A GIS BASED APPROACH TO THE ESTABLISHMENT OF AN ADEQUATE NETWORK OF AIR QUALITY MONITORING STATIONS IN AREAS SURROUNDING COAL MINES IN THE LATROBE VALLEY

14,053 words

Thesis submitted in (partial) fulfilment of the requirements

for the degree of Master of Applied Science

J Gordon

B.Sc (Geography and Environmental Science)

Monash University, Australia

School of Mathematical and Geospatial Sciences

RMIT University

January 2015

DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement fate of the approved research program; any editorial work, paid or unpaid, carried out by a third part is acknowledged; and, ethics procedures and guidelines have been followed.

J Gordon

ABSTRACT

A GIS BASED ASSESSMENT OF AIR MONITORING IN AREAS SURROUNDING COAL MINES IN THE LATROBE VALLEY

J Gordon

School of Mathematical and Geospatial Sciences

Master of Applied Science

The Latrobe Valley is an important source for brown coal in Victoria as it is used to fuel the local coal fired power stations. However a fire which occurred in the Hazelwood mine, a technological disaster, posed a severe risk to residents within the valley particularly in Morwell. Poor efficiency of setting up monitoring equipment meant that the local population was unable to get detailed information about what they were experiencing from the smoke they were inadvertently inhaling. This thesis successfully attempted to determine areas in the Latrobe Valley that were at risk of mine pollution from fire events and suggested an adequate network to be set up for future monitoring of air pollution in the area. The network comprised of five permanent monitoring stations and eight temporary monitoring sites in order to maximise the ability to monitor the risk imposed upon the local population and provide necessary information for future events to assist with risk management, evacuations and to issue warnings.

ACKNOWLEDGMENTS

I would first and foremost like to thank Dr. Gang-Jun Liu for his assistance and guidance throughout my entire thesis. Without his assistance, the task of writing this thesis would have been much greater.

I would also like to thank the Postgraduate Coursework Leader Dr Colin Arrowsmith for his understanding and care. He contributed greatly to alleviating pressures of research throughout my thesis.

I would also like to thank the School of Mathematical and Geospatial Science and by extension RMIT for the opportunity to conduct my Masters degree and thank them greatly for everything I have learned during my time of study.

I would like to make a mention of thanks to the Bureau of Meteorology, EPA Victoria and the Australian Bureau of Statistics for data contributions which were made accessible free of charge.

Most importantly, I would like to thank my brother Chris, mother Leanne, father Lindsay, the rest of my family and all my friends. Your support and caring during this time has been greatly appreciated. Every comment of encouragement and constructive criticism has been valuable in assisting me conduct something I never fathomed I would have initiated.

DEDICATION

I dedicate this paper to those affected in any way, by the fire that occurred within the Hazelwood coal mine on February to March 2014, and hope that it may assist in contributing to a greater awareness, respect and acknowledgement towards public safety by companies, governments and local authorities in Australia in the future.

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1.1 Introduction

On the 9th of February 2014, a fire (believed to be arson) ignited the Hazelwood open cut coal mine near Morwell, Victoria (Herald Sun 2014). The fire burned for over one month and affected nearby townships of Morwell and Traralgon due to smoke, gases and other particulate matter directly emitted from the coal seam fire (ABC News 2014).

The Victorian Environment Protection Authority (EPA) has an office located in Traralgon near where the fires occurred. Near this office is one permanent air monitoring station run by the EPA which monitors Carbon Monoxide, Ozone, Nitrogen Dioxide, Sulphur Dioxide and Particles at PM2.5 and PM10.

On the 12th of February 2014 a new temporary station was set up in Morwell East and on the 19th of February 2014 a second temporary station was set up in Morwell South. This means the two stations were set up 3 and 10 days after the fire had started inside the Hazelwood coal mine.

These stations provided information for the general public but were only of use to people who were living or working downwind of a set monitoring station. These temporary stations suit well for the Morwell south township however there is severe data loss at surrounding mines and at different bearings to the mine sites based on typical climatologic wind patterns in the area.

There are a number of classes which can be deemed as at risk and they are as follows: human population distribution, economically sensitive areas and areas of environmental importance. The primary focus in any hazard is human health and wellbeing which is then followed by the need to protect infrastructure and economically important areas (such as farming and businesses) and the least concern is environmental significance. In terms of the fire which occurred in the Hazelwood mine, the human health impact was the primary focus of many media and official reports.

1.2 Research objectives and research questions

The objective of this study initially was to look at the dispersion of pollutants due to the mine fire through the utilisation of computer modelling software that was approved by the Victorian EPA. As time progressed the study started to uncover a more important question which appeared to override the previous objective.

Whilst it is important to understand who were affected by the pollutants originating from the fire, doing so is a reactionary response to a technological disaster which could have been prevented. Instead there needs to be an overarching monitoring program implemented in order to prevent disasters from occurring rather than simply dealing with disasters as they occur.

Because of this, more appropriate questions were developed:

- Where and why were the areas adjacent to the mines not actively monitored for atmospheric pollutants?
- What is being done as a response to what occurred? And finally,
- What can Victoria do in order to improve its monitoring capacity in order to prevent such similar scenarios from occurring in the future due to disasters /hazards?

1.3 Outline of the thesis

This thesis will cover a literature review of the current challenges relating to impacts from mine fires on human health, the economy and environment. It will look at the local as well as global approaches to these challenges and then look at the adequacies and inadequacies in the current methods of managing these approaches.

It will then extend into the research methodology conducted by looking into how the study area was selected, what the research outputs are expected to be and what inputs are required to achieve these outputs. It also discusses the collection and preparation of the input data and how the data is analysed and visualised.

Discussion of the study area then commences showing the localities in the study area which also includes the land use. The demographics of the area are also researched to show populations of interest. Finally, the meteorology and air pollution monitoring stations are then displayed.

The results are then displayed which show the areas which were covered by the air quality monitoring stations and the proposed locations for new air quality monitoring stations including prioritising them based upon spatial necessity. Depiction of an adequate network for air monitoring in the area is then displayed based on specifically chosen site selection parameters.

Finally there is a discussion of all the information presented and a conclusion made about what research could be further investigated in the future and how the results of the thesis can be utilised in practise.

Chapter 2 Literature Review

2.1 Introduction

Coal mine fire literature in Australia is incredibly hard to come by as there have not been any detailed studies conducted at the time of writing this thesis. However, there are numerous papers which have been published internationally in response to coal mine fires, how they work and ways to mitigate their potential of occurring as well as the effects they have on the areas surrounding said mines.

The only information available at present in Australia relating to coal fires is the Hazelwood Mine Fire Inquiry report. The report was written in an effort to identify what happened, why it happened and provide recommendations to the local and state government (and their departments) as well as to the mine operator to avoid such an event occurring in the future.

Regardless of fire events, there is substantial information regarding the geology of the Latrobe Valley, coal mining methods, coal composition and international analysis of coal dust/pollutant dispersion from open cut mines. Included in this is also information of the health effects associated with coal dust and other pollutants that are associated either with the mining of coal or the combustion of it.

These pollutants not only affect the health of humans but they also have adverse effects on the economy and environment of the region as well. Due to the effect on human health, it can cause difficulty for people to work which results in economic loss due to failure of work being completed. This sort of effect is largely due to the mismanagement of employees own personal health and or the lack of education of the health implications of the pollutants.

The environmental effects don't tend to be as much of a concern as the health and economic impacts are. The usual environmental impacts are the deposition of pollutants on the ground surface including water courses and water bodies. If any of these pollutants contain dangerous chemicals such as Mercury, then these accumulations in the environment can become more concerning. However due to the absence of such metalloids and other chemicals, the environmental impact is limited to only coating of surfaces and the potential for secondary dust effect to occur (erosion of the deposited material by wind).

2.2 Local Approaches to the Challenges

The Latrobe Valley in Victoria, Australia has a world class brown coal reserve made up of three main deposits: the Traralgon, Morwell and Yallourn complexes (Barton, Gloe & Holdgate 1993). Brown coal is one of the earlier types of coal formation usually containing around 50-70% water and containing 45-55% volatile matter (Hill, Charsley & Ottaway 1985). The high levels of volatile matter mean that brown coal is a high fire hazard especially once mined and crushed (due to increased surface area). However, brown coals high water content also means that it is relatively inefficient in terms of energy transformation in the production of electricity when compared to anthracite (black coal) which has a lower water content)

Coal fires can be very difficult to extinguish not to mention they can also be quite hazardous. When coal is combusted it can release many different pollutants into the atmosphere including but not limited to carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x) as well as particulate matter at sizes of 2.5μm and 10μm (Weng et al. 2012). Coal that occurs in veins due to folds in rock formations mean that fire has the potential to move underground which can become nearly impossible to extinguish not to mention cause considerable risk of land subsidence due to weakening of the landform through the combustion of the coal layer.

The Latrobe valley is bordered to the south and north by large hills and small mountains respectively. Sea breezes are common in the area and tend to flow between the hill ranges of Haunted hills and the Strzelecki Range. This is a secondary valley region with the primary valley being between the Strzelecki range and the Great Dividing range. The valley averages between 50-150m in height. The southern ranges are between 350m and 700m in height and the Great Dividing range rises to 1500m.

Studies have been conducted on the wind flow throughout the Latrobe Valley including pollution dispersion of the power station stack plumes. Physick and Abbs (1991) discovered that during the summer months, the Latrobe Valley is dominated by winds coming from the east due to the coast nearby. The easterly wind sea breeze is common below a height of 1,500m during the evening time. Due to the shape of the valley narrowing the further west it goes, it causes a funnelling effect of winds (and a resulting increase in velocity) from the east in the evening and this tends to override any potential flows coming from the Morwell River saddle which lies between the Haunted hills and Strzelecki range. Figure 1 shows the topography of the specific area of interest being the Latrobe Valley (black line) along with the Hazelwood mine in blue, Yallourn mine in red, Loy Yang mine in green and Weather stations as black markers. The area of the mines is considerably low lying with respect to the surrounding area. The Strzelecki range is the white peaked region to the South-East, the Haunted Hills are the region to the South-West and the Great Dividing Range is to the North. This topography is the basis of what is used when describing the local meteorological influences.

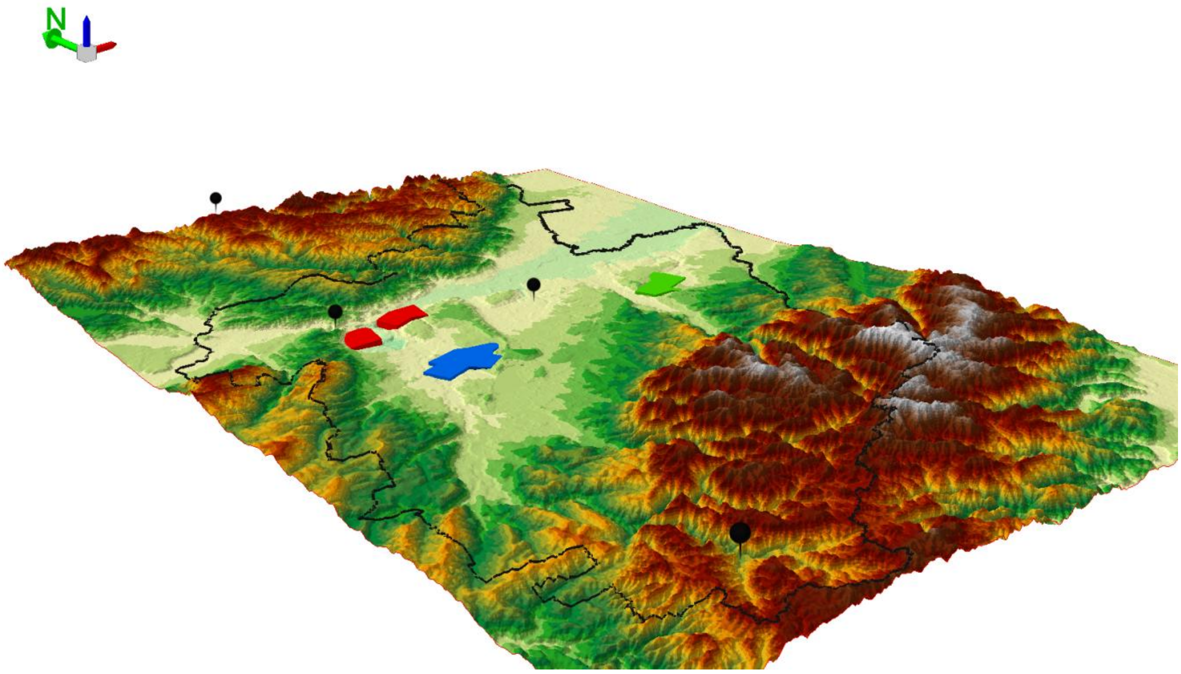

Figure 1 - Topographic representation of Latrobe Valley (Geoscience Australia 2015)

Particulate matter is concerning because the particles are not singular molecules, and as a result have the ability to carry pollutants (such as heavy metals) which cause further problems to individuals when inhaled or ingested (Weng et al. 2012). Respiratory distress is the primary symptom that PM 2.5 presents in humans and in particular young growing/developing and old and sick people are the most vulnerable to this hazard as it has the ability to increase mortality in these populations.

A study was conducted in 1997 which looked at the effect brown coal dust had on lung function (in particular Forced Expiratory Volume or 'FEV'). This study concluded that reducing the standards for exposure to such pollutants at that time was not warranted in order to prevent respiratory disease. However it should be noted that 42% of the subjects were smokers with another 29% on top of that who were ex smokers. As a result this shows that the study was done with approximately 71% of the subjects who would have already had a diminished FEV value due to their smoking habits. It was raised however that exposure to brown coal dust should be monitored and exposure to the pollutants be kept as low as possible (Finocchiaro et al. 1997).

In terms of local approaches, there has only been one real study conducted on mine fires in Australia and it is in fact on the exact fire this paper is looking at. As a result of the fire, on the 21st March 2014 the Victorian Government ordered an Inquiry into the fire. The inquiry board was made up of three people; The Honourable Bernard Teague AO, Professor Charles Catford and Ms Sonia Anne Petering. The aim of this investigation was:

- To determine how the fire occurred and how it entered into the Hazelwood coal mine;
- An assessment of the adequacy and effectiveness of the owner and operator of the mine in terms of fire prevention and the subsequent reactions once the fire had taken hold within the mine;
- The adequacy and effectiveness of regulatory regimes in terms of the risk posed by the fire and the response made as a result;
- The adequacy and effectiveness in the response to the fire by;
    - Emergency services;
    - Government agencies (which includes health and environment);
- Anything else that is considered to be of importance in relation to the above objectives;

The inquiry lasted for approximately 161 days as it ended with the presentation of the findings on the 29th of August 2014.

Of most importance to this thesis is the Health and Wellbeing section of the inquiry report. This section of the report looked at the types of pollutants which were emitted by the fire and what the concentrations of these pollutants were when they exhibit symptoms in people when inhaled. Particularly they highlight particulate matter which is the concerning factor of this thesis.

The demographics are investigated and the life expectancy of both males and females displayed. Along with this there are figures depicting the effect certain diseases have on the reduction of life longevity. Some of these diseases in particular relate to the effect some of the pollutants that were emitted from the fire have on people. According to the results, Latrobe has an overall higher rate of disease life years lost than surrounding regions as well as a higher rate than the Victoria average for both males and females. The life expectancy for females and males in the Latrobe valley is 79.6 years and 75.7 years respectively whilst the life expectancy for females and males in Victoria on average is 84.3 years and 81.5 years respectively. This shows that the average life expectancy in the Latrobe valley is considerably lower than the state average. Additionally, there is a pattern of health behaviour whereby there are higher rates of mental health issues, emergency department presentations and community health occasions than the state average.

Economically the Latrobe Valley is also at a disadvantage when compared to the rest of Victoria. In the Latrobe Valley 6.5% of the population is unemployed compared to 5.4% for the Victorian average. Income of individuals being less than $400 per week in the Latrobe Valley is 45.2% of the population when compared to the Victorian state average of 39.9%. The median household income sits at $942 for the valley compared to the state average of $1,216 (Teague, Catford & Petering 2014).

2.3 Global Approaches to the Challenges

The health impacts of coal mining are well documented internationally. In particular with the focus of this paper, particulate matter is of considerable concern due to its nature of being capable of containing additional impurities which can in turn cause additional health effects and problems. A recent study by Raanan Raz et al. (2014) highlighted a potential link between elevated levels of PM 2.5 exposure during the third trimester stages of pregnancy, and the increased risk of the development of Autism

Spectrum Disorder within the child. It was noted that removing the threat of such pollution from entering the mother during pregnancy lead to a lowered chance of Autism Spectrum Disorder being developed. Furthermore it highlighted that by preventing a known potential contributor of Autism Spectrum Disorder, there was an ability to prevent the potential societal and economic effects associated with the conception of a child with Autism Spectrum Disorder.

