**Hazelwood Mine Fire Inquiry Report 2015/2016 VOLUME II – Investigations into 2009–2014 deaths**

**PART FIVE**

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PART 5 EXPERT ANALYSIS OF THE DEATH

RECORDS PROVIDED TO THE INQUIRY

After the Hazelwood Mine Fire Inquiry was re-opened on 26 May 2015, the Board of Inquiry held public hearings in September 2015 to consider whether the Hazelwood mine fire contributed to an increase in deaths in 2014, having regard to any relevant evidence for the period 2009 to 2014.

The Board heard from experts, namely Emeritus Professor Bruce Armstrong, a medical practitioner, public health physician and epidemiologist from the School of Public Health, University of Sydney; Professor Ian Gordon, Director of the Statistical Consulting Centre and Professor of Statistics in the School of Mathematics and Statistics, University of Melbourne; Associate Professor Adrian Barnett, a statistician from the Institute of Health and Biomedical Innovation and School of Public Health,

Queensland University of Technology; and Dr Louisa Flander, a senior research fellow from the Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne. The Board also received a report from Professor John McNeil, Professor and Head of the Department of Epidemiology and Preventive Medicine at Monash University.

The Board held a further hearing into evidence provided to the Inquiry after the September public hearings concluded. That hearing is discussed in Part 6 of this report.

**5.1 EXPERT ANALYSIS PROVIDED TO THE INQUIRY**

Upon the re-opening of the Inquiry, the Board retained Professor Armstrong to provide expert opinion in relation to questions that the Board must consider under the Inquiry’s Terms of Reference, namely:

* Was there an increase in the number of deaths during the mine fire?
* If so, did the mine fire contribute to that increase in deaths?

Professor Armstrong is a medical practitioner, public health physician and an epidemiologist and is currently Emeritus Professor at the School of Public Health, The University of Sydney, Senior

Advisor to the Sax Institute, and Chairman of the Bureau of Health Information, Government of New South Wales.1 Professor Armstrong authored a report titled *Expert assessment and advice regarding mortality information as it relates to the Hazelwood Mine Fire Inquiry Terms of Reference* – *Final report*, dated August 2015.2

Voices of the Valley retained Professor Gordon to provide an opinion on the questions posed to the Board of Inquiry. Professor Gordon is the Director of the Statistical Consulting Centre and a Professor of Statistics in the School of Mathematics and Statistics at the University of Melbourne. Professor Gordon has a PhD in Mathematical Statistics from the University of Melbourne and is accredited as

a statistician by the Statistical Society of Australia Incorporated. Professor Gordon is also a founding member of the Australasian Epidemiological Association.3 Professor Gordon authored a report titled *Commentary on the Hazelwood mine fire and possible contribution to deaths*, dated 11 August 2015.4

Dr Rosemary Lester, former Chief Health Officer, Department of Health, retained Professor McNeil to provide an opinion on the questions posed to the Board under Term of Reference 6. Professor McNeil is a Professor and Head of the Department of Epidemiology and Preventive Medicine at Monash University. Professor McNeil provided a report to the Board under cover of a letter to Dr Lester’s solicitors, dated 28 August 2015. Professor McNeil’s report is a critique of the reports undertaken by Associate Professor Barnett and Dr Flander. Professor McNeil’s report does not include any conclusions on the questions posed to the Board of Inquiry by way of his own analysis of the death data provided to him by Dr Lester’s solicitors. Accordingly, Professor McNeil did not give evidence at the hearing or participate in the expert meeting on 31 August 2015, however his report was tendered as evidence to the Inquiry.5

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As discussed in Part 4 of this report, the Board also obtained the reports of Associate Professor Barnett and Dr Flander, which included opinions on whether there was an increase in deaths in the Latrobe Valley during the Hazelwood mine fire.

In the days leading up to the public hearings, the Board invited Professor Armstrong, Professor Gordon, Associate Professor Barnett and Dr Flander to discuss their analyses and respective conclusions as a group. During the discussion on 31 August 2015, Professor Armstrong, Professor Gordon, Associate Professor Barnett and Dr Flander produced a joint expert report that identified areas of agreement and disagreement in relation to the conclusions reached in Professor Armstrong’s report.6 Each of the experts also gave evidence to the Board as a panel at the public hearings in September 2015.

**5.2 DATA AND METHODOLOGY**

In order to understand the conclusions reached by these experts, this section provides an overview of the data considered, and the methodologies and analytical tools used.

DATA USED FOR ANALYSIS

The data provided to Professor Armstrong, Professor Gordon and Associate Professor Barnett was:

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Monthly death records data for the years 2009–2014 for four postcodes—3840 (Morwell), 3825 (Moe), 3842 (Churchill), and 3844 (Traralgon)

Daily death records data for the years 2013 and 2014 for the same four postcodes

Records of emergency hospital admissions for the years 2013 and 2014 for each of the same four postcodes

Data on mean temperatures in Morwell for 2014

Particulate matter readings (actual or estimated) in each of the same four postcodes for the period of the Hazelwood mine fire.7

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Professor Armstrong and Professor Gordon also received daily death records data provided by the Victorian Registry of Births, Deaths and Marriages to the Board in July 2015, including cause of death information, for the period January 2009–July 2015.

