respiratory and cardiovascular diseases), an adverse effect of wildfire smoke on respiratory health was found in 22 of 23 studies and in 7 of 11 studies evaluating cardiovascular health. Asthma and COPD were the respiratory diseases most frequently studied and affected by wildfire smoke (38, 42, 44, 48, 51, 57, 58, 61-64, 67). Among cardiovascular diseases, ischaemic heart disease and congestive heart failure were mostly commonly studied and exacerbated by fire smoke (48, 57, 58, 63).

Respiratory diseases have been more commonly studied than other diseases and most results show an association of wildfire smoke with poor respiratory health. The results of studies evaluating cardiovascular health effects are not so consistent, with a number of studies unable to demonstrate a deleterious effect on these outcomes. Yet, some populations appear to be more vulnerable to such effects such as Indigenous Australians (48) and people in lower socio-economic strata (58) . As already discussed above in regard to Morgan's paper (25), pollution from wildfires seems to affect respiratory and cardiovascular health outcomes differently.

The large number of studies around the world identified in this review showing an association between wildfire smoke exposure and hospitalisations, ED visits and outpatient visits provide clear evidence of a detrimental effect of this type of pollution on severe morbidity outcomes. Sugar cane fires in South America (Table 7) will not be discussed further, because the particulate exposure is qualitatively different.

There are other environmental smoke events which could possibly lead to harmful health consequences to communities such as fires of hazardous chemicals(80) and oil depots (81). These events are beyond the scope of this review.