Other studies about pollution effects on human health are old in scientific terms (around ten years) and as a result shows that they are well known and backed up. In 2003 a study was conducted which showed the effect that PM2.5 and PM10 had on the lung permeability (Fernandez et al. 2003). The effect was that total lung capacity and vital capacity were reduced when exposed to these pollutants including fly ash. Lung damage is capable of occurring quickly and often recovery is slow. This would undoubtedly have an effect on the economy of the area due to people being unable to work at their full capacity due to the effects of the pollution and time taken in order to recover fully (if at all).

In Colombia where there are vast numbers of open pit coal mines, a lot of pollution is emitted due to transportation of coal. Whilst this is not as much the case in the Latrobe Valley, the paper by Huertas et al. (2012) conducted a computer model based analysis in order to determine the establishment of an appropriate clean air program. The results of the computer model were compared to actual measurements conducted in the area and it was determined that there were a range of risk areas which were affected by activities as a direct result of the coal mining. The final results of the paper resulted in the Columbian government implementing decontamination measures on the companies that were running the mines. More alarmingly, the results caused the permanent relocation of local villages adjacent to the mines at the expense of the coal mine operators. Whilst the Latrobe Valley mining techniques may limit the coal dust emitted from the mines, it is still concerning that even a country at a lower development when compared to Australia is more concerned about the impacts of mining than the Victorian and Federal governments are.

2.4 Inadequacies in the current approaches

Inadequacies in current approaches apply heavily to the local approaches more so than the global. Australia has a vested interest in coal mining as coal is currently its largest export and as a result it is also a large portion of the GDP (Australian Bureau of Statistics 2012). Because of this it is expected that any kind of policy or regulation against the coal mining industry would be met with hesitation by anyone with a vested interest in preserving the substantial wealth that can be generated by exporting to profitable countries. This stems typically at a federal level as any kind of move against coal in one state can quite easily gain national attention and steamroll throughout the other states where coal is mined.

Perceived leniency for the mining of coal is evident due to the actions that occurred during the time of Prime Minister Abbott in 2013/2014 whereby legislation for the mining tax and more importantly, the carbon tax both of which were installed by Mr Abbotts predecessor Ex-Prime Minister Gillard in 2012. These two reforms were designed to hurt the industry in a way to make them become more accountable for their actions and to reinforce the importance of environmental responsibility of corporations; showing that the government does indeed care about environmental impacts caused due to industrialisation.

The Liberal party did not see the value of the environment in the same fashion that the Labor party did which resulted in the dismantling of already working legislation. During the time of Gillard and Abbott, the state government of Victoria was held by the Liberal party which has since changed hands in favour of the Labor party. The change of power in favour of the Labor Party also brings with it two members of the Greens party which shows a great deal of potential advocacy against coal use/mining into the future. The Victorian Liberal government actually intended to expand the coal mining operation within the Latrobe Valley (Arup 2012) which on one hand secures and increases jobs and the economy but on the other hand is detrimental to the environment.

It is evident that policy surrounding the limitation of coal fired power stations is a controversial topic in terms of local, state and federal politics. Unfortunately, coal is such a large factor in the economy that many politicians see no other means other than allowing the mining of brown coal for power generation to continue. There seems to be a lack of interest in the renewable sector which if further expanded would in fact lead to more jobs and a transfer of roles from current power stations to new greener technologies.

In response to the fire, the EPA conducted some investigative computer modelling in order to try and determine what areas were affected by the mine fire. However, computer models are not true measurements of what happened, they are simply best guess scenarios based off information they have at the time. A paper by Thornton (2010) stated that although computer models are great for gaining this sort of information, they cannot and should not substitute for real world data. It is because of this the implementation of a new monitoring scenario needs to take place within the Latrobe Valley as one single permanent station is not adequate.

2.5 Summary

The method which has aimed to be utilised in this thesis was unable to be found in current scientific literature. Only information indicating the severity and risks associated with mine fire outputs were able to be discovered. The most serious risks involved respiratory distress to people who are already sick or elderly as well as expecting mothers as the particulate matter pollutants were found to cause an increased rate in the development of Autism Spectrum Disorders in children within the womb.

Nevertheless the review was able to also uncover significant information surrounding the local area meteorological effects including the impact that the south eastern coast winds had on the valley against the south west winds which funnelled through the Haunted Hills/Strzelecki Range valley. There was also a reasonable amount of information showing that other countries around the world at a considerably different level of development (usually lower), appeared to be more concerned about the health and well-being people who lived near open cut coal mines. It is reasonable, therefore, to state that Australia is not doing enough in terms of monitoring and maintaining the safety of those around their coal mining operations.

Chapter 3 Research Methodology

3.1 Introduction – the general GIS-based methodology

In order to conduct the research, the use of the geospatial analysis program Arc GIS 10.1 was required. This program was able to visualise the information from various sources to assist the understanding of the area as well as to assist answering the research questions proposed through the use of inputting data, running a process, producing an output and then appropriately visualising the information in a communicable fashion.

All of this data was displayed in the GIS platform using the projected coordinate system VICGrid 94 also known as Geocentric Datum of Australia 1994 (GDA94). Its technical specifications are listed in Table 1 below.

Projected Coordinate System	VicGrid (GDA94 Datum)
Projection	Lambert_Conformal_Conic
false_easting	2500000.00000000
false_northing	2500000.00000000
central_meridian	145.00000000
standard_parallel_1	-36.00000000
standard_parallel_2	-38.00000000
latitude_of_origin	-37.00000000
Linear Unit	Meter
Geographic Coordinate System	Geocentric_Datum_of_Australia_1994
Datum	D_GDA_1994
Prime Meridian	Greenwich
Angular Unit	Degree

Table 1 - Metadata of GIS analysis parameters for visualisation.

3.2 Selecting the study area

There were a number of different ways to select the study area. The main types involved geopolitical boundaries and environmental boundaries. In terms of impact upon human population, environmental boundaries such as catchments become irrelevant and instead it is important to focus on geopolitical boundaries.

There are a number of different types of geopolitical boundaries. First, there are localities which make up small areas usually encasing a localised suburb or township. There are many suburbs within the Latrobe valley and as such it is not useful to select based on locality, however the locality is useful in describing smaller areas. Parishes are also not suitable as there is no singular governing authority and merely similar to localities in terms of describing locations. State assembly areas are close to being an appropriate boundary to use however this is used as a state level of government whereas this issue is more of a localised issue (that is not to say that resulting findings won't affect wider communities and areas). Wards are not appropriate boundaries to use as they are the zones making up the local government areas and each ward has a representative whom sits within the local government authority's council. The best zoning to use is the Local Government Authority. This shows the total area which is governed by the local government of the Latrobe Valley Council. In accordance with the wards, the local government authority encases the entire area where the mines are situated and is the smallest level of government for the region and as such is in an appropriate position to act upon the findings of this and any other research findings.

3.3 Research Outputs Expected

The expected outputs from the research involves highlighting areas where there are high population densities around the Latrobe valley area and which of these areas are essentially downwind of the mine sites based upon wind climatology of the region. A map should be able to be generated which depicts the regions that are downwind of the mines and as a result further outputs can be generated which show potential overlap between the three mine sites.

Because population density is an important factor in this analysis, it stands to reason that it should have an influence on how important it is to monitor certain areas. This should impact upon the final map showing the impact the mines have on the surrounding residential areas and thus give vital information that can be used to determine where future stations should be located as either permanent or temporary stations.

3.4 Inputs Required

In order to conduct this analysis, a number of different sources of information were required to assist the construction of the GIS platform.

- Polygonal extent of the Latrobe Valley Local Government Authority boundary
- Localities polygons (to enable description of the maps more effectively)
- LandSat imagery of the mines since 1987 until 2014
- Planning scheme zones depicting land use categories
- Population density meshblock data
- EPA monitoring station location information
- Weather station location information

Other information which is also to be derived which was not able to be added into the GIS platform.

- Air pollutant concentration data at time of fire event
- Wind speed and direction data at time of fire event
- Wind speed and direction climatology data
- Digital Elevation Map data (which can be used to see a 3D representation of the area in question.)

3.5 Data collection and preparation

Data for the geopolitical boundaries and the planning boundaries was obtained from the Victorian Government's Land Channel website which contains a large data repository of geospatial information. To start with, the Local Government Authority (LGA) boundary needed to be identified. This was obtained easily and inserted into the GIS platform. Once the LGA of Latrobe Valley was obtained, the localities that the LGA boundary intercepted were identified. The data depository utilised locality based data requests which means if a certain piece of information is required (for example the planning zones) then the locality must be used as the search term.

The planning zones were then able to be added to the geospatial platform. In order to extract the key areas of interest, the areas considered to be residential in nature were selected and the rest of the zones were removed. This gave an overlay of every residential zone capable of housing people within the Latrobe Valley Council area. Of course though there was some overlap showing areas outside of the Latrobe valley government authority boundary. To remedy this, the residential zones were clipped to the LGA boundary.

The population density information data was then obtained from the Australian Bureau of Statistics 2011 census. This data came as a meshblock and had a very large volume of information covering much of Australia. This data was clipped to the LGA boundary by filtering the data that did not have the same meshblock code as the LGA. The data contained the amount of people based on the meshblock they were in. In order to gain a more relatable and easier to understand method of determining the amount of people, the area of the meshblocks were calculated and input into the attribute table for the population data. After this, the population for a meshblock was divided by the area of the meshblock (in kilometres) and this gave the population per square kilometre for each entry.

In order to visualise this information appropriately based upon where people live (or have the potential to live), the population data was clipped to the residential zones within the Latrobe valley. This gave an accurate depiction of how many people are living per km^2 in residential zones.

The Australian Bureau of Meteorology has a database of weather stations along with what data they contain and how long they have been recording. The only station utilised which conveniently was centred in the middle of all three mine sites, was the Latrobe Valley Airport weather station. This station contained wind speed and direction which was critical for this thesis analysis. The latitude and longitude co-ordinates were entered into the GIS platform and a point was created with information detailing it as a weather station. The data for the wind speed and direction was obtained through a secondary provider of the Bureau's data called Weatherzone which was free of charge. Once all this direction and speed data was obtained, it was inserted into Excel and processed in order to extact the data such that the frequency of wind speed and direction could be identified and then placed into a radar type graph.

The Environment Protection Authority was able to provide latitude and longitude co-ordinates for each of the three atmospheric pollution monitoring station sites they had running during the fire event. Just like the weather station, these were inputted into the GIS platform and were assigned the term EPA stations. In order to obtain the data showing the pollution over time, the EPA has a constant hourly updated website which displays current pollution levels. This information was copy-pasted into excel line by line in order to capture the full length of data which was available to the public at the time of the fire incident.

3.6 Data analysis and visualization

After analysing the wind patterns during the event and looking at the wind climatology for the region, it was determined that the most frequent wind events were from the West to South West and from the North East to East directions (compass bearings 270° - 225° and 45° - 90°). In order to visualise this, a work around needed to be done manually as ArcGIS lacks the tools in order to create directional buffers such as what is required when conducting a wind direction analysis.

To start with, the EPA monitoring stations and the Latrobe Valley government boundary were displayed. New features were created manually as lines starting at the centre of each EPA station point with snap to feature set on. In order to get an exact direction for the line right clicking the mouse and selecting 'Direction' allowed cardinal point numbers to be entered based upon the interpreted value that represents the appropriate direction in the map. This then forced the line to follow a constant path along the set bearing and hence the line was then ended when it snapped to the furthest boundary line of the Latrobe valley polygon. This was repeated for all cardinal points in order to set a basis of data in case modification was required later.

However, in order to appropriately assume that wind is coming from a specific direction and as a result interpret the wind rose appropriately onto the map, the single cardinal points of North = 0° would not suffice as it would assume it is coming from only that bearing. To negate this, the 16 bearings had their minimum and maximum azimuths calculated and are shown in Table 2.

Cardinal Point	Minimum Azimuth	Centre Azimuth	Maximum Azimuth
North	348.8°	0°	11.2°
North North-East	11.3°	22.5°	33.7°
North-East	33.8°	45°	56.2°
East North-East	56.3°	67.5°	78.7°
East	78.8°	90°	101.2°
East South-East	101.3°	112.5°	123.7°
South-East	123.8°	135°	146.2°
South South-East	146.3°	157.5°	168.7°
South	168.8°	180°	191.2°
South South-West	191.3°	202.5°	213.7°
South-West	213.8°	225°	236.2°
West South-West	236.3°	247.5°	258.7°
West	258.8°	270°	281.2°
West North-West	281.3°	292.5°	303.7°
North-West	303.8°	315°	326.2°
North North-West	326.3°	337.5°	348.7°

Table 2 - Table of azimuths used for mapping

As a result, the final cardinal directions used for the stations were 33.8° - 101.2° for the North-East to East direction and 213.8° - 281.2° for the West to South-West direction. These numbers were also used for the mine influence limits.

In order to construct the polygon showing the area that is covered by the stations, a new feature is created as a polygonal feature class. This polygon is then essentially traced along the lines that represent the North East – East and West – South West. The line then snaps to the existing features of the Latrobe Valley boundary and the EPA point. The polygon was then joined up around the outside of the boundary very simply and the ArcGIS ‘Clip’ tool was utilised to clip the newly created polygon by the confines of the Latrobe Valley border. This finalised the boundary of areas that the monitoring stations essentially received their air to analyse from based upon the wind climatology of the Latrobe Valley Airport meteorological station. This process yielded the two images in Figure 15 and Figure 16.

This was only half of the picture as a similar process also needed to be carried out with the mine areas. Instead of simple points like the EPA stations, the mines were displayed as polygons. This meant that in order to conduct a similar analysis points needed to be derived based upon the tips of the polygons furthest points that maximised their influence area. This was done by an eye based assessment as yet again ArcGIS lacks the tools necessary in order to conduct such an analysis. The same bearing directions were used as in the EPA station analysis as this was the direction of the wind. Each mine had two lines used in order to define the limit of each of their individual influence areas. These lines were made from the northern most and southern most limits of the mine along the correct azimuth directions and ended at the Latrobe Valley border. This then gave the ability to construct the polygon to show the area that is potentially affected by each of the individual mine sites. In the same way as the EPA polygon was constructed, the mine influence polygon was also clipped by the Latrobe Valley border. This presented a neat polygon which highlighted the areas which are down-wind of the mine sites based upon the wind climatology of the area for two scenarios of westerly winds and the other of easterly winds.

Once the mine influence area was constructed it was necessary to identify which residential areas were at risk of exposure to the mines based upon the primary wind directions should the mines ever catch fire. To do this numerous levels of the same process were run. To start with, the population density residential layer was shown which was then clipped based upon each individual mine site and each individual direction. This produced six new layers which were named along the lines of 'Mine site_wind direction_residential'. The 'Intercept' tool was then used in order to figure out areas that were affected be different numbers of either: three mines, two mines, one mine or no mines. This was done for both the easterly and westerly directions. The individual layers were then assigned colours in order to show their level of severity going from light green as least affected to light red being most affected. These outputs were then displayed as Figure 14. In order to appropriately determine areas that the monitoring stations covered, the station coverage and the mine coverage were overlaid alongside one another in their hashed patterns in order to highlight interceptions. The mine polygons used as the limits of the wind flow meant that if a station was within the polygon it had the ability to read the pollution that was being emitted by the mine and as a result meant it was useful. If the station was not within the mine influence polygon then it was determined that the station was un-usable for monitoring the mine pollution.

In order to produce the image in Figure 22, the individual layers of the westerly affected areas and easterly affected areas had their attribute tables manipulated by the addition of an extra field called 'West_mine_inf' and 'East_mine_inf' in each layer respectively. Within these columns each parcel was assigned a number based upon the number of mines that affected it. These individual layers were then merged into two layers called 'West_affected' and 'East_affected'. This amalgamated the polygons for easier manipulation of the attribute tables. In order to be able to merge the west and east features together, it was necessary to find their intercept and move it from each layer. Once the intercept was found and erased from both layers, the three layers were merged into one single layer. This single layer then had its attribute table manipulated by the formation of a new column called 'West_plus_East' which as it suggests, added the mine influence values of west and east together to show the total risk area of the residential zones based upon the total influence of both the west and east direction of mine influences. However this was not far enough as there was no accounting for population density. In order to rectify this, the final 'West_plus_East' value was multiplied by the population density. This in essence weighted the mine risk based upon population density. For example an area of 100ppl/km^2 with a mine risk of 1 would be considered just as important as an area of 50ppl/km^2 with a mine risk of 2 (100 x 1 = 100 and 50 x 2 = 100). This calculation gave an arbitrary index number which could be considered as risk by population per square kilometre. The resulting map was able to be created in Figure 22 which was used for the final analysis of station requirements. The risk was displayed in order of lowest risk in green to extreme risk in red (not to be confused with the Yallourn mine which has maintained a constant red throughout the entire thesis). The risk index values were displayed using four natural breaks in the data series to represent the maximum amount of mine influence overlap.