Dr Flander analysed daily death records, which she received directly from the Department of Health, including information about cause of death, for the years 2009–2015 for four postcodes—3840 (Morwell), 3825 (Moe), 3842 (Churchill), and 3844 (Traralgon). The Department also provided

Dr Flander data on temperature, air pollution and hospital admissions for the same period and areas.

Associate Professor Barnett analysed monthly death records data for the years 2004–2014 for six postcodes—3840 (Morwell), 3825 (Moe), 3842 (Churchill), 3844 (Traralgon), 3869 (Yinnar) and 3870 (Boolarra South)—and data on temperature for the same period and areas.

There was discussion at the Inquiry’s public hearings about whether the data was available to the experts in a form that allowed them to reach the conclusions that they articulate in their respective reports.

Dr Flander acknowledged that whilst the death records she considered had cause of death information, they did not contain complete medical records about the deceased, nor information about whether the deceased had been exposed to air pollution from the mine fire, or to high temperatures. Dr Flander told the Board that it would be useful to know whether or not the deceased were actually resident in the Latrobe Valley at the time of the mine fire and what their levels of exposure were to the air pollution from the mine fire.8 Associate Professor Barnett agreed with this statement.9

Associate Professor Barnett acknowledged that a more accurate analysis could be undertaken if death records data for the period of the mine fire excluded deaths that were not possibly related to the mine fire. However, he qualified that excluding deaths on this basis would be challenging as air pollution

is associated with many causes of death.10

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**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

Professor McNeil indicated in his report that the monthly data used by Associate Professor Barnett was ‘very crude’ as it did not include age-specific death rates and there was no information about changing age structures or population numbers within each of the postcodes.11 Associate Professor Barnett accepted that the monthly death records data was crude relative to daily death records data.12

METHODOLOGY

Professor Gordon explained to the Board that each expert assessed the death records to calculate the statistical average of the number of deaths in the Latrobe Valley for the 2009–2013 period, and then predicted what number of deaths they expected to see in 2014, based on this statistical average. Each expert then compared the statistical average, or predicted number of deaths for 2014, with the actual observed number of deaths in 2014.13

In interpreting their results, the experts used several tools or indicators to assess whether their observations were significant and not the result of chance or random variation, including relative risk ratios, 95 per cent confidence intervals and probability (P) values. The experts described these tools and their application to the Board as follows:

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A relative risk ratio of the observed actual number of deaths in 2014 was calculated to indicate the excess or reduction relative to the predicted number of deaths.14

A ‘confidence interval’ was used to demonstrate whether the predicted number of deaths and observed number of deaths fall within a range where the statistician can be 95 per cent confident that the true unknown value falls within that interval. The confidence interval is intended to reflect the imprecision that arises through natural variation when dealing with a

hypothetical.15 According to Professor Gordon, a confidence interval demonstrates the size of the effect and what interval may contain that effect.16 A credible interval demonstrates that there is a 95 per cent probability that the true value is within the interval or range.17

A P-value is a probability between zero and one, which attempts to show the likelihood of the data performing to the expectation or theory. The closer the P-value is to zero, the more it demonstrates that the data is not conforming to the predicted average.18 Professor Gordon explained to the Board that there is a conventional level of statistical significance used in research, which is 0.05.19 Accordingly, P-values that are 0.05 or lower are said to be more

statistically significant and tend to show stronger statistical evidence. However, there was some agreement between Professor Gordon and Professor Armstrong that the threshold of 0.05 was not ‘magic’ and they did not consider it to be a critical threshold.20

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Professor Armstrong told the Board that these tools are used in combination with other evidence that the expert considers relevant to the situation:

[E]ssentially what we’re doing through a statistical analysis like this is trying to get some of the evidence that we need to make a decision about whether this is the way the world is or this is what’s happened versus something else. So we get our relative risk, if that’s what we’ve calculated, that is one bit of information…then we’ve got the 95 per cent confidence interval, that is another bit of information, and then we have the P-value, that is another bit of information. That doesn’t allow us to say well, yes, the P-value is very low, the [relative risk] ratio is higher, the confidence [interval] is narrow, therefore definitely this caused that. There is a number of other factors that have to be taken into consideration…in epidemiology…even if we do get a very strong association with a low P-value and so on, we still have to consider all of those things that might bias that and give us still a misleading result. So my message is that’s just some of the evidence that we use ultimately to decide, in this particular situation, how strongly we believe in the proposition that the death rate in Morwell in the first part of 2014 was more than you’d expect to see under normal circumstances and therefore something must have caused it, perhaps, and then all the possibilities that we might put on the table.21

Dr Flander agreed with explanations about the application of statistical tools provided by other experts.22 Dr Flander told the Board that the outcome of the analysis would depend on the quality of the data (which is crucial), the kind of analysis used and the assumptions adopted.23

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**Hazelwood Mine Fire Inquiry Report 2015/2016 VOLUME II – Investigations into 2009–2014 deaths**

**5.3 WAS THERE AN INCREASE IN DEATHS IN THE LATROBE VALLEY DURING THE MINE FIRE?**

This section discusses the analyses conducted by the experts, as well as the content of the joint expert report. This section also describes the evidence provided by the experts as a panel at the public hearings held in September 2015.