The final few processes were all conducted by eye view analysis and not any pre-programmed tools used in ArcGIS. The recommendation of permanent future EPA stations was based upon the risk map generated in Figure 22. Initially it was thought that the stations should be upwind of the residential areas but downwind of the mines. However this was considered somewhat impractical as it produced a large quantity of stations that would not justify the potential risk of the mines catching alight. Because of this it was considered appropriate to have two separate station types. The stations within the population centres of highest risk would be permanent stations and the second type of station would be temporary emergency response stations. The permanent stations would as the word suggests, be permanent where as the emergency stations would only be required to be set up in the event of a mine fire in the future. The temporary stations can provide real time indicative updates of what is coming out of the mines whilst the permanent stations can visualise at a high accuracy what is being experienced in the population centres. At any one time it is assumed that it is unlikely for more than one mine to catch fire so the temporary station recommendations should be assumed to only be needed at any one mine.

3.7 Summary

ArcGIS is a great tool to use for GIS analysis. However the requirements of this thesis meant that the tools available in ArcGIS were limited to clipping and modifying the visual look of the features with little in the way of complex analysis. As a result much of the work was required to be done manually and through the use of constant clipping, erasing and merging. Nevertheless the analysis was still successful even though the initial concept and method changed a few times from its initial idea of having a single map of the mine versus station coverage which resulted in many more maps than expected in order to appropriately visualise the data. Finally information and change in how the problem should be assessed took place but still results were discovered that were different to the current level of monitoring requirements in the Latrobe Valley.

Chapter 4 The Study Area

4.1 Introduction

In order to appropriately make an evaluation of air quality monitoring in the area, the regions characteristics need to be understood. There are many factors at play which lead to the type of impact atmospheric pollution has on the region. First, the primary factor is what is producing the air pollution? Secondly, where are people located based upon the source of the pollution either in a living and or working capacity? Finally, how do the wind characteristics affect where the atmospheric pollution is most likely to be distributed? Once these parameters are understood, an evaluation of how appropriate the coverage of monitoring in the area can be done as well as where more coverage is required.

4.2 Localities and Land Use

The Latrobe Valley Government Authority border was used as the basis for selecting localities that intersected its border and hence are governed by the council. Upon processing, a total of 53 localities were identified to have intersections with the Latrobe Valley Government boundary. From this the correct locality information was able to be sourced for land use analysis. The total area of the Latrobe Valley Government boundary is 1,426.1km^2 and the total area of the localities that make up the Latrobe valley Government area is 2,481.9km^2. The local government only has a partial governance of some of these localities and covers only 57.46% of the total area of these localities.

Land use for the area was determined through the use of the Victorian Planning Scheme zoning codes. In the Victorian planning scheme there are a number of codes which correspond to residential areas where people live. Although the Government recently required changes to all municipality Zonings, (some of which have not yet been adopted), for the purposes of this paper I will use the zonings in place at the time of the fire. They were as follows: Low Density Residential Zone (LDRZ), Residential Zone 1 (R1Z), Rural Living Zone (RLZ), Rural Living Zone 1 (RLZ1), Rural Living Zone 2 (RLZ2), Rural Living Zone 3 (RLZ3), Rural Living Zone 4 (RLZ4), Rural Living Zone 5 (RLZ5) and Rural Living Zone 6 (RLZ6). Figure 2 shows the extent of residential zones in the Latrobe valley in relation to the coal mines as well as the weather monitoring and air pollution monitoring stations. The total area of all the above zones is approximately 122.43km^2 which is only 8.58% of the total area contained within the Latrobe Valley government authority boundary. Of these residentially zoned areas there are approximately 34,205 individual parcels. These parcels are each capable of holding a place of residence and based upon the data from the Australian Bureau of Statistics (2011a) there are approximately 31,877 dwellings contained within the constraints of these parcels. It is important to note that the data used to showcase the residential zones was created in 2014 and the data used to find the number of dwellings was created in 2011. As a result there will be some slight discrepancies in terms of new zoned areas and parcels which may not have had dwellings in 2011 but do now in 2014. It should be expected that the zones will more likely than not increase in size over time and the amount of dwellings will also increase as more parcels are created in response to newer zoned areas.

There are a number of key areas where there are high concentrations of residential zones. These areas include the Moe/Newborough area to the West of the Yallourn Mine, the Traralgon/Traralgon East area to the North of the Loy Yang Mine, the Morwell area to the North East of the Hazelwood mine, the Hazelwood North area located to the South West of the Loy Yang mine and to the East of the Hazelwood mine and finally the Yinnar South/Jerralang Junction/Churchill area to the South of the Hazelwood mine. These are the most prominent sized areas based off of a personal eye assessment of the information.

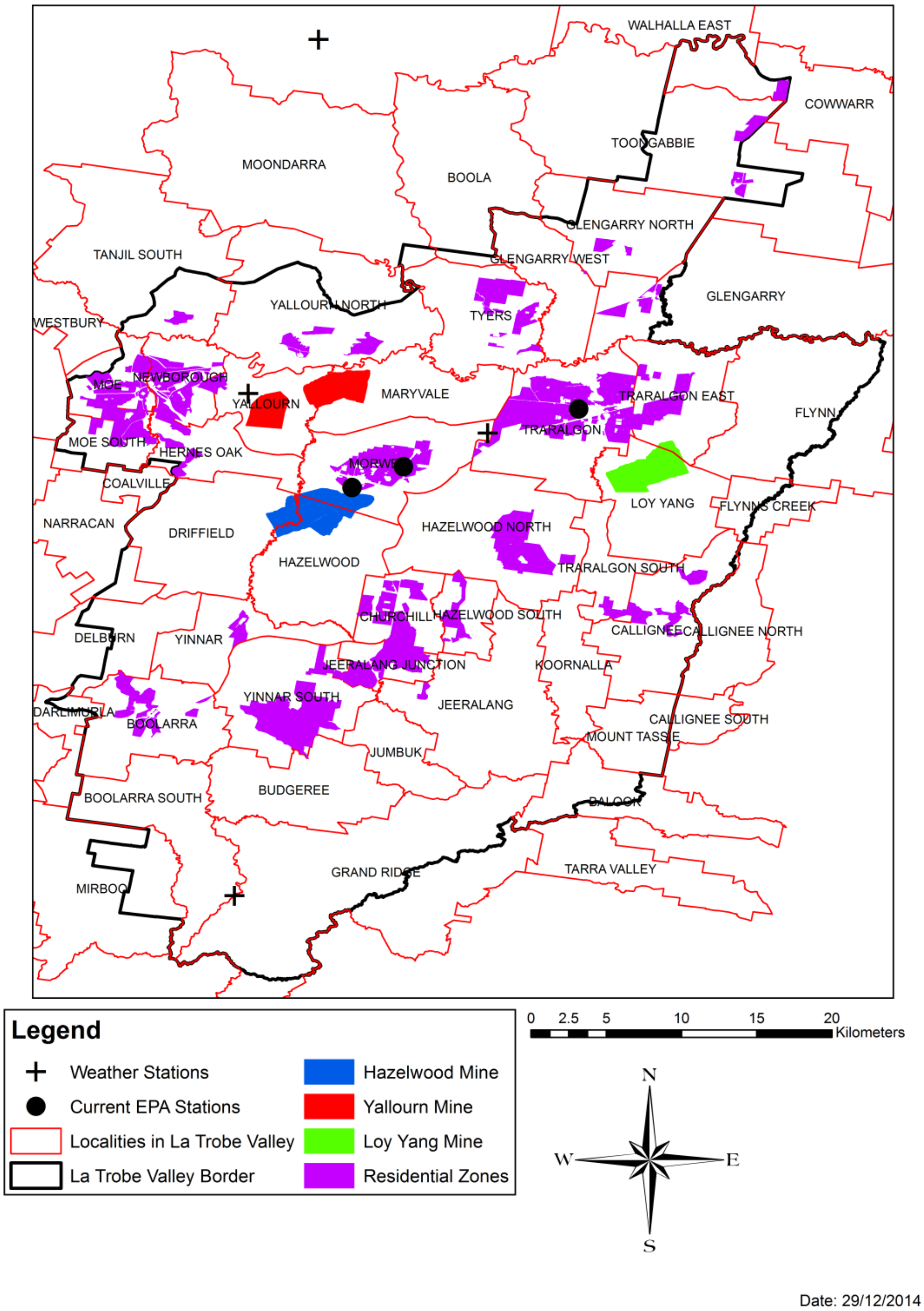

Figure 2 - Map of residential zones in relation to the location of coal mines and monitoring stations in the Latrobe Valley (Victorian Government 2014)

There are also numerous other zones available such as commercial, industrial special use and environmental use zones, however for the purposes of this research the key areas of importance were areas where people have the capacity to live. It is worth noting that although there is the possibility that some of these areas classed as residential may have differing circumstances which mean no-one is living at the location however it is important that these areas are still considered living areas as these situations have the potential to change in the future whereas their location in relation to the mine sites will not.

4.3 Demographics

The demographics of the Latrobe Valley can be identified through the utilisation of the 2011 Australian Bureau of Statistics Census data. According to the information, there are approximately 72,217 people resident over 32,347 private dwellings. This equates to approximately 2.4 people per household. The age of the population has a bimodal distribution curve which peaks around 15-19 years of age and at 50-54 years of age (Australian Bureau of Statistics 2011b). This means that there are a considerable number of people in the young growing and development stages of their lives whilst there are an increasing number of people living longer at a more vulnerable older age.

Extending off the data displayed in Figure 2, the residential zones depicted can be manipulated in order to showcase the population density of the region. A description of how this was achieved is explained within the Research Method chapter under the section 3.5 Data collection and preparation. Figure 3 displays the population density which shows a better representation of how many people actually reside within the residential zones based on a people per square kilometre unit. From this interpretation the areas of importance become more obvious in terms of higher density population centres in brown compared with the sparser density population in yellow.

The key areas of interest still appear to be similar to the areas stated previously with the exception of Yinnar South and Jeeralang Junction having a considerably lower volume of population density than other areas such as Churchill. Hazelwood North however appears orange much like the Western flank of Traralgon so it still remains an important area of interest.

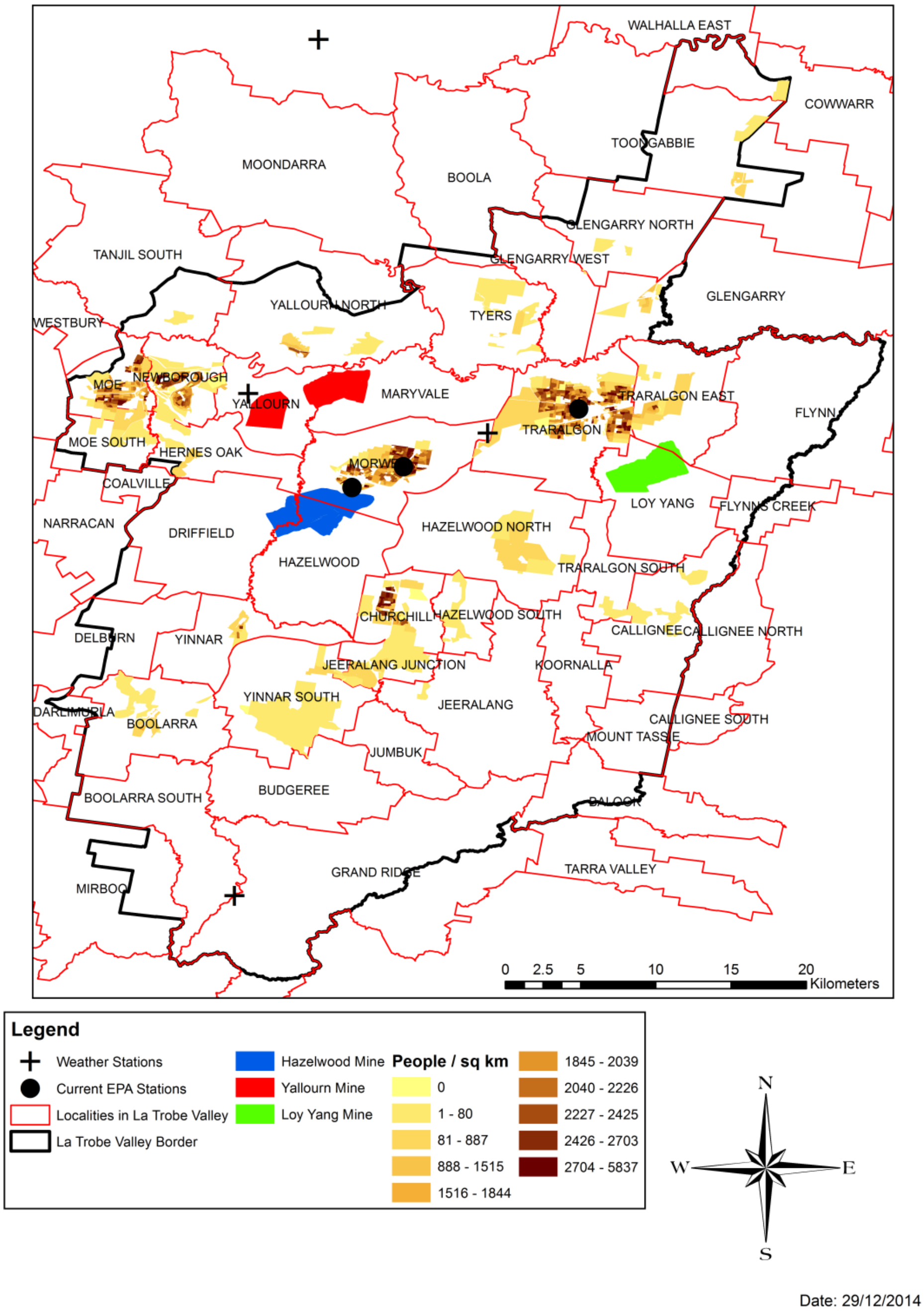

Figure 3 - Population density of the Latrobe Valley within residential zones (Australian Bureau of Statistics 2011a; Victorian Government 2014)

The Australian Bureau of Statistics (2011b) has stated that in 2011 the population was made up of approximately 65.5% of the population being of working age namely 15-64 years. The unemployment rate of these working age people is 2,591 or 7.9% of the population which is considerably high when compared to the state of Victoria average of 5.4% or even the Australian average of 5.6%.

4.4 Mine Sites

Mapping the extent of the mine sites was conducted by the utilisation of Landsat imagery and generating polygons which envelop the total dug out area of the mines. It needs to be noted that this is a subjective assessment due to the potential for areas with overburden removed to have regrowth of vegetation that could cause the area to appear unaffected by mining activities. Nevertheless it is still a great indicator as to the approximate area that has been excavated since the initial image captured in 1987. The reddish coloured newly excavated areas are easily recognised against the background of green vegetation cover or lighter pink soil. The mine sites are designated as Hazelwood, Yallourn and Loy-Yang according to the locality which the mines primarily occupy. Figure 4 displays the areal extent of the mines over time from 1987 – 2014 (1987 was the first available image from Landsat). It is obvious that rapid expansion occurred only recently in the last 20 years and the mines appear to be extending at a rate close to 100m per year. These rapid expansions of the mines are creating a larger and larger surface area of exposed coal at the surface which is therefore at risk of potential ignition.