COMPARISON OF 2014 DEATH RECORDS

As discussed in Part 4 of this report, Associate Professor Barnett reached the conclusion in his second report that, after adjusting the death record data for monthly temperatures, there was an 82 per cent probability that the death rate was higher during the fire than the average number of deaths. This meant that there is an 18 per cent probability that the death rate was not higher during the mine fire than the average. The mean increase in deaths as a relative risk was calculated as 1.1 (or a 10 per cent increase from the average). Associate Professor Barnett ultimately concluded that the likely number of deaths across the six postcodes for the two-month period was an additional 9.6 deaths.

Dr Flander concluded in her third report that the statistical uncertainty in these estimates, expressed by broad confidence intervals for each of the rate ratios for the years 2009–2013, showed a lack

of statistical evidence to demonstrate an overall higher rate of deaths in 2014.24

In his report to the Board titled *Expert assessment and advice regarding mortality information as it relates to the Hazelwood Mine Fire Inquiry Terms of Reference – Final Report*, dated August 2015, Professor Armstrong undertook a further analysis of the research published by Dr Flander and others in their third report for the Department of Health, titled *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.*25

Professor Armstrong disagreed with some of the conclusions reached by Dr Flander and others in their third report, including the conclusion that there is ‘a lack of statistical evidence [to demonstrate]…

an overall higher mortality in 2014 than in 2009–2013.’26 Professor Armstrong considered that there is ‘moderate evidence’ to demonstrate an increase in deaths from all causes of death and from cardiovascular disease in 2014, relative to 2009–2013.27 He further concluded that there is ‘some

evidence’ that the increase in deaths between February and March 2014 was greater than the increase in deaths in the period February to June 2014.28

**Table 3: Deaths in the Latrobe Valley in 2009–2013 compared to 2014, for the months February to**

**June and February to March, produced by Professor Armstrong as Table 2 in his expert report .**29

**Years**

**February–June**

**Rate ratio**

**February–March**

**95% CI**

**P-value**

**Rate ratio**

**95% CI**

**P-value**

**Deaths from all causes**

2014

1

1

2009–2013

0.90

0.80–1.00

0.04

0.83

0.68–1.02

0.08

**Deaths from respiratory causes**

2014

1

1

2009–2013

1.20

0.88–1.66

0.25

1.31

0.77–2.23

0.31

**Deaths from cardiovascular causes**

2014

1

1

**2009–2013**

0.80

0.61–1.04

0.10

0.64

0.42– 0.97

0.04

42

**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

Professor Armstrong explained to the Board that the analysis he undertook for the period February– March shows a 17 per cent lower rate of death in 2009–2013 compared with the rate of death in 2014, and that there is a 1 in 12 probability that this result was from chance.30

Professor Armstrong explained that his conclusion was based on his assessment of the P-values he calculated. He told the Board:

I see the P-value as a useful indicator of the strength of the statistical evidence for a particular proposition and while, you know, there is this convention around 0.05 which I don’t adhere to, once you start to get down with P-values below 0.05 you say well, I’m starting to believe the proposition.31

Professor Armstrong told the Board that his understanding is that exposure to particulate matter would lead to an increase in cardiovascular deaths, but not necessarily an increase in respiratory deaths.

In his analysis, Professor Armstrong saw an increase of around 20 per cent more deaths caused by cardiovascular disease in 2014 than in 2009–2013, and around 20 per cent fewer deaths caused by respiratory causes in 2014 than in 2009–2013.32

Professor Gordon arrived at a similar conclusion to that reached by Professor Armstrong. At pages 3 and 4 of his report titled *Commentary on the Hazelwood mine fire and possible contribution to deaths,* Professor Gordon reviewed the analysis undertaken by Dr Flander and Professor English in their first report for the Department of Health, titled *Review of Birth Deaths & Marriages Victoria (BDMV) mortality*

*data for the Latrobe Valley at the time of the Hazelwood coalmine fire in Morwell,*33 and undertook some further analysis.34 Professor Gordon stated in this report that:

it is reasonable to believe that any effect of the fire on mortality may have continued for some time after the fire was declared safe on 25 March 2014. It is not hard to envisage scenarios for which this is a logical possibility. A frail elderly person with chronic obstructive pulmonary disease, for example, could have their respiratory system stressed by the air pollution from the fire in such a way that their death is accelerated, without it necessarily occurring during the period of the fire.35

Professor Gordon supplemented the analysis undertaken by Dr Flander and Professor English by setting out the observed and predicted number of deaths for individual months (February and March) and then as a range of months, and then calculating a P-value for each.36 Professor Gordon’s calculations are set out in Table 4.37

**Table 4: Comparison of observed and predicted numbers of deaths in 2014, adapted from Table 1 in the Flander and English report, produced by Professor Gordon.**38

**Period**

February 2014

**Predicted**

43.38

**Observed**

50

**Ratio**

1.15

**P-value**

0.175

March 2014

52.98

62

1.17

0.122

Feb–March 2014

96.36

112

1.16

0.064

Feb –April 2014

146.26

166

1.13

0.058

Feb –May 2014

199.24

228

1.14

0.024

Feb –June 2014

249.64

285

1.14

0.015

43

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Professor Gordon concluded that, based on the numbers extracted from Dr Flander’s report, there was ‘quite strong and statistically significant evidence that the death rates from February to June 2014 were abnormally high.’39