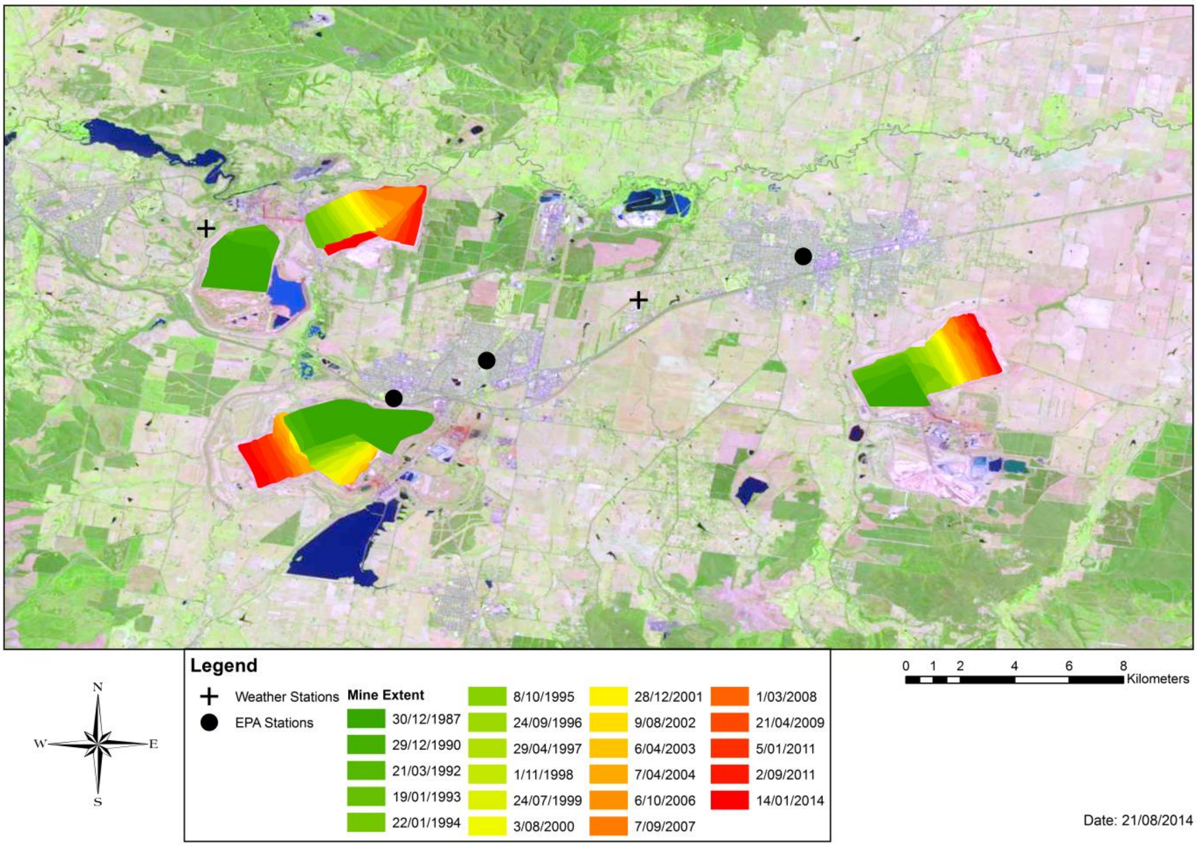

Figure 4 - Map of mine expansion from 1987 to 2014 for the Latrobe Valley

The figure also shows the placement of EPA air monitoring stations near the mines. The one on the far east is the Traralgon station which pre-dated the fire. The middle one is the Morwell East station setup as a temporary station and the far west is the Morwell South station also set up as a temporary station. The far east weather station is the Latrobe Valley Airport station which contained a vast amount of data during the fire period including wind speed and direction. The far west weather station was the Yallourn SEC station which unfortunately had no usable data during the event. The Latrobe Valley airport station is placed in a convenient location as it aligns almost perfectly with the three EPA air monitoring stations. In terms of the stations locations relative to the Hazelwood mine, all stations lie roughly ENE of the Hazelwood mine site and have a maximum variance of 9° between any two stations.

4.5 Meteorological Observations

Latrobe Valley Airport's weather station is the only station able to provide data about wind speed and direction within the Latrobe Valley itself. Observations continued completely from the start of the fire until its extinguishing which means an accurate wind rose is able to be constructed showing the frequency of wind speeds and directions for the entire duration of the fire. Figure 5 shows such a wind rose made from 2,392 observations (not specific to time of day) from between 9th February 2014 and 25th March 2014. Its primary axis displays the percentage of total observations which each direction and wind speed class occurred. The total duration of calm which was observed was 7.6% of total observations.

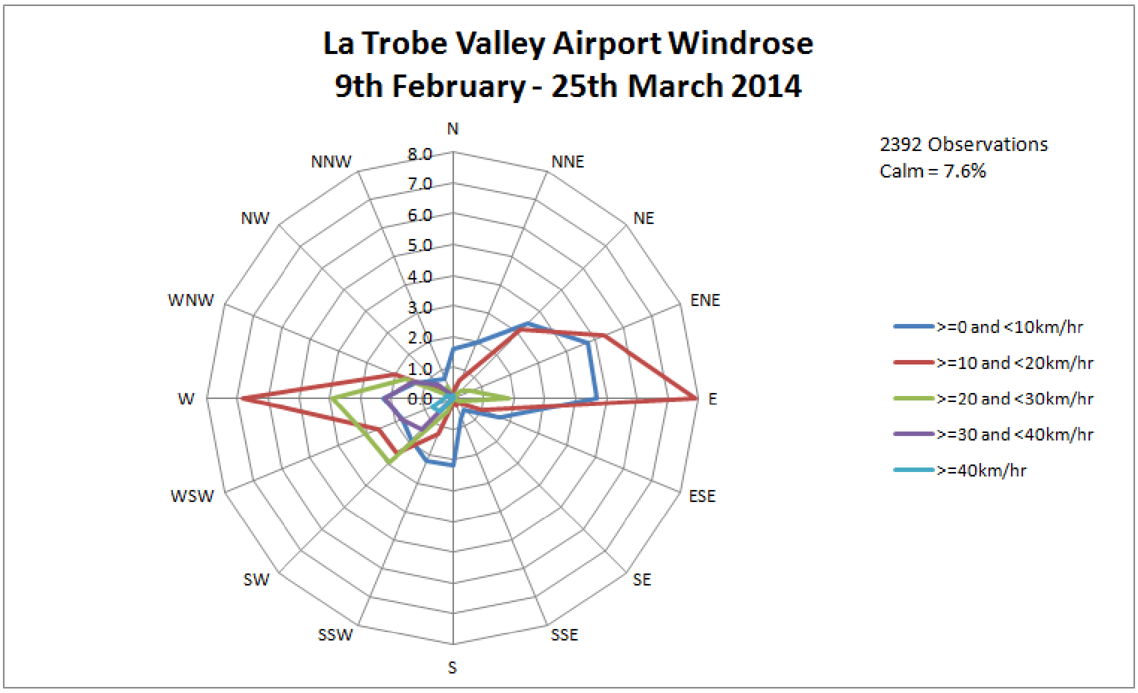

Figure 5 – Wind rose from Latrobe Valley airport during the Hazelwood mine fire event (Australian Bureau of Meteorology 2014)

Easterly winds (total of ENE to ESE) were typically between 0 and 20km/hr and occurred 28% of the time. Westerly winds (total of WSW to WNW) were between 10 and 30km/hr and occurred 32% of the time. This shows that winds occurred 60% of the time in an easterly or westerly direction and very rarely occurred in a North of South direction (13% of the time). The wind rose generated during the event looks quite similar to the Bureau of Meteorology's wind rose for the same weather station for November to March averages. Figure 6 shows the average wind conditions at the Latrobe Valley Airport for the peak fire risk period of November to March and spans data from 1984 to 2010.

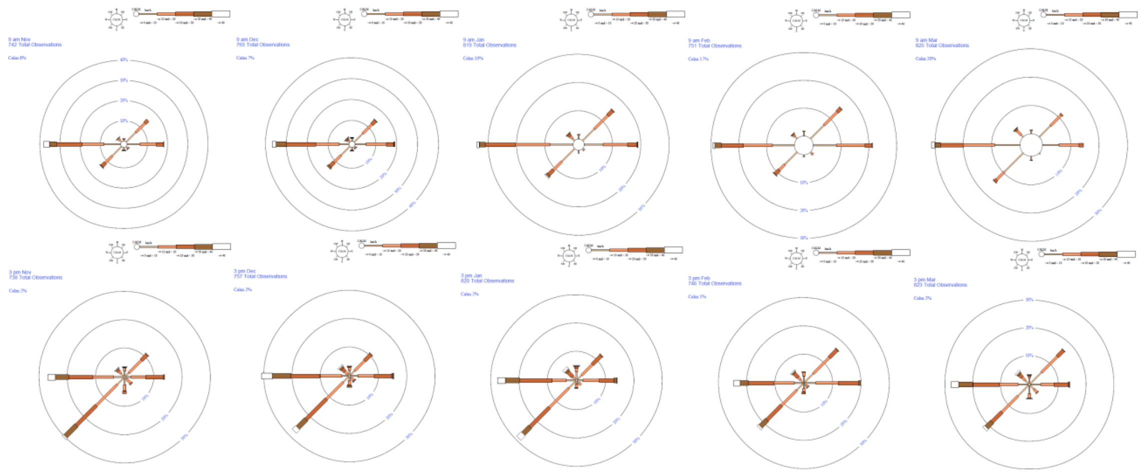

Figure 6 - Summer wind roses for Latrobe Valley Airport weather station from January 1984 to September 2010 (Australian Bureau of Meteorology 2014)

As evident from these graphs, the predominant wind direction is from the West in the morning and trends towards the South-West in the afternoon. There are occasions where winds come from the East and North-East but winds very rarely ever come from the North, South, North-West or South-East. Because of this it would be appropriate to assume that there is potential for primary wind flows in West, South-West, East and North-East directions surrounding the mine sites.

The wind roses also display that during the morning there is always a higher occurrence of calm weather as opposed to afternoon periods where calm weather is scarce. This is typical of sea breeze where the land warms at a faster rate than water does; the land air rises and air from the ocean moves inland to replace it creating wind. Increased calm during the evening to morning can be concerning in a scenario where pollutant sources are concerned as it allows the pollutants to increase drastically in concentration due to the lack of wind to ventilate the valley area.

Another factor which impacts upon the area is the topography of the landscape. The Latrobe Valley is in all aspects of the word, a valley. As with most valley settings it is capable of pooling pollutants that are typically heavier than the surrounding air thereby increasing concentration of these pollutants and consequently toxicity of the air for people living within the valleys confines. These events are more common when the area is under a high pressure weather system which acts to suppress atmospheric movement of air, thereby increasing the stability and reducing the potential for pressure gradients to form. Furthermore, the high pressure can act significantly on valley areas trapping air within the confines of mountains and create a fumigating effect within the valley. This effect remains until the atmosphere becomes unstable such that wind is able to be generated at the surface which is sufficient enough to clear the air.

4.6 Air pollution Observations

As stated previously, two of the monitoring stations were set up some time after the fire started. Table 3 outlines the time when the first readings of the monitoring stations took place and the time since the fire started for the first reading to take place. For Traralgon the majority of sampling was already setup except for PM2.5 which was never established and carbon monoxide monitoring was set up around 3 weeks since the fire ignition. Morwell South the closest station to the mine, took the longest time to have its monitoring set up with the fastest being setup 12 days after the start of the fire for carbon monoxide and sulphur dioxide followed by PM2.5 a day later. Morwell East though set up faster than Morwell South still took 9 days to establish monitoring for PM2.5 and 10 days for carbon monoxide.

	Carbon Monoxide	Ozone	Nitrogen Oxides	Sulphur Dioxide	PM2.5	PM10	Visibility Index
Morwell South	21st Feb (12 days)	6th Mar (25 days)	6th Mar (25 days)	21st Feb (12 days)	22nd Feb (13 days)	N/A	21st Feb (12 days)
Morwell East	19th Feb (10 days)	N/A	N/A	19th Feb (10 days)	18th Feb (9 days)	N/A	13th Feb (4 days)
Traralgon	4th Mar (23 days)	9th Feb (0 days)	9th Feb (0 days)	9th Feb (0 days)	N/A	9th Feb (0 days)	9th Feb (0 days)

Table 3 - Air monitoring station pollution type recording start dates (Environment Protection Authority Victoria 2014)

There are international guidelines published by the World Health Organisation surrounding levels of air pollution which are acceptable for the general public to be exposed to without any deemed hazardous risk. These are outlined in Table 4.

Pollution type	Annual Mean limit	24-hour mean limit	x-hr/min mean

PM 2.5	10µg/m^3	25 µg/m^3	-
PM 10	20 µg/m^3	50 µg/m^3	-
O_3	-	-	100 µg/m^3 (8 hrs)
NO_2	40 µg/m^3		200 µg/m^3 (1 hr)
SO_2	-	20 µg/m^3	500 µg/m^3 (10mins)

Table 4 - Pollution limit levels before becoming hazardous to health

(World Health Organisation 2005)

Based upon data obtained through the EPA Victoria website, the Morwell South air monitoring station shows no data from the starting date of the fire on the 9th of February 2014 until its commencement of monitoring on the 21st of February 2014. This lack of information over the period of 12 days can be considered dangerous if pollution levels were at similar levels to those shown in Figure 7 which would be above the mean 24 hour limit in Table 4 for PM2.5. This means that people in the area near the mine were exposed to these pollutants without knowing just how high the levels of these pollutants were.

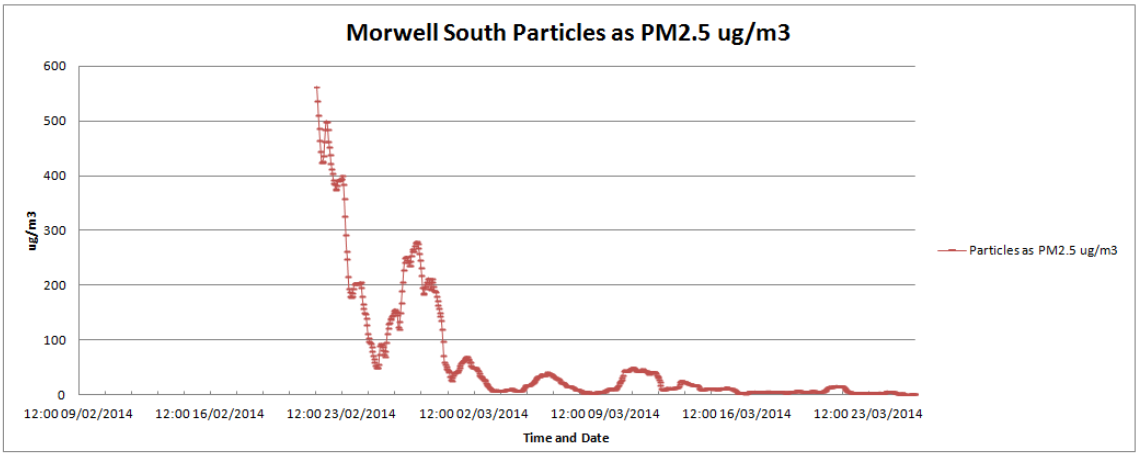

Figure 7- PM2.5 plot from 9th February - 25th March for Morwell South EPA station

(Environment Protection Authority Victoria 2014)

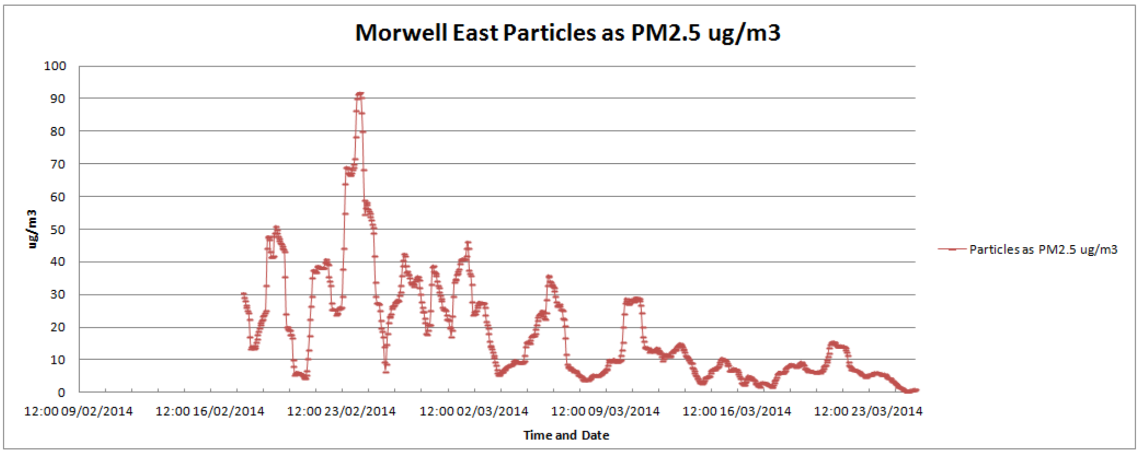

Figure 8 - PM2.5 plot from 9th February - 25th March for Morwell East EPA station (Environment Protection Authority Victoria 2014)

There are a couple of trends to take notice of in both Figure 7 and Figure 8. The fire fighting efforts occurred on a diurnal cycle and as such aerial bombardment could not occur during the night time due to a lack of light to safely operate. This caused a steady rise in pollutant levels over night until they generally peaked in the morning at around 9am. Once aerial bombardment started, the pollutant loads are somewhat suppressed due to lower combustion rates of the coal and precipitation is expected to lead to the deposition of pollutants out of the atmosphere onto the land surface. Figure 9 shows the combination of both the Morwell South and Morwell East PM 2.5 observations along with the observed rainfall since 9am from the Bureau of Meteorology weather station located at Latrobe Valley Airport. The first instance of rainfall which peaked at 16mm on the 20th of February 2014 coincided with a reduction of PM2.5 concentration at the Morwell East station which is more obvious in Figure 10.