During the hearing, Dr Flander disagreed with Professors Armstrong and Gordon about whether a more appropriate statistical analysis involved a comparison of the 2014 data with an average of the 2009– 2013 data (the method adopted by Professors Armstrong and Gordon), or with each of the years from 2009 to 2013 (the method adopted by Dr Flander).40 Professor Armstrong told the Board that the analysis approach should be governed by the question posed, and that:

the question as I understood it was, was there a higher death rate in Latrobe Valley in Morwell, either or both, in 2014, than would usually be expected and that might be attributable to the mine fire? With that question I would say that what I said was the preferred approach would be what most people would do, that is to say they wouldn’t say well, we will just compare with 2013 or with 2009, we’ll take a number of years to try and get a reasonable estimate of what it’s usually like and then make the comparison, so 2014 with 2009 to 2013. If the question is a more complex one well, how is mortality varied and how does it compare between 2014 and different years, well then surely do it year by year. You can unpack if it you want but there is a phenomenon in this that I worry about, I don’t know that every analyst worries about it, and that’s what we refer to as multiple testing.41

Professor Gordon agreed with Professor Armstrong on this point.42

Dr Flander explained that she stood by the approach she adopted because ‘if we had treated those years as a single unit and just averaged them we would have lost information we may find out to be useful.’43 Dr Flander accepted that the different approaches would give a different outcome: ‘I think we have abundant evidence that every time we make a pass through these data and alter the, how should I put it, the architecture of it, which variables go in and how we perform the analysis, we will get slightly different results.’44

CONCLUSIONS REACHED BY THE EXPERTS

In his review of Associate Professor Barnett’s reports, which was tendered as evidence at the Inquiry’s public hearings, Professor McNeil concluded that the observed number of deaths during the months of the Hazelwood mine fire was within the range of variation seen in the same postcodes during previous years.45

In his report, Professor Armstrong concluded that there is ‘moderate evidence’ for an increase in deaths from all causes of death and from cardiovascular disease in 2014 compared with 2009–2013. He also concluded that there is ‘some evidence’ that the increases in deaths in February to March 2014 were greater than those in the longer period of February to June 2014.46 Professor Armstrong described this latter conclusion as being supported by ‘some’ or ‘weak’ evidence.47 Professor Armstrong told the Board that he considered these terms to describe the same concept.48

In their joint expert report dated 31 August 2015, Professor Gordon, Associate Professor Barnett and Dr Flander agreed with Professor Armstrong’s conclusions, preferring to use the terminology ‘some evidence’ over ‘weak evidence’ with respect to the second conclusion.49

Further, assuming that the period of risk to health extended beyond the actual duration of the mine fire (for example, to May 2014), the experts agreed that the excess of deaths for that longer period is statistically significant at conventional levels (that is, a P-value of 0.05 or less).50

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**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

**5.4 IF THERE WAS AN INCREASE IN DEATHS, DID THE MINE FIRE CONTRIBUTE TO THE INCREASE?**

The second question posed to the Board was, if there was an increase in deaths, did the mine fire contribute to any increase?

Professor Armstrong explained to the Board the role of epidemiology in the assessment of data.51 Professor Armstrong stated:

This is where you start to move from just, you know, numbers and confidence intervals into causal thinking, what caused what to happen…it is not just description of numbers, it’s about making a decision at least as I understand this Inquiry’s purpose, that firstly whether or not there was a higher death rate in 2014 than would be normally expected to be, and secondly, what caused it. Once you ask the second question you then have to think what is the universe of possible causes...52

The joint report of the experts dated 31 August 2015 identified that there were four possible factors, exposure to which might have increased mortality in the Latrobe Valley during the mine fire.53 These factors were:

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associated bushfires

fine particulate matter air pollution carbon monoxide air pollution high temperatures.

Each of these factors is discussed in turn below.

ASSOCIATED BUSHFIRES

Professor Armstrong’s analysis included testing whether bushfires had a contributing effect on the increase in mortality in the Latrobe Valley in 2014. He compared data from 2009 death records against data from 2014 death records, because in both these years major bushfires affected the Latrobe Valley area.54

In February 2009, parts of the Latrobe Valley were affected by the Black Saturday bushfires, during which 11 people in Churchill died.55 In February 2014, the Latrobe Valley was affected by the bushfires that started in Hernes Oak and Driffield and burnt for about three weeks.56

Using data from the third report of Dr Flander and others, Professor Armstrong concluded that the number of deaths from all causes of death in February and March, and between February and June 2014, was closer to that in the corresponding periods of 2009 than those for the overall period 2009– 2013. Professor Armstrong considered that this comparison may suggest that bushfires contributed to the probable increase in mortality from all causes of death in 2014. However, he noted that there was no evidence of a relationship between the bushfires and deaths from cardiovascular disease, suggesting that something else, not present in 2009, was responsible for the increase in deaths from cardiovascular causes in 2014.57

Professor Armstrong’s calculations are recorded in Table 5.