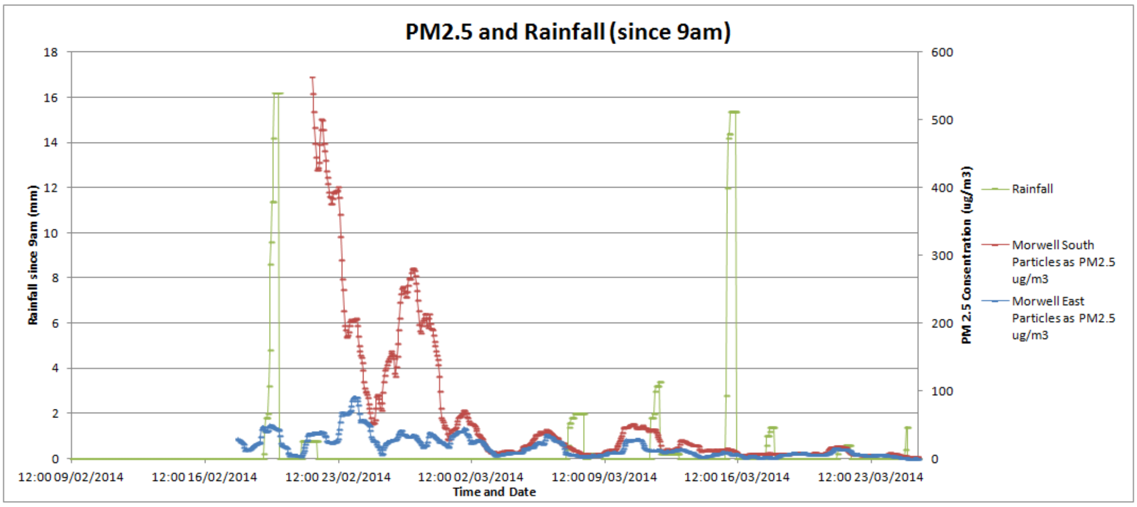

Figure 9 - Morwell South and East PM2.5 record compared to rainfall from 9th February 2014 - 25th March 2014 (Environment Protection Authority Victoria 2014)

It can be seen that as the rain increases towards its maximum amount of 16mm the concentration of PM2.5 at the Morwell East station does reduce by up to 10μg/m^3. Rain during the summer months is not very high when compared to the levels experienced during winter. As a result it needs to be understood that rain does not have a significant impact during the summer months as its occurrence is not frequent.

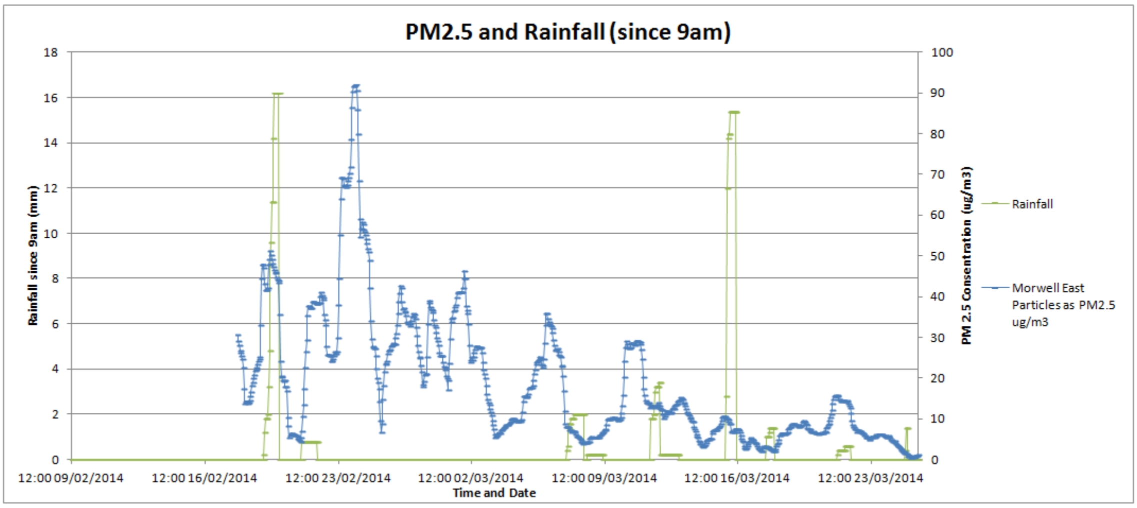

Figure 10 - Morwell East PM2.5 record compared to rainfall from 9th February 2014 - 25th March 2014 (Environment Protection Authority Victoria 2014)

Figure 11 shows the observed concentrations of PM10 from the Traralgon EPA station. It has a much more sporadic pattern however it also tappers off over time the same way as the PM2.5 concentrations at the Morwell East and South stations due to prolonged fire fighting efforts. The Traralgon station is also considerably further from the mine than the Morwell stations are and because of this the concentrations would always be lower than those expected closer to the source within the mine.

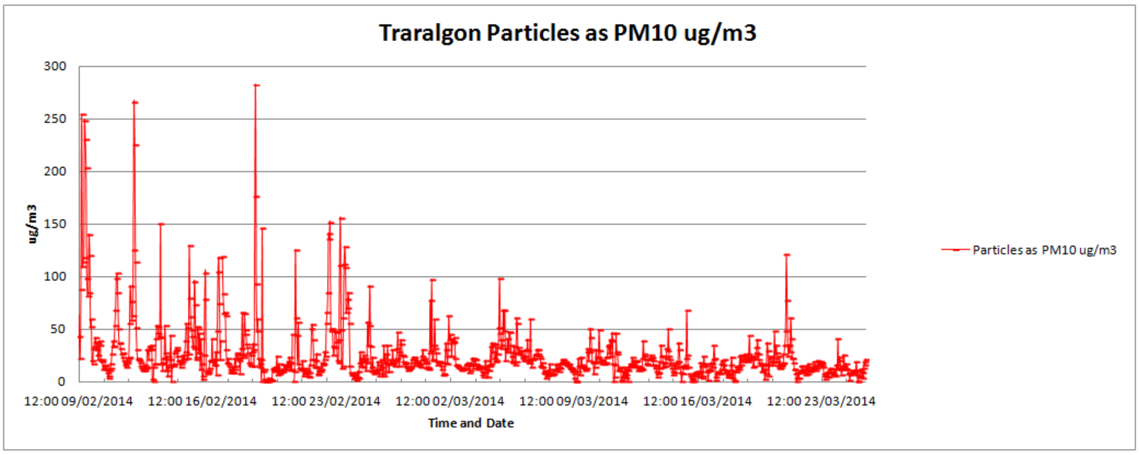

Figure 11 - PM10 plot from 9th February - 25th March for Traralgon EPA station (Environment Protection Authority Victoria 2014)

Whilst the Morwell South and East stations measure PM2.5, the Traralgon station only measures PM10; because of this the Traralgon station is not directly comparable to the Morwell stations. This leads to question why the temporary stations were not set up to reflect the pre-existing Traralgon station and vice versa. Nevertheless, the WHO guidelines on particulate matter can be applied to all the stations and give a generalised indication of the hazard level for surrounding populations. The WHO pollutant guidelines in Table 4 show that in a 24 hour period, concentrations over 25µg/m^3 for PM2.5 and 50 µg/m^3 for PM10 can lead to increased mortality risk. Through the use of the observed levels the mortality risk can be ascertained by applying the rule of increasing 2.5% mortality for every increase in concentration of PM2.5 being 25µg/m^3 and the same for every increase of PM10 being 50µg/m^3.

Table 5 shows the highest occurrence of mortality risk increase over a single 24 hour period (from midnight to midnight). Morwell South showed the highest level of increased risk due to PM2.5 peaking at 40% increased mortality risk with Morwell South increasing by only 7%. Traralgon's highest occurrence of PM10 was only 2.5% which is actually not far from acceptable conditions. Nevertheless, the levels detected for Morwell South are concerning.

	PM 2.5 24hr highest	PM 2.5 % mortality risk increase	PM 10 24hr highest	PM 10 % mortality risk increase
Morwell South	407	40%	N/A	N/A
Morwell East	72	7%	N/A	N/A
Traralgon	N/A	N/A	48	2.5%

Table 5 - Highest levels on 24 hour average PM concentrations and their interpreted mortality risk increase (Environment Protection Authority Victoria 2014)

4.7 Summary

Before the fire occurred, there was only one permanent monitoring station in place at Traralgon. Within two weeks of the fire occurring, two temporary stations were set up at Morwell South and Morwell East. PM2.5 and PM10 were identified as some of the more concerning pollutants being emitted by the fire event. Unfortunately not all three stations were comparable for the entire length of the incident due to differences in pollutants monitored. Nevertheless it can be assumed that the particulate matter followed a similar trend regardless of size type (if PM10 increased then PM2.5 would have increased also). At their measured peak, concentrations of particulate matter in the air surrounding the mine reached considerably dangerous levels which can be translated as an increased mortality risk of 40% in Morwell South and 7% in Morwell East. The Traralgon station measured elevated levels of pollutants prior to the temporary stations were set up at Morwell which indicates that the peak levels detected could well have not been the actual peak levels that occurred.

Chapter 5 The Results

5.1 Introduction

Prior to determination of the results, a number of hypotheses were proposed. First, it was thought that the findings would show that the existing monitoring station in Traralgon was inappropriately far away from residentially zoned areas which were close to the Hazelwood mine. This meant that there were not accurate figures for pollutant concentrations closer to the source.

Secondly, the temporary stations that were set up were set up too late in terms of when the fire started and when the stations came online and started to stream data to the EPA online services for the public to become informed. There needs to be at least two stations on standby that can be rapidly deployed to nearby mine sites in the case of a future fire event.

Thirdly, permanent stations need to be set up on the Eastern and Southern flanks of all three mine sites in the region in order to adequately cover the highest likelihood of wind blow pollution from any of the mines in the future.

5.2 Areas Covered by Mine sites

The first step in assessing the air monitoring adequacy within the Latrobe Valley involves discovering the areas that the mine sites affect. As described previously, the mine sites used minimum and maximum azimuths of the primary wind directions in order to discern the most likely wind directions. These were applied to the relative furthest distance of the mine edge in order to achieve the maximum potential influence area from any given mine.

Given there are two wind scenarios, one being westerly winds and the other being easterly winds, two maps were produced in order to show the potential mine influence overlap of residential zones within the Latrobe Valley. Figure 12 displays the mine influence that easterly winds would have on the region. The patterns have been deliberately hashed in order to enable simplicity of showing residential zones where influential overlap from multiple mines occurs. The range limit for the winds in this scenario was bearings of 33.8° (North-East minimum azimuth) to 101.2° (East maximum azimuth).

The Yallourn polygon covers 236.85km^2, the Loy Yang polygon covers 871.20km^2 and the Hazelwood polygon covers 219.14Km^2 with the total area coverage being 1,327.19km^2. This is 93.06% of the total area of the Latrobe Valley.

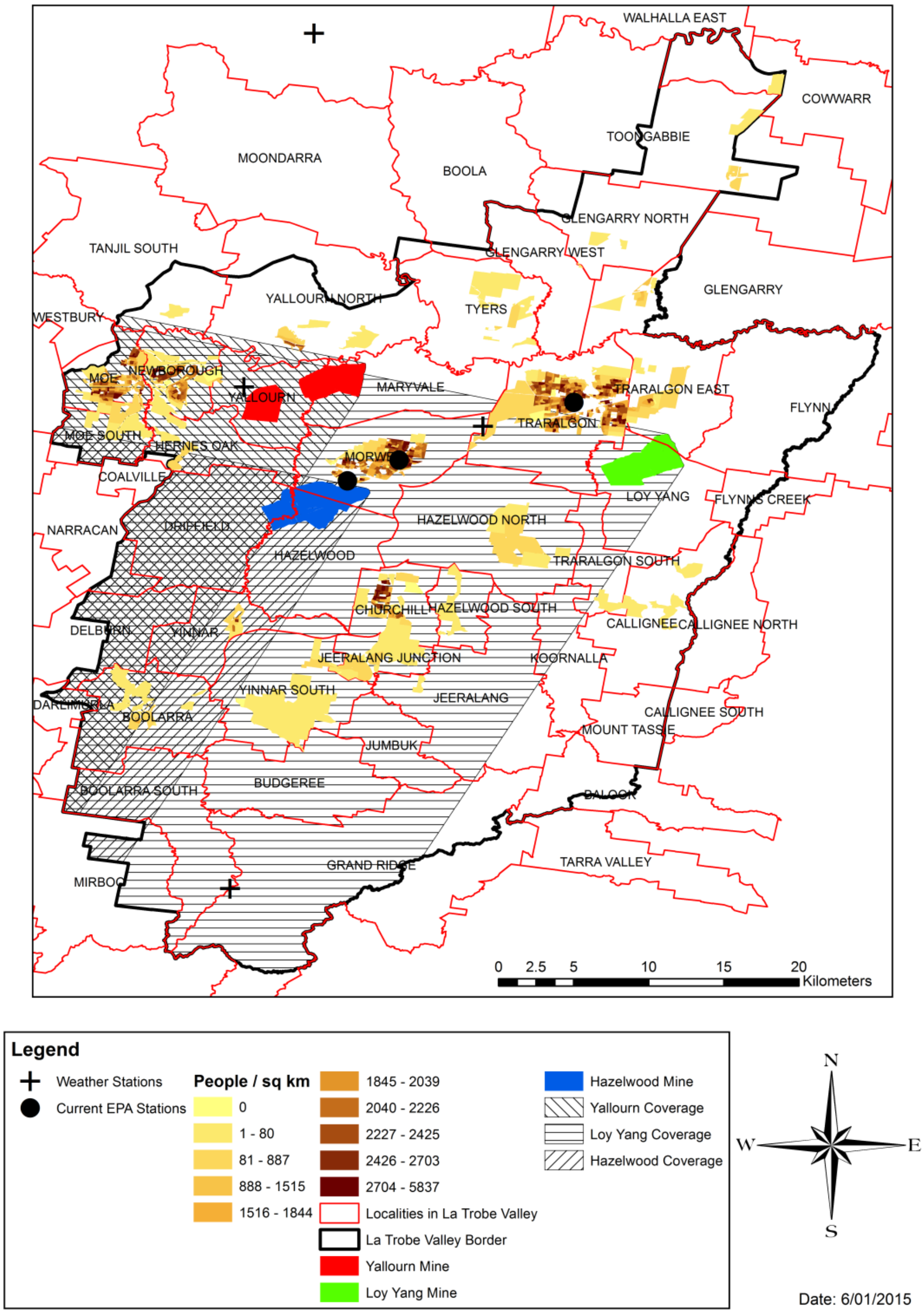

Figure 12 - Easterly winds mine influence

Figure 13 shows the mine influence that the westerly winds would have on the region. As with Figure 12, the symbols have been hashed in order to simplify the ability to see areas that are affected by multiple mine sites. The range limits for the wind in this scenario were bearings of 213.8° (South-

West minimum azimuth) and 281.2° (West maximum azimuth). The Yallourn polygon covers 469.57km^2, the Loy Yang polygon covers 109km^2 and the Hazelwood polygon covers 385.95Km^2 with the total area coverage being 964.52km^2. This is 67.63% of the total area of the Latrobe Valley.