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**Table 5: Latrobe Valley mortality in 2009–2013 compared with 2014, for the months February to June and February to March, produced by Professor Armstrong as Table 3 in his expert report.**58

**Years**

**February–June**

**Rate ratio**

**February–March**

**95% CI**

**P-value**

**Rate ratio**

**95% CI**

**P-value**

**Deaths from all causes**

2014

1

1

2009

0.93

0.81–1.06

0.30

1.01

0.79–1.28

0.91

2009–2013

0.90

0.80–1.00

0.04

0.83

0.62–1.02

0.08

**Deaths from respiratory causes**

2014

1

1

2009

0.95

0.61–1.47

0.82

1.08

0.54–2.17

0.81

2009–2013

1.20

0.88–1.66

0.25

1.31

0.77–2.23

0.31

**Deaths from cardiovascular causes**

1

2014

1

2009

0.70

0.49–1.00

0.06

0.58

0.34 – 0.99

0.05

2009–2013

0.80

0.61–1.04

0.10

0.64

0.42– 0.97

0.04

Professor Armstrong explained to the Board that his conclusions were based on the fact that the rate ratios from all causes of death and for respiratory causes of death in 2009 were closer to one (which is the 2014 reference value), than the rate ratios for the period 2009–2013. This suggests that deaths from all causes or from respiratory causes in 2009 may have been more similar to those in 2014 than the average from 2009–2013.59

The joint expert report dated 31 August 2015 recorded the agreement of Professor Armstrong, Professor Gordon and Dr Flander that:

Mortality from all causes in February and March and February to June 2014 was closer to that in the corresponding periods of 2009 than those of 2009–2013. 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.60

Professor Gordon clarified this joint conclusion for the Board, stating that the words ‘may suggest’ were carefully selected to convey that it was a logical possibility, but by no means a certainty, that bushfires contributed to the probable increase in mortality.61

Associate Professor Barnett did not agree with this conclusion. The joint report notes his reservation that in 2014 there were two sources of fire (bushfire and the mine fire) and that there is a difficulty in distinguishing between their impacts. Associate Professor Barnett was of the view that it would be desirable to compare further air quality data across the two time periods, and to get an expert opinion about what proportion of the air pollution was due to the mine fire, before reaching a conclusion.62

During the public hearings for this Inquiry, Professor Gordon questioned whether the 2009 death records data should be modified to exclude those deaths that were the direct consequence of bushfires (excluding from the data the death records of those who died in the Black Saturday bushfires in February 2009). He suggested that a comparison of the adjusted 2009 death records data and the 2014 death records data would demonstrate that the years were not as similar as Professor Armstrong’s calculations suggested, and that the 2009 data would likely look similar to data for the years 2010–2013.63 Assuming this analysis could be done, there was some uncertainty about what number of deaths should be deducted.64

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**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

After attending the public hearings on 2 September 2015, Professor Gordon undertook a further analysis of the 2014 death records data compared with the 2009 data,65 after deducting 11 deaths from the February 2009 data.66 The results of this additional analysis are described in Table 6 and demonstrate

a lower predicted number of deaths for each of the periods (with the exception of March, which remained the same).67

**Table 6: Comparison of observed and predicted number of deaths in 2014, based on Table 1 in the Flander and English report, but adjusted to account for deaths caused by the Black Saturday bushfires, produced by Professor Gordon.**68

**Period**

February 2014

**Predicted**

41.67

**Observed**

50

**Ratio**

1.20

**P-value**

0.115

March 2014

52.98

62

1.17

0.122

Feb–March 2014

94.6569

112

1.18

0.044

Feb–April 2014

144.5570

166

1.15

0.043

Feb–May 2014

197.5371

228

1.15

0.018

Feb–June 2014

247.9372

285

1.15

0.011

Dr Flander told the Board that the analysis undertaken by Professor Gordon ‘makes good sense’ but that she was unable to say whether it would affect the results she obtained due to the difficulty in comparing the two results. Dr Flander had modelled her analysis on temperature and exposure to particulate matter

(PM ), whereas Professor Gordon had not.73

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FINE PARTICULATE MATTER AIR POLLUTION

Professor Armstrong informed the Board that any emission from a fire is potentially inhalable and can cause illness and death. In relation to particulate matter (an emission from a fire), Professor Armstrong

noted that smaller particulate matter such as PM 74 was able persist in the lungs longer than larger

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particulate matter, and can have effects on the functional level of the lungs and on the heart.75 Professor Armstrong further stated that the dominant effect of air pollution on health is cardiovascular rather than respiratory.76

Professor Armstrong stated that one would expect to see increased deaths, caused by inhalation of particulate matter, as occurring proximate to the air pollution event. However, notwithstanding that expectation, he analysed the death records data covering a longer period of time to consider whether there was evidence of an increase in deaths in that longer period.77

Associate Professor Barnett referred to reports published by the American Heart Association and World Health Organization, which describe the relationship between particulate matter pollution and death and morbidity, and demonstrate that there is very strong evidence of the short and long-term effects

of air pollution on stroke, increased risk of death, and increased risk of emergency hospital admissions for cardiovascular and respiratory disease.78

Dr Flander noted that given the evidence of a probable increase in deaths, a causal relationship between exposure to particulate matter and deaths could not be excluded.79

In their joint expert report dated 31 August 2015, the experts agreed that across the period 2009– 2014, the number of deaths in the Latrobe Valley in both February and March and from February to June was higher on days when particulate air pollution was greater than or equal to 50 micrograms

per cubic metre of PM , relative to when particulate air pollution was lower than this level.80 Professor

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Gordon noted that his agreement with this conclusion was qualified, as he had not independently assessed the data.81 Associate Professor Barnett also qualified his agreement with this conclusion,

as he considered that the method adopted was not the best available way to analyse the impact of air pollution on health. He suggested that air pollution be considered as a linear variable rather than as

a threshold scale.82 He provided no explanation to the Board as to what effect this would have on the observations of death rates.