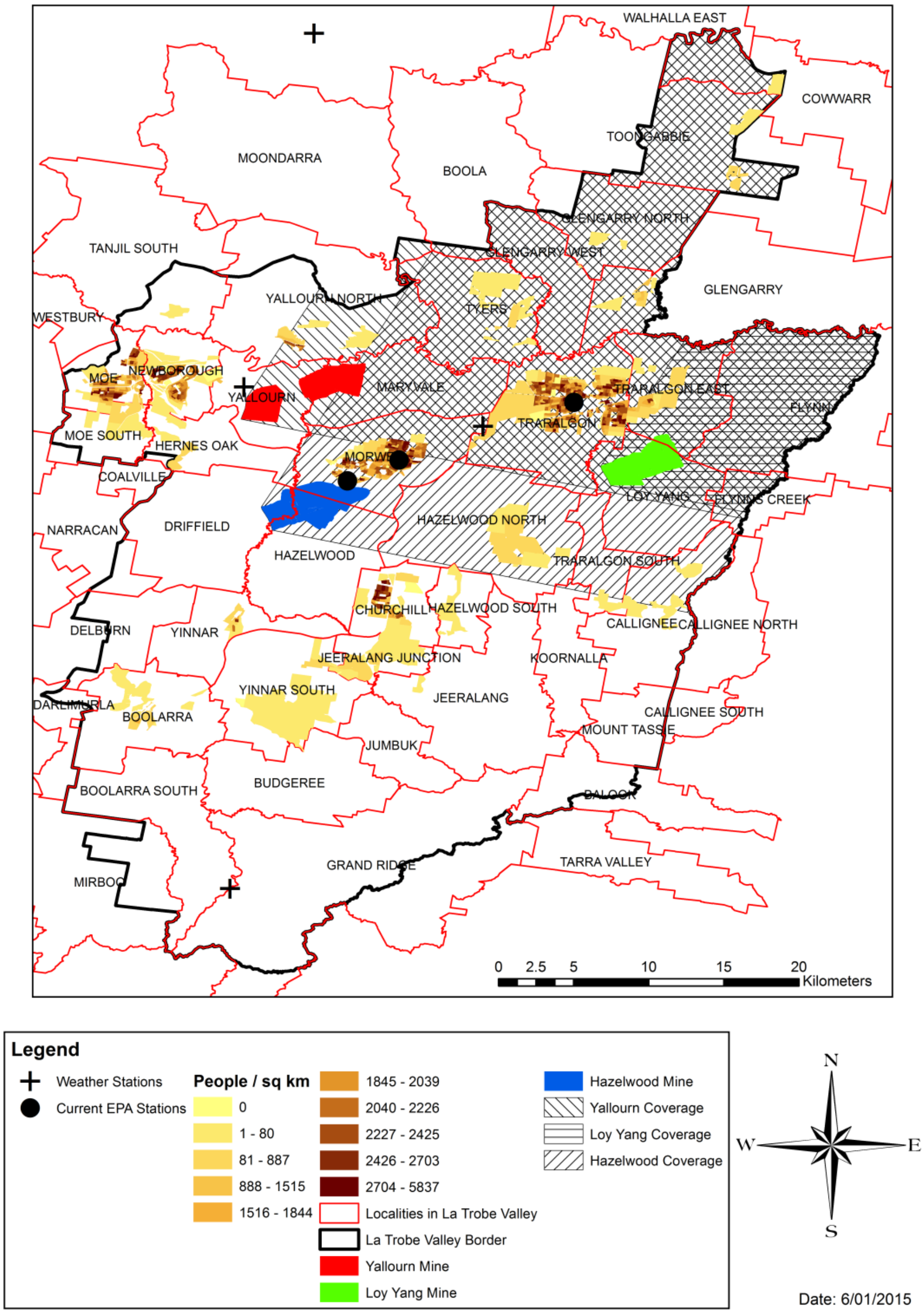

Figure 13 - Westerly winds mine influence

To more appropriately highlight the areas which are individually affected by the mine sites on a single map, Figure 14 was created. The residential zones were colour coded by the levels on overlapping mine area influence. Areas that are affected by all three mines are coloured light red and represent the highest risk. Areas that are affected by only two mines are colour coded light orange. Areas that are affected by a single mine are colour coded light yellow. Finally, the areas that have no influence imposed upon them by the mines in either scenario are colour coded light green (not to be confused with the Loy Yang mine which is a more vibrant green which has been a continuous colour throughout this thesis). The categories for each of these from hence forth are as follows: Red= Extreme risk, Orange= High risk, Yellow= Medium risk, Green= Low risk.

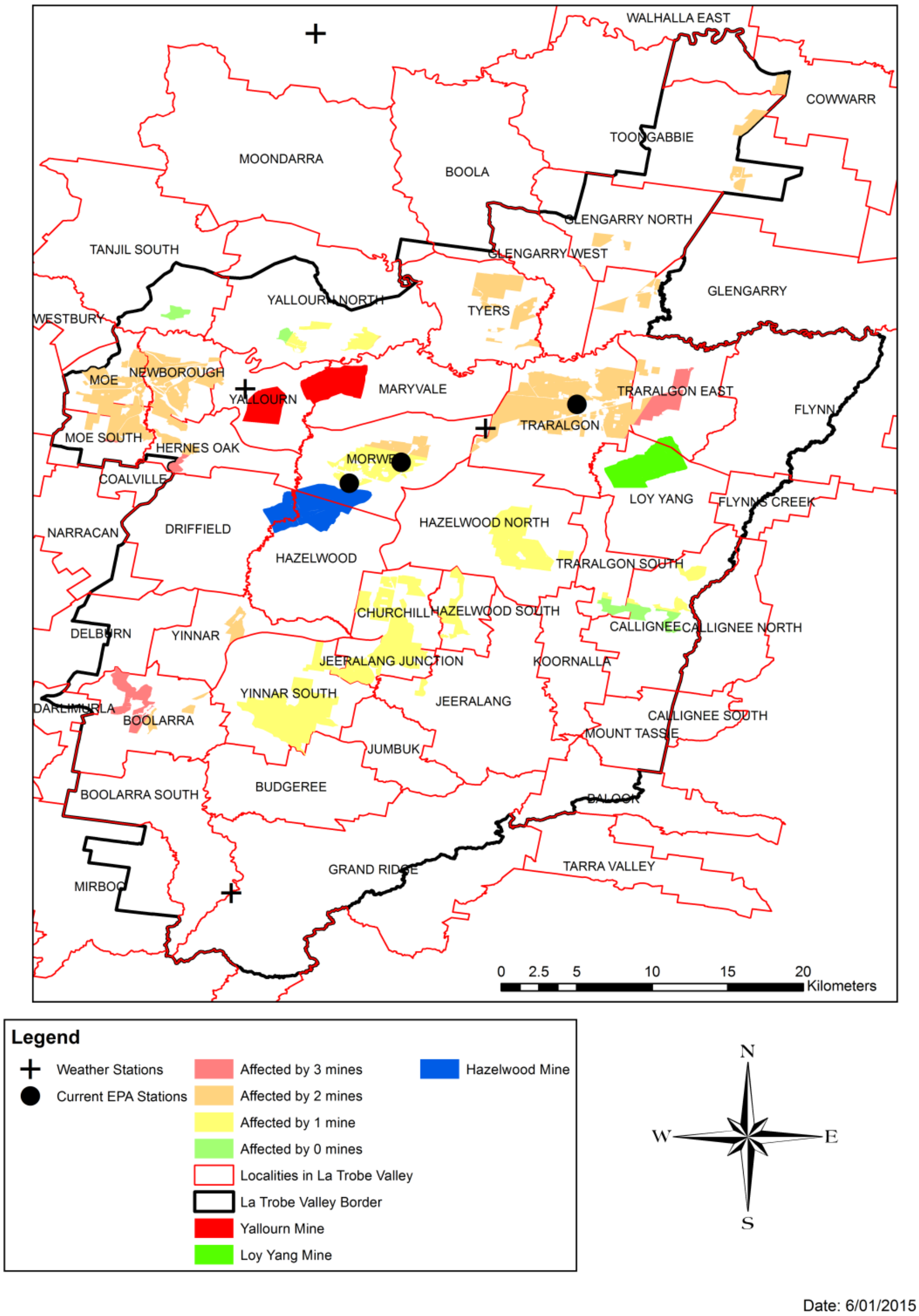

Figure 14 - Mine influence risk map

Each scenario was able to have its statistics calculated as to how many people are likely to be living in the area as well as how many dwellings would be occupied by the people when compared to the total for the Latrobe Valley. For the Westerly areas the Extreme zones have 1,392 people resident over 487 dwellings which is 1.93% of the total population over 1.5% of the total dwellings. The High zones have 32,603 people resident over 14,060 dwellings which is 45.15% of the total population and 44.47% of the total dwellings. Finally, the Medium zones have 14,385 people resident over 6,880 dwellings which is 19.92% of the total population and 21.27% of dwellings.

For the Easterly areas the Extreme zones have 1,294 people resident over 562 dwellings which is 1.79% of the total population over 1.74% of the total dwellings. The High zones have 18,186 people resident over 8,611 dwellings which is 25.18% of the total population and 26.62% of the total dwellings. Finally, the Medium zones have 27,153 people resident over 12,190 dwellings which is 37.60% of the total population and 37.69% of dwellings. To note, the Low zones had 1,541 people resident over 674 dwellings which is 2.13% of the population and 2.08% of the dwellings.

5.3 Areas Covered by Existing Air Quality Monitoring Stations

The air pollution monitoring stations were made up of three sites at Morwell South, Morwell East and Traralgon. Their latitude and longitude co-ordinates are as follows:

Traralgon: -38.19543839, 146.5274353

Morwell South: -38.24199677, 146.3936768

Morwell East: -38.22948837, 146.4244232

The direction of wind utilised was based off the Australian Bureau of Meteorology's weather station located at the Morwell Airport which was within 8km of the Morwell South station, 4km of the Morwell East station and 5km of the Traralgon station. From the Morwell South station, the two other air pollution monitoring stations as well as the weather station aligned in approximately the East-North-East direction with the furthest deviation being between the weather station and Traralgon station where the Traralgon station was a bearing of 71° from the weather station. Because of all this it was appropriate to apply the climatological wind direction data from the weather station at Morwell Airport to all three air pollution monitoring stations. Due to the presence of two main wind conditions being Westerlies and Easterlies, maps were produced to showcase each individual scenario as in the previous section for the mine influence areas.

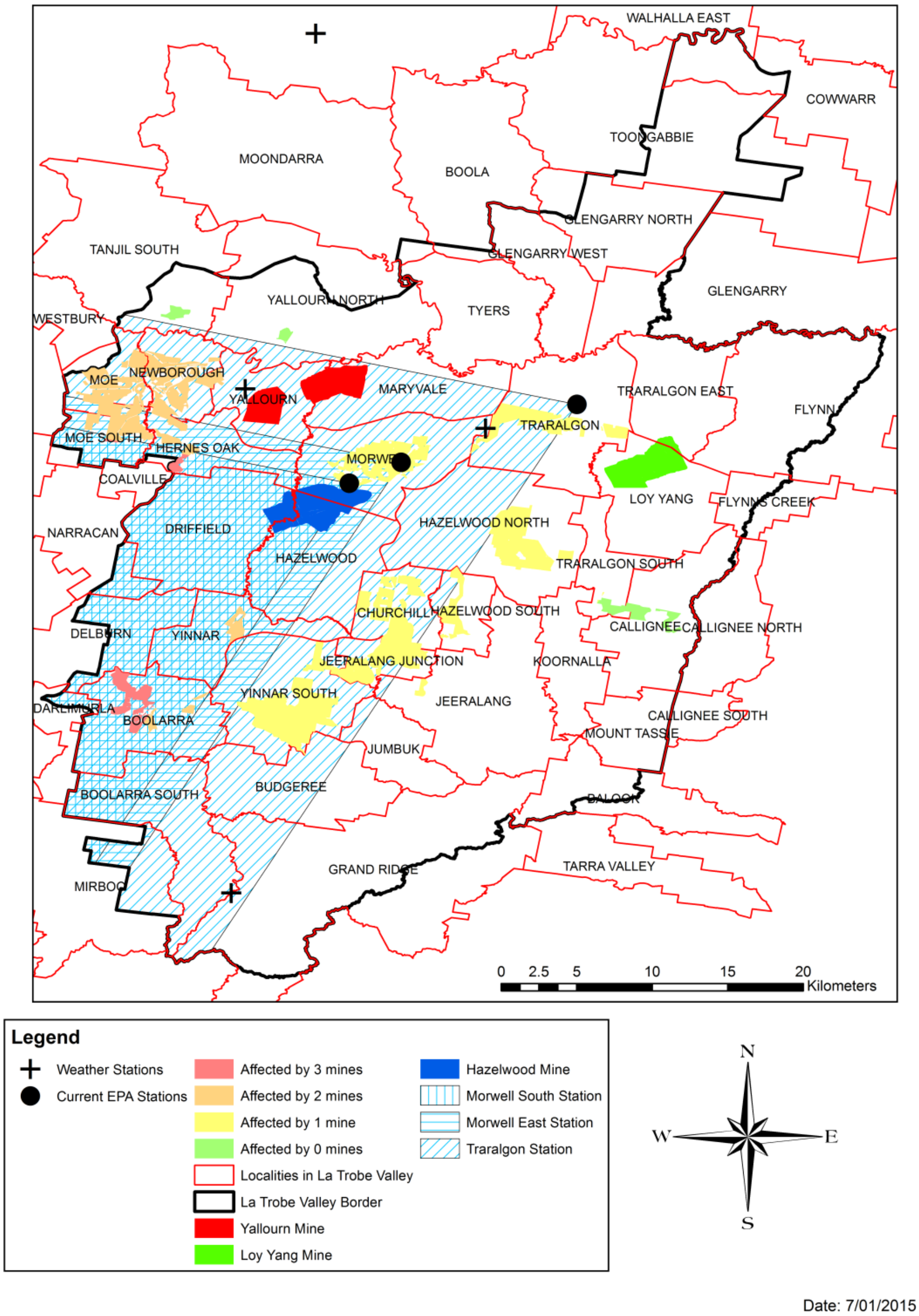

Figure 15 - Map of air pollution station coverage for westerly winds in Latrobe Valley

Figure 15 displays the approximate coverage of the three air monitoring stations combined as the light blue hashed symbols (done in a similar fashion as the mine influence in order to see overlap) with the three individual mine sites, nearby weather stations and the three air pollution monitoring stations from west to east as Morwell South, Morwell East and Traralgon. The map represents the Westerly wind detection coverage for the region and is inverted from the Westerly map of the mines in Figure 13 because it shows the mines that can be detected by each individual station. In order to show the true effect that these mines have on the surrounding areas and what is plausible for detection by the stations, maps needed to be created which showed an overlay of not just the mine coverage but the coverage of the stations at the same time. This enables the ability to truly see which stations are upwind and downwind of the potential mine pollution sources. However, this is only effective if the station measuring the potential output lies within the mine output polygon.

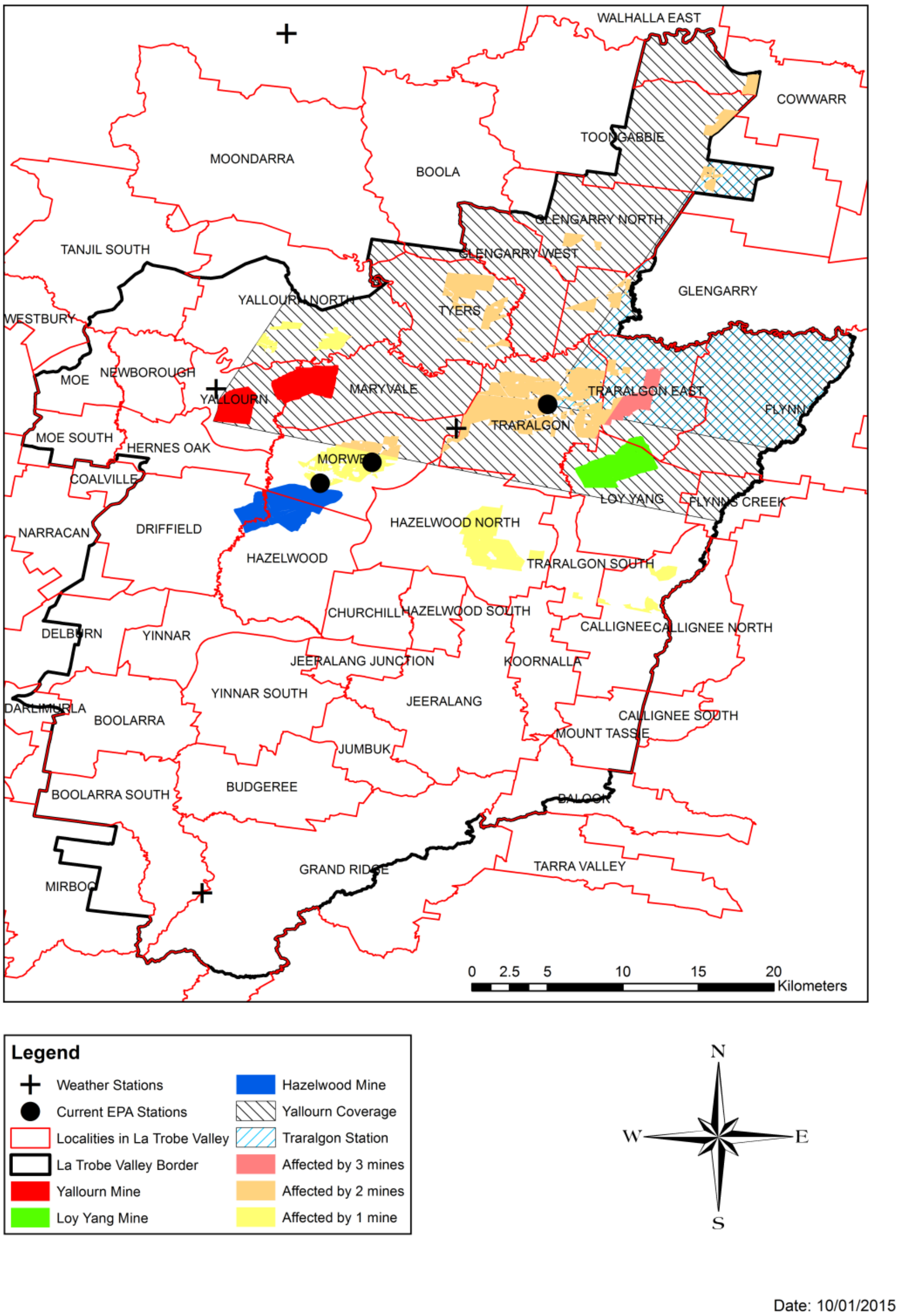

Figure 16 - Map of the Yallourn westerly wind coverage with useable station coverage

Figure 16 displays the area affected by Yallourn due to westerly winds and the coverage provided by the Traralgon air monitoring station based upon the same azimuths as the mine coverage.

The statistics state that the number of people that lie within the shadow of the Yallourn mine is 35,400 over 15,206 dwellings. The total number of people that are within the Yallourn mine shadow but are not downwind of the Traralgon monitoring station are 24,247 people (68.49%) over 10,463 dwellings (68.81%). The Morwell South and Morwell East stations do not lie within the boundaries of the

Yallourn mine coverage area and as a result they can offer no information to residents of the pollution emitted from the mine and as such are not included in the analysis.

Figure 17 displays the coverage for the Loy Yang mine with the usable coverage from stations. As none of the stations lie within the coverage area of the Loy Yang mine, none of the stations can be used to detect any kind of pollution coming from the mine as a result of westerly winds. As a result the total population affected by the mine is 1,392 over 487 dwellings with no monitoring makes it 100% of the population at risk.

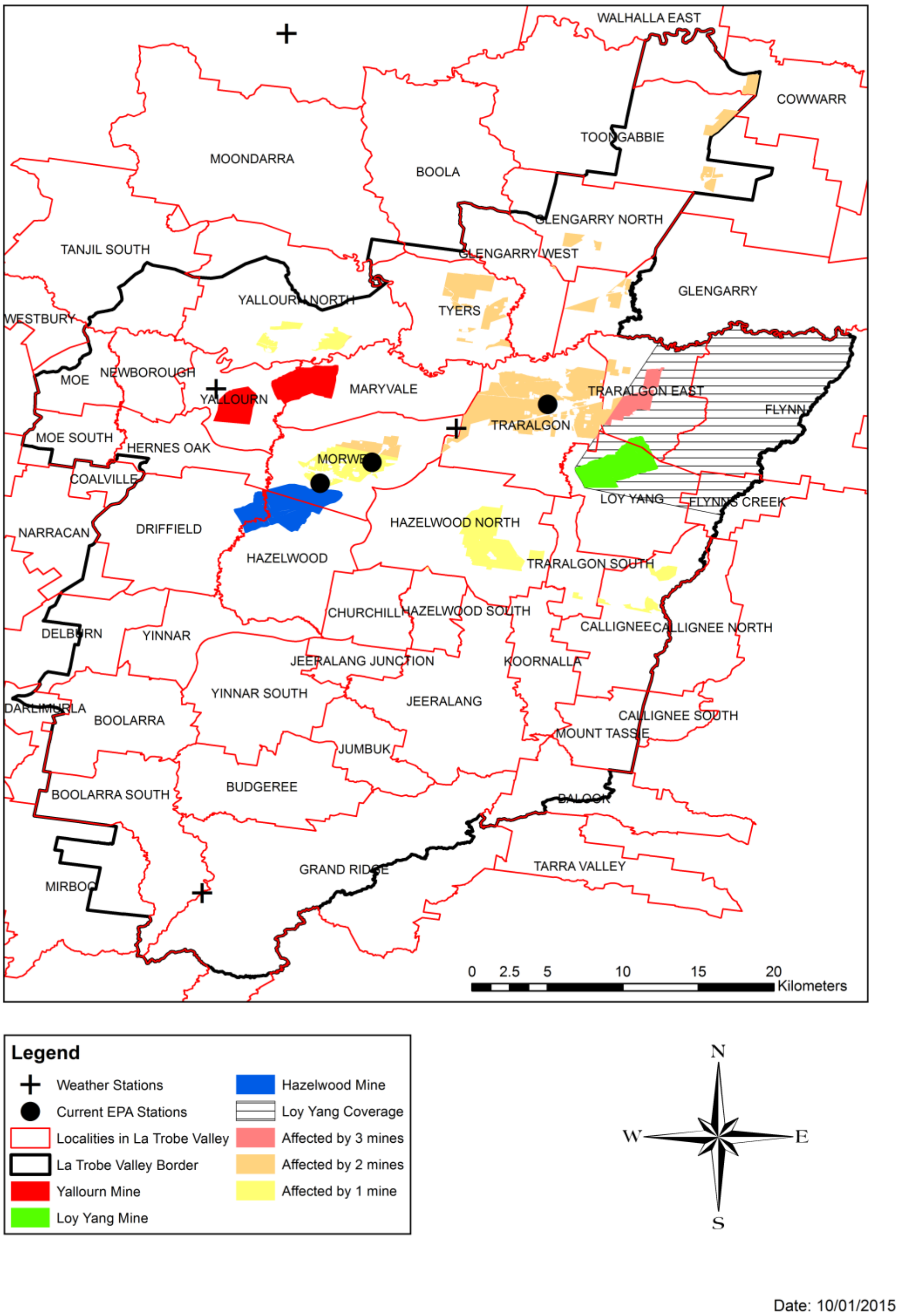

Figure 17 - Map of westerly wind Loy Yang coverage with usable station coverage

Figure 18 displays the Hazelwood mine coverage area with only the Morwell South station coverage displayed due to the fact that the Morwell East and Traralgon stations all lie within the Morwell South coverage area and means that they provide no beneficial extra coverage that the Morwell South station doesn't already cover.

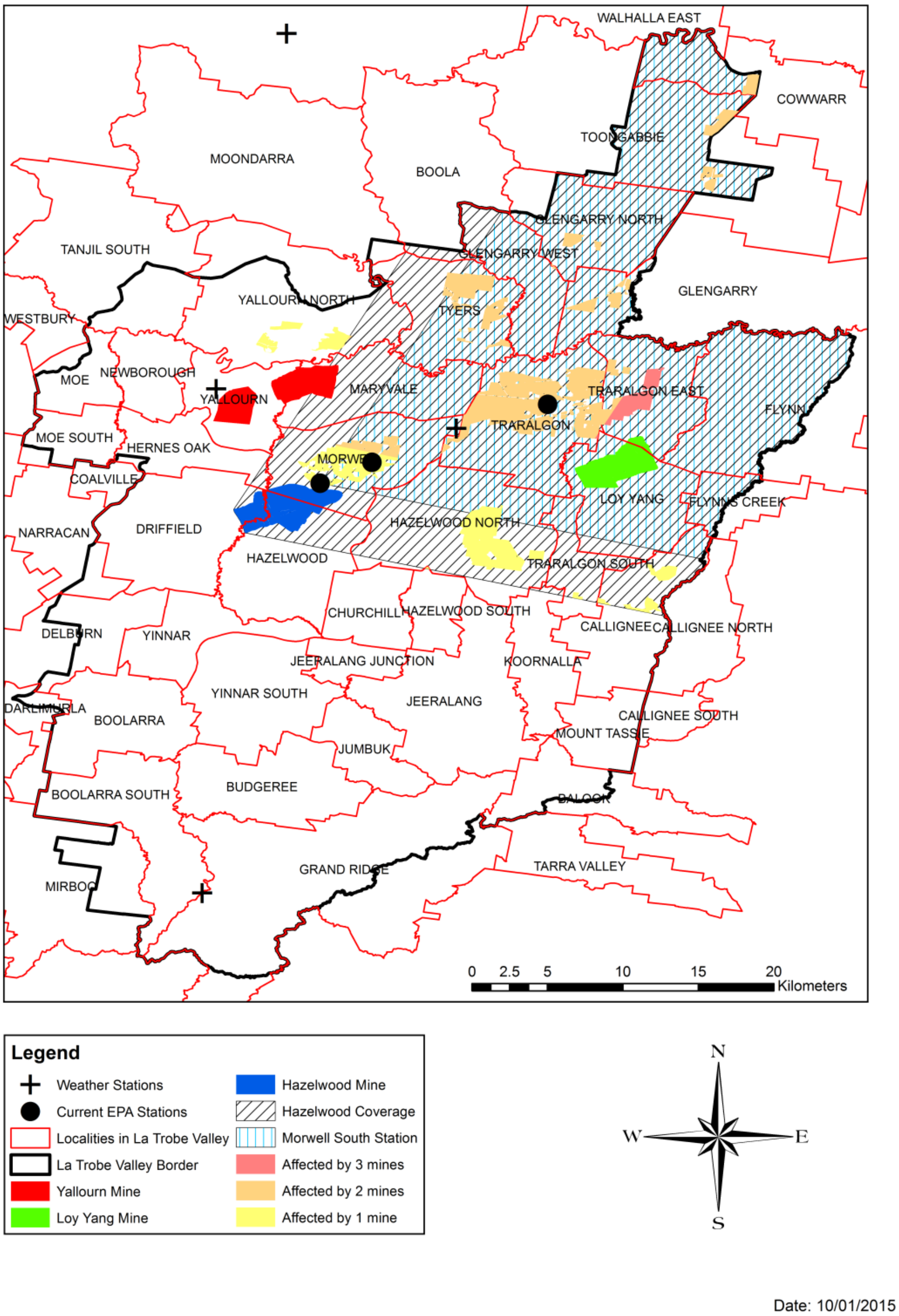

Figure 18 - Map of Hazelwood coverage with usable station coverage

According to the statistics, there are 46,975 people within the shadow of the Hazelwood mine over 20,768 dwellings. The proportion of these people that lie within the area that cannot be monitored downwind of the Morwell South station is 4,045 (8.61%) over 1,781 dwellings (8.57%).

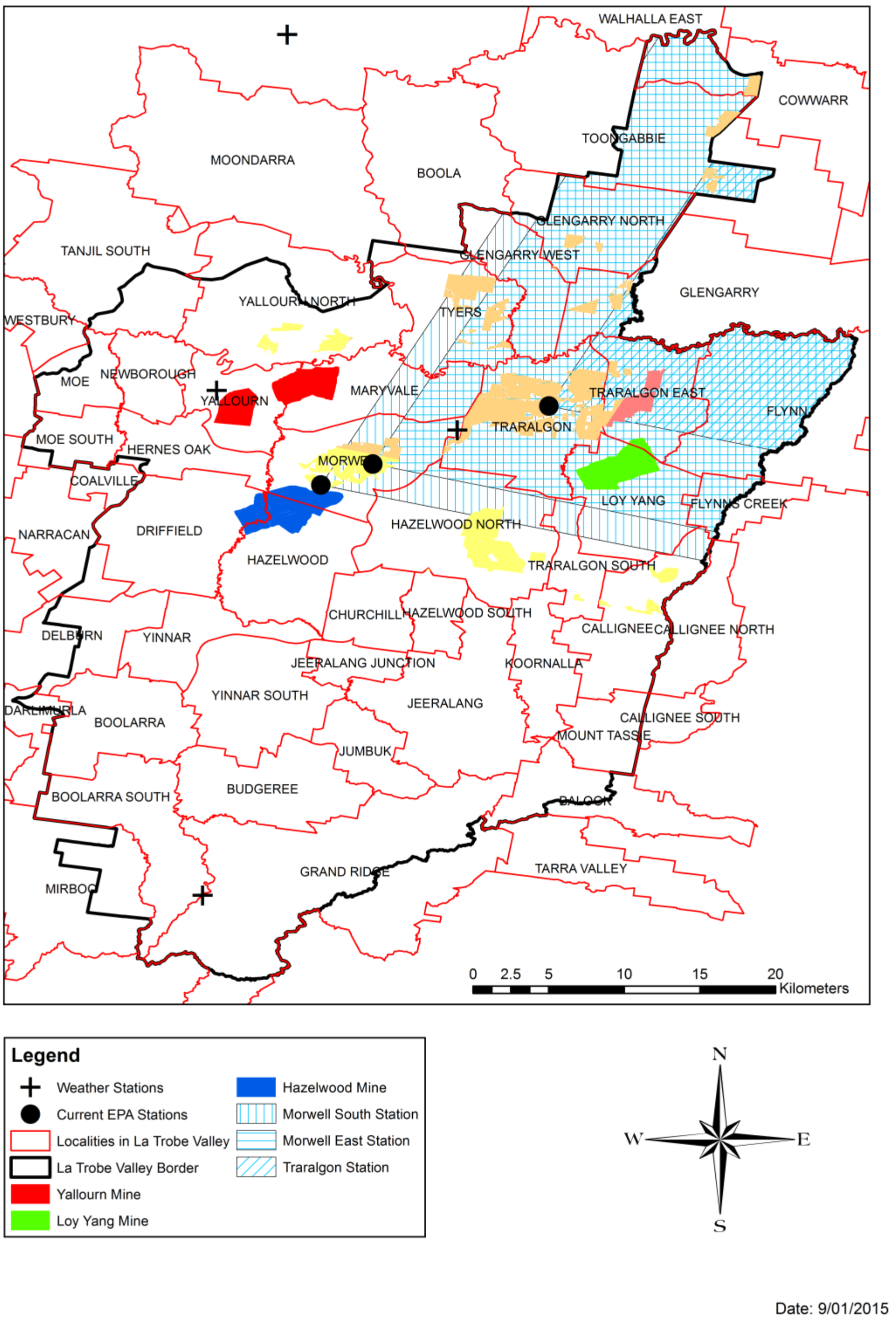

Figure 19 – Map of air pollution station coverage of Easterly winds

Figure 19 displays the approximate coverage of the three air monitoring stations combined in the same way as shown in Figure 15. The map represents the Easterly wind detection coverage for the region and is inverted from the Easterly map of the mines Figure 12 because it shows the potential mines that can be detected by each individual station. Additionally the population density is included to show the areas that are covered by the monitoring stations. The total area covered by the Station Coverage is 883.8km^2. When compared to the total size of the Latrobe Valley (1,426.1km^2), the area covered by the monitoring stations is 62% of the total area. Analysing the residential zones in this area shows 49,032 people within this area over 21,813 dwellings which is 67.9% of the population and 67.4% of dwellings.

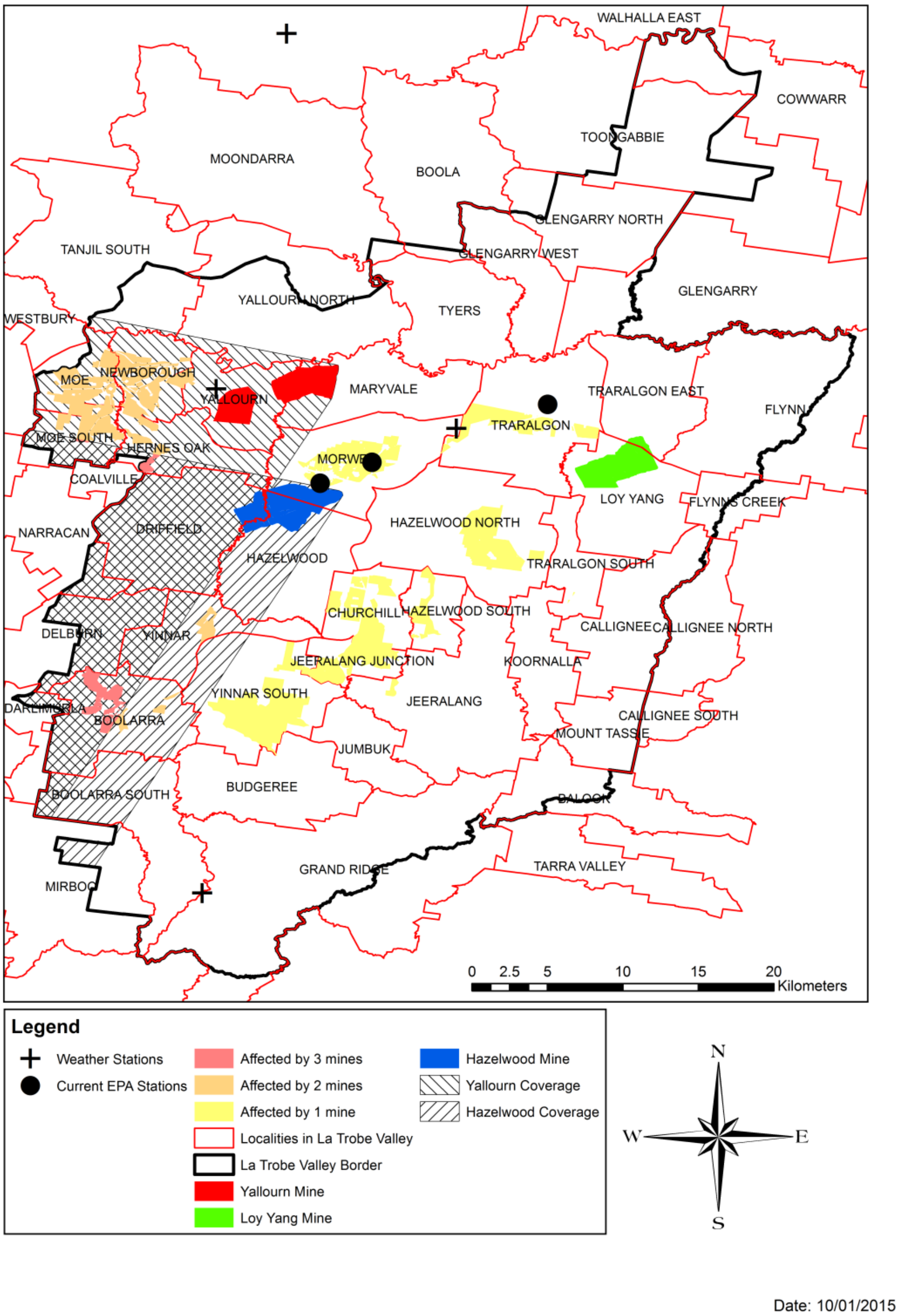

Figure 20 - Map of Hazelwood and Yallourn mine coverage with easterly winds

Figure 20 displays the mine coverage of the Hazelwood and Yallourn mines along with the residential zones as their coverage risk levels. Unfortunately none of the air monitoring stations lie within either the Hazelwood or Yallourn coverage polygons which means that the entire population that lies within the mine polygons is at risk of not knowing what lies upwind from the mines. The Hazelwood mine has 2,831 people over 1,266 dwellings at risk. The Yallourn mine has 17,946 people over 8,469 dwellings at risk.