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The experts further agreed that there was no evidence that deaths from all causes, or from cardiovascular causes during the duration of the Hazelwood mine fire, were more frequent on days with

higher PM levels than on days with lower PM levels. This observation was not consistent with the

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2.5

work of Flander and others in their third report, where it was concluded that mortality from all causes over the whole period 2009–2014 was approximately two-fold higher for Latrobe Valley residents

exposed to PM at levels of 50 micrograms per cubic metre or more on the day of death than in people

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not so exposed.83 Notwithstanding those observations, the experts agreed that Dr Flander’s reasoning was sound and that it was very likely that ‘particulate air pollution during the mine fire caused an increase in deaths, realistically, perhaps, more in the period after the mine fire than during it.’84

Professor Armstrong told the Board that he and Dr Flander undertook two different analyses to consider the effect of particulate matter on death rates. Whilst Professor Armstrong indicated that the two analyses should have obtained ‘roughly the same results’, Dr Flander’s results (showing an association between particulate exposure and an increase in deaths) had ‘more statistical power.’85 Professor Armstrong explained that there was a weakness in his analysis, which was that the estimates of exposure that he used potentially led to significant measurement error. This measurement error may have obscured associations that may otherwise be present.86

Professor Gordon noted that his agreement with this conclusion was qualified, as he had not independently assessed the data. Associate Professor Barnett also qualified his agreement with

this conclusion, as he considered that PM should be regarded as a linear variable rather than as a

10

threshold scale.87 Again, Associate Professor Barnett did not indicate what effect this would have on the observations of the effect of particulate matter on the rate of deaths.

CARBON MONOXIDE AIR POLLUTION

A conclusion reached in Professor Armstrong’s expert report was that ‘there is good evidence that environmental exposure to increased levels of carbon monoxide is associated with an increased risk of emergency department visits and hospitalisations for cardiovascular disease.’88 The evidence that carbon monoxide is also associated with an increased risk of death is less certain, particularly whether its effect on health is due solely to exposure or also to other air pollutants that are commonly correlated with carbon monoxide.89 As described in the 2014 Hazelwood Mine Fire Inquiry Report, carbon monoxide is produced as a result of the incomplete combustion of coal.90

Given this context, Professor Armstrong investigated whether there was any evidence that carbon monoxide played a role in the probable increase in deaths in the Latrobe Valley during the mine fire.

Professor Armstrong did not find any consistent evidence showing any effect of carbon monoxide on the number of deaths in Morwell and the Latrobe Valley.91

Dr Flander, Associate Professor Barnett and Professor Gordon did not address the effect of carbon monoxide on the number of deaths in the Latrobe Valley in their respective reports.

In their joint report dated 31 August 2015, the experts agreed with the conclusions reached by Professor Armstrong that there was no consistent evidence that deaths from all causes or from cardiovascular disease during the mine fire were more frequent on days with higher carbon monoxide levels than on days with lower carbon monoxide levels.92

Professor Gordon agreed with this conclusion, with the reservation that he had not independently assessed the data.93 Associate Professor Barnett also agreed with this conclusion, with a reservation that he had concerns about the use of carbon monoxide as a threshold scale rather than as a linear measure.94 Again, Associate Professor Barnett did not indicate what effect this might have on the observations of the effect of carbon monoxide on the rate of deaths.

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**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

HIGH TEMPERATURES

Dr Flander, Associate Professor Barnett and Professor Armstrong all conducted analyses that took into account the effect of temperature on deaths in the Latrobe Valley.

Dr Flander noted that there were more deaths occurring on days with mean temperatures at or over 30 degrees in 2009 and 2014, than in the years 2010–2013. There were 27 deaths that occurred on

days with mean temperatures at or over 30 degrees in the four Latrobe Valley postcodes, with 13 of those deaths in 2009 and seven in 2014. In their third report, Dr Flander and others concluded that there was no statistical evidence of an association between higher temperatures and all causes of mortality in the

February–March period in 2009–2013, compared with February–March 2014. Rather, there was ‘moderate evidence’ of an association of colder temperatures with mortality for the months February to June.95

Professor Armstrong also concluded that there was no evidence to suggest that higher temperatures in the Latrobe Valley during the mine fire were associated with a higher risk of death.96

In their joint expert report dated 31 August 2015, the experts agreed that across the whole period 2009–2014, the number of deaths in the Latrobe Valley in February to June was greater on days when the temperature was less than 30 degrees than on days when it was higher. This difference was not evident in February and March of those years.97 Professor Gordon agreed with this conclusion, with the reservation that he had not independently assessed the data.98

The experts also agreed in their joint expert report that there is no evidence that higher temperatures

in the Latrobe Valley during the period of the mine fire were associated with a higher number of deaths, whereas there is strong evidence that a higher death rate was associated with lower temperatures.

Lower temperatures, however, do not appear to explain the higher death rate in February and March 2014, as compared with the same months in 2009–2013, as the mean daily temperatures in these two periods were observed to be nearly identical.99

DECREASED OBSERVED NUMBER OF DEATHS IN MORWELL DURING THE MINE FIRE

The death records provided by the Registry shows that the number of deaths during the Hazelwood mine fire for persons who usually resided in Morwell, was less than preceding years. This is discussed in Part 3 of this report.

Associate Professor Barnett also observed in his second report that Morwell had a decreased mean risk of death over the duration of the mine fire.100

Professor Armstrong told the Board that whilst the observed number of deaths in Morwell seemed inconsistent with a theory that Morwell would see the greatest increase in deaths given its proximity to air pollution from the mine fire, the statistical evidence supporting the difference in death rates between Morwell and the other locations is ‘not strong.’101 Professor Armstrong considered it possible that factors

such as the small sample size of the death records data in Morwell, might have ‘obscured an effect of the mine fire’ on mortality rates.102 Professor Armstrong concluded that he would ‘discount that inconsistency’ (the lower death rate in Morwell) in reaching a conclusion about whether there was an increase in deaths overall during the mine fire.103

Professor Gordon agreed with Professor Armstrong about the death rate in Morwell, and also referred to the possibility of natural variation affecting the results observed for Morwell, considering the small sample size.104

Professor Armstrong identified that another factor that may have played a role in reducing the deaths in Morwell was the Department of Health’s relocation advice. It was possible that the advice to the community for vulnerable people to relocate during the mine fire could have ‘reduced the population at

risk in Morwell, that is the people who are likely to suffer death during that period, by a material number.’105

Professor Gordon noted that there was a level of uncertainty regarding the number of people who travelled to Morwell for work during the mine fire, but who lived in other towns, and the number of people who lived in Morwell, but who worked in other towns during the mine fire. He stated to the Board that this circumstance may have impacted Morwell residents’ exposure to air pollution from the mine fire and the death rate in Morwell.106

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**Hazelwood Mine Fire Inquiry Report 2015/2016 VOLUME II – Investigations into 2009–2014 deaths**

Professor Armstrong told the Board that whilst he had not seen any data that indicated the actual number of people who vacated Morwell during the mine fire, it was not unreasonable to speculate that the circumstance of some people vacating the area could have had an impact on the overall death rate in Morwell in the relevant period.107

In their joint expert report dated 31 August 2015, Professor Armstrong, Professor Gordon, Associate Professor Barnett and Dr Flander agreed that as Morwell was the most exposed of the Latrobe Valley towns to emissions from the mine fire, the comparative lack of greater deaths in Morwell in 2014 relative to 2009–2013 is inconsistent with the mine fire being the cause of an increase in deaths in the Latrobe Valley. However, the experts also agreed that this conclusion does not take into account the evacuation of some residents from Morwell during the period of the mine fire.108

Further, the experts considered that there was ‘statistical uncertainty’ in relation to the finding in Associate Professor Barnett’s second report that there was a decrease in deaths in Morwell during the mine fire. Accordingly, the experts agreed that ‘a large increase in mortality in Morwell cannot be ruled out.’109 Professor Armstrong told the Board that, based on Barnett’s analysis and the large confidence intervals, a large decrease in deaths could also not be ruled out.110

HOSPITAL ADMISSION RECORDS

Professor Armstrong undertook a statistical analysis of the frequency of emergency hospital admissions in 2014 relative to 2013. The purpose of this analysis was to test whether there was any association between the number of admissions to hospital and the mine fire. Professor Armstrong suggested to the Board that if there was an increase in emergency admissions in 2014 from 2013, then the mine fire may have caused an increase in adverse health effects, and therefore also an increase in deaths.111

Professor Armstrong’s analysis indicated that:

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The rate of emergency hospital admissions for all conditions in the Latrobe Valley during the mine fire was 16 per cent greater in 2014 than it was for the same period in 2013 and that the probability that this was due to chance is 1 in 1,000 (P-value of 0.0001).

The rate of emergency hospital admissions for cardiovascular conditions was also 16 per cent greater in 2014 than it was for the same period in 2013, and the probability that this difference was due to chance is 1 in 4 (P-value of 0.26).

The rate of emergency hospital admissions for all other conditions was also 16 per cent greater in 2014 than it was for the same period in 2013 (P-value of 0.006).

The rate of emergency hospital admissions for respiratory conditions was 31 per cent greater in 2014 than it was for the same period in 2013 (P-value of 0.07).

The rate of emergency hospital admissions for cancers was 16 per cent less in 2014 than it was for the same period in 2013, albeit with greater uncertainty about the statistical significance of this difference (P-value of 0.61).

The rate of emergency hospital admissions for the age group 0–4 years was 16 per cent greater in 2014 than it was for the same period in 2013, however statistical evidence for this finding is weak (P-value of 0.48).

The rate of emergency hospital admissions for the age group 25–39 years was 64 per cent greater in 2014 than it was for the same period in 2013, and the probability that this was due to chance is 1 in 1,000.