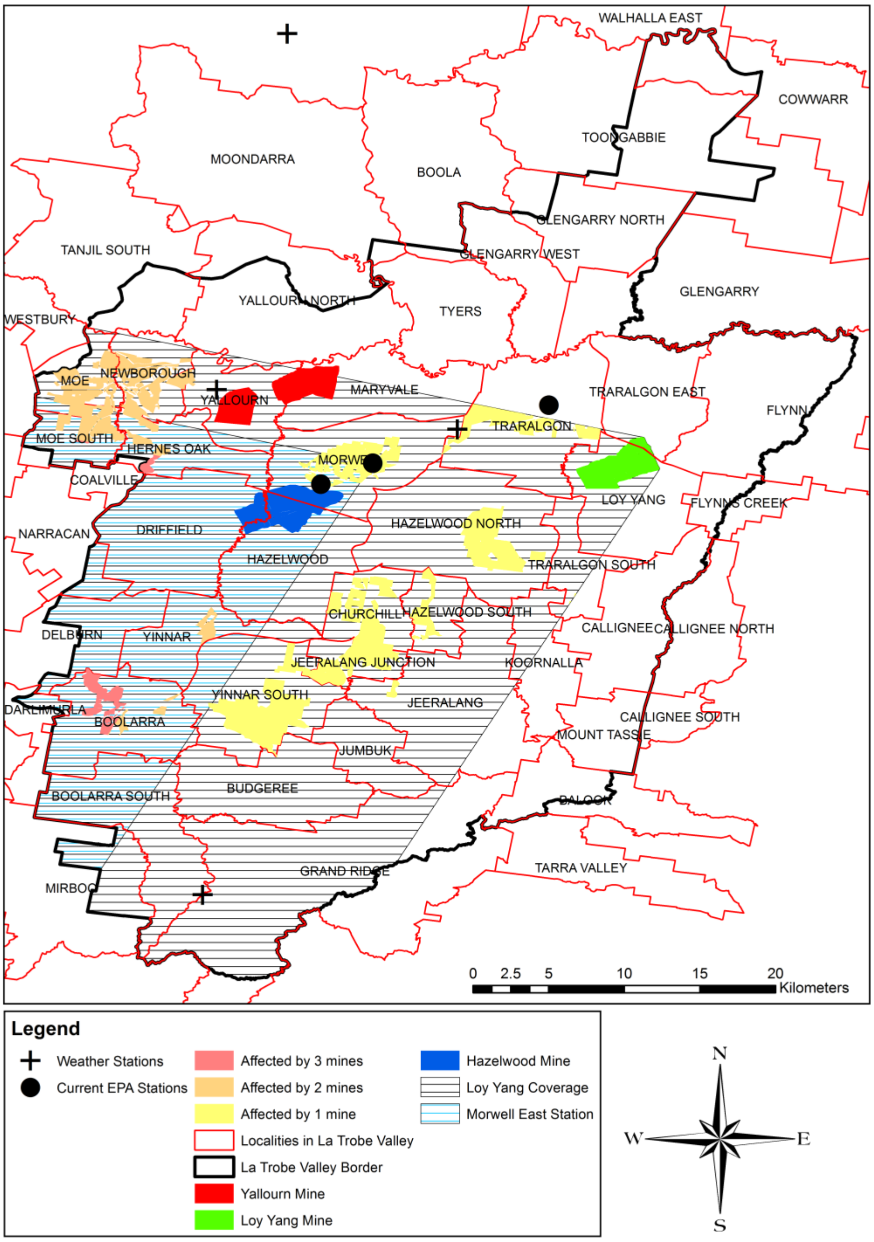

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Figure 21 - Map of Loy Yang coverage with easterly winds and Morwell East station coverage

Figure 21 displays the Loy Yang mine coverage area with only the Morwell East station coverage displayed due to the fact that the Morwell South station lies within the Morwell East coverage area and means it provides no beneficial extra coverage that the Morwell East station doesn't already cover.

Based upon the statistics, the total population within residential zones that lie within the Loy Yang polygon that have no up wind monitoring of them are 35,259 people (75.61%) over 15,904 dwellings (74.45%).

5.4 Locations for New Air Quality Monitoring Stations

By amalgamating the two scenario risks into one single overall mine influence risk map, Figure 22 was able to be produced. It shows the combined East and West mine influenced residential zones multiplied by the population density in order to reflect how population density is an important factor along with the number of mines covering the region. Areas that did not fall within the mine influence polygons were omitted completely. The risk levels are labelled from Low risk to Extreme risk, as such it would be important to eliminate the Extreme risk areas first and then proceed backwards toward the lower risk spectrum.

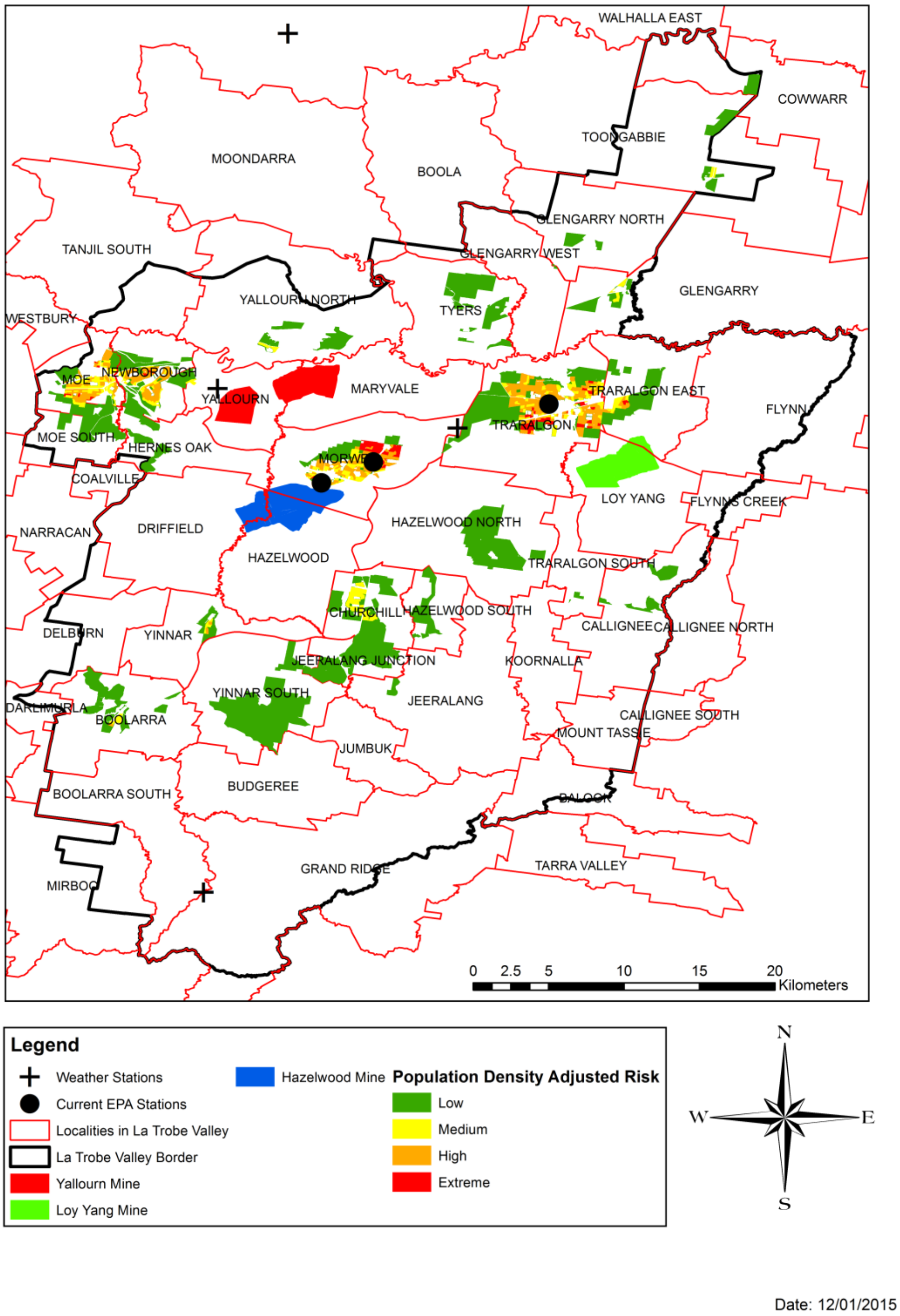

Figure 22 - Combined risk map adjusted with population density

Even though it was the Hazelwood coal mine which caught fire, it stands to reason that both the Yallourn and Loy Yang mines have the potential to have similar events occur. As such it is imperative that adequate air monitoring is set up for residents in areas surrounding each of the three mines rather than just one of the mines. The population is distributed around the mines in such a way that the effects of Hazelwood mine burning would affect different population centres than the Yallourn or Loy Yang mines would, were they to have similar disastrous events. It would be ideal to have a single station set up on the outskirts of every town centre on each side closest to the direction of a mine site so as to give enough forewarning to the general public as to what the pollutant content of the atmosphere is before it is too late. However this is not always possible due to funding and practicality constraints. The use of Figure 14 is important in determining the highest risk areas that require monitoring. As such it would be acceptable for some areas to remain unmonitored depending upon the population sizes and with low number of mines impacting them.

Whilst wind direction is important in terms of pollution dispersion, there is one important factor to not neglect, and that is the lack of wind in periods of a calm and stable atmosphere. These events which can sometimes lead to inversions within the valley that cause fumigation mean that some of the areas that are not downwind of any of the mine sites are still vulnerable to fumigation events. These fumigation events can often lead to higher concentrations of pollutants simply because the pollutants are not being ventilated and continue to accumulate in the same area until wind acts to blow the pollution out of the valley.

Monitoring the environment does cost money and other resources. Sometimes these resources can be stretched thin and are required to be deployed only by necessity. By taking this into consideration it is worthwhile considering the installation of temporary monitoring stations which operate during the peak fire risk period of the year between November and March. Alternatively, a combination of permanent and temporary stations could be set up. Ideally these stations should be between the fire risk source (the open cut mines) and residential areas.

5.5 Priority Ranking of New Air Quality Monitoring Stations

Implementation on new equipment is not a simple task as it requires an assessment of if it is actually necessary and following that what areas require it more than others. This research has attempted to display this by the prioritisation of residential zoned areas and their population density over all other aspects (environmental or economical). In order to determine a prioritisation structure it would be useful to highlight the need of a station based upon the prevailing wind direction and the population density of the areas.

The best method of approach is to actually install permanent monitoring stations which have high accuracy measurements, within the central population centres that have areas of risk rated Medium to Extreme. This results in Figure 23 which displays recommendations of where the future monitoring stations should be in pink. If Traralgon is considered the only permanent monitoring station and Morwell South and Morwell East are considered temporary stations, then Figure 23 suggests that an additional four stations be set up in order to provide high accuracy monitoring for the key populations in the Latrobe valley which have been considered at risk. The areas required are as follows: Yinnar due to its ranking of High risk, Churchill due to its relatively large area and its risk rating of Medium, Newborough and by extension Moe due to their ratings of Extreme risk and finally Morwell East upgraded to a permanent station due to its Extreme risk and the retention of the already permanent Traralgon site.

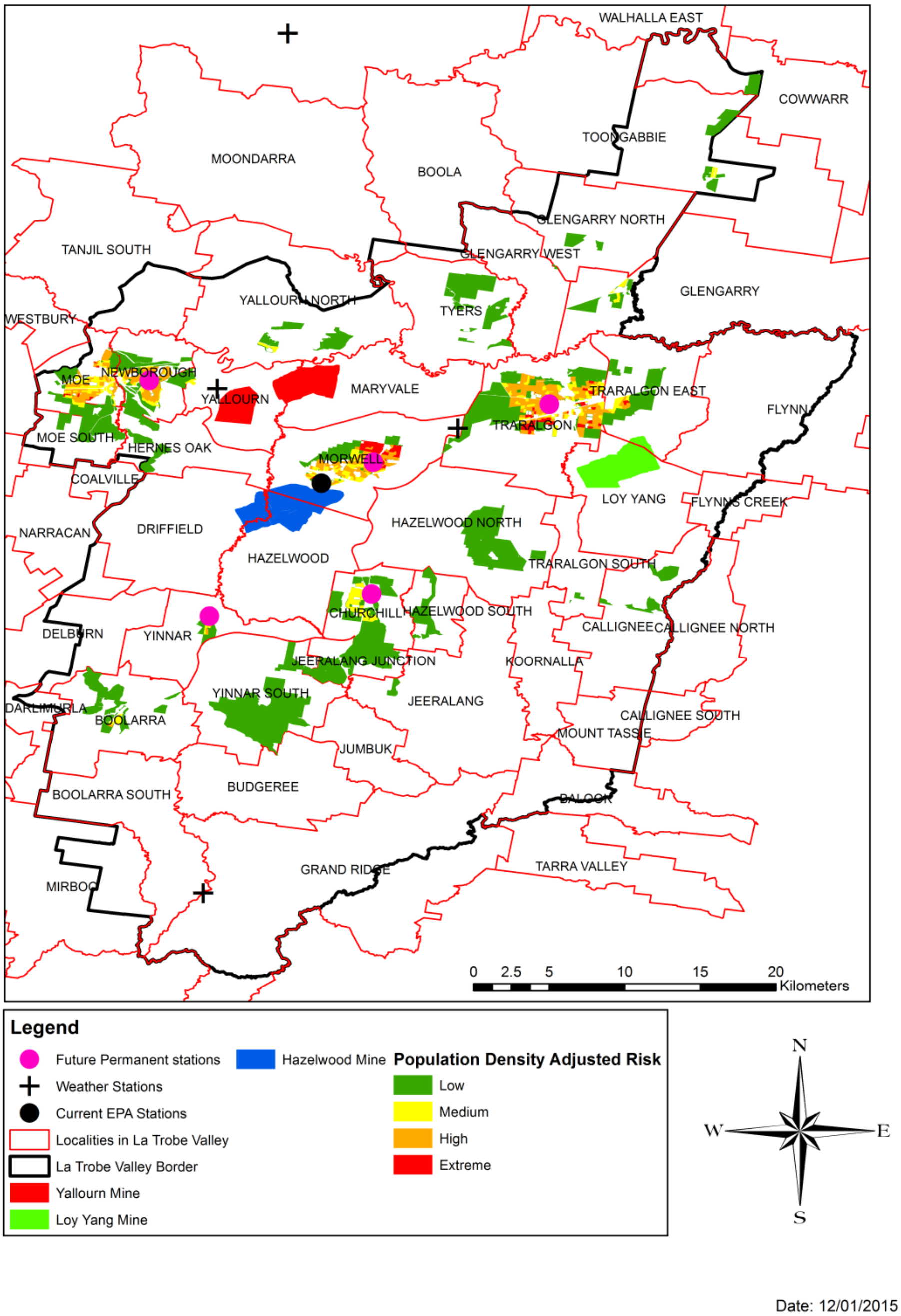

Figure 23 - Future permanent monitoring station recommendations

In order to extrapolate reasonably, it should be taken into consideration that during a fire event monitoring would be important near the specific mine in which the incident is occurring. Because of this, an additional map has been created which highlights suggested areas where stations should be setup in the case of a fire at any of the mines. These can be temporary stations that are able to be rapidly deployed and do not require excessive correcting and tweaking in order to provide high accuracy results. Indicative results would be more than necessary as there would be permanent stations already set up in the high risk areas which can provide more important high accuracy information to the local residents in their area of deployment. These stations are depicted in Figure 24 and when compared to