The rate of emergency hospital admissions for the age group 65–74 years was 38 per cent greater in 2014 than it was for the same period in 2013, and the probability that this was due to chance is 1 in 110.112

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Professor Armstrong told the Board that the evidence of an increase in hospital admissions strengthens the proposition that there was an increase in deaths during the period of the mine fire.113

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**Part Five Expert Analysis of the Death Records Provided to the Inquiry**

In their joint expert report dated 31 August 2015, all the experts agreed to the following conclusions (with a qualification from Professor Gordon that he had not independently assessed the data):

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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, although the statistical evidence for these increases is weaker.

There is strong evidence that emergency hospital admissions were greater in 2014 than in 2009–2013 for people aged 25–39 years.

Emergency hospital admissions were greater in infants and children (0–4 years of age), albeit with statistically weaker evidence in 2014 than in 2009–2013. This age group is recognised as vulnerable to adverse health impacts from pollution.

Emergency hospital admissions were greater for older people (aged 65–74 years and to a lesser extent, for those aged 75 years and older). This age group is recognised as vulnerable to adverse health impacts from pollution.114

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CONCLUSIONS REACHED BY THE EXPERTS

In answer to the question whether the mine fire contributed to any increase in deaths in the Latrobe Valley, Professor Armstrong told the Board that:

Firstly, I think we have as described moderate evidence for an increase in deaths during that period so anything I say about the cause of it has to take into account the fact that the evidence for the increase itself is not strong…But given that evidence, I think of the various explanations that one can put forward, the most likely is that an increase, if one occurred, was due to the increase in the particulate pollution of the air during that period of time, most likely due to the mine fire but possibly added to by bushfires that occurred at the same time…115

Professor Armstrong told the Board that his conclusion was based on strong evidence that there

is a relationship between particulate pollution and risk of death. He stated that short-term increases

in particulate pollution are associated with short-term increases in deaths and that long-term exposures are associated with longer-term increases in deaths.116 Professor Armstrong relied on the results obtained by Dr Flander, rather than his own, with respect to the effect of air pollution.117

Professor Gordon told the Board that he was in ‘substantial agreement’ with Professor Armstrong’s conclusions.118 In explaining to the Board the cautious approach that he took to this question,

he indicated that:

we are in a situation here where causation cannot be attributed on the basis of the gold standard paradigm in science of a randomised controlled—we’re nowhere near that, nonetheless there are plenty of very important situations in research and in life where we have to think about this question of causation without the paradigm and epidemiologists and statisticians have thought about that issue a lot and have addressed their minds to the criteria one might apply to draw a conclusion of various strengths…I agree with Professor Armstrong, taking into totality the statistical evidence, the other factors that were looked at that might partly explain the results such as temperature, which in my view do partly explain it but not nearly enough to remove the apparent effect of the coal mine fire.119

Associate Professor Barnett’s conclusion on this question was informed by his understanding of the health effects of air pollution and its association with increases in morbidity and mortality. Associate Professor Barnett indicated to the Board that ‘it really feels from my point of view that there would have to be something very surprising going on in Morwell not to see that increase [in deaths].’120 Associate Professor Barnett further explained that his conclusion took into account that the relative risk of an increase in deaths, being between 10 and 15 per cent, was around the size expected by him, and that the increase in emergency hospital admissions was likely associated with an increase in deaths.121 Associate Professor Barnett also agreed with the observations made by Professors Armstrong and Gordon.122

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**Hazelwood Mine Fire Inquiry Report 2015/2016 VOLUME II – Investigations into 2009–2014 deaths**

Associate Professor Barnett considered that it was not merely a coincidence that there was an increase in deaths at the same time as the mine fire. He indicated the probability results he obtained were based on a regression model analysis, which worked on having a known cause and looking for an effect.123

Dr Flander indicated that she had ‘no fundamental disagreement with information that Professor Armstrong put forward’ and ‘no objection to the further analyses done by Associate Professor Barnett or Professor Gordon.’124 Dr Flander stated to the Board:

So my answer to the first question is yes, there is moderate evidence of an increase, these data do

show that. Do I have a feeling or opinion or judgment about the effect of exposure to PM ? Yes, I

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do, I think we do show that. I think I concluded…that there is uncertainty around these estimates… as a final caveat I would just like to say that we make our best estimate and we use different methods and we have different judgments and assumptions, and in the case of small numbers we’re dealing with here we all have been taught well that we do not want to conclude there is an effect if there is none, nor do we want to miss an effect if there is one.125

Dr Flander further stated that in this matter, she did not consider that there were enough observations to enable her to choose between alternative explanations, which means that no explanation can be ruled out.126

Dr Flander noted that the longitudinal health study (the Hazelwood Mine Fire Health Study, referred to in Part 3) will assist to inform the effect of the exposure to the mine fire on health. She noted that the value of the study is that it ‘yields more robust information, information we could not hope to get from the kind of study we did.’127

Professor McNeil noted in his report that the data provided in the reports of Associate Professor Barnett and Dr Flander did not exclude an excess of deaths amongst those most exposed to the mine fire. He stated that ‘any increase in a smaller number exposed may have been concealed within the much larger group with little exposure.’128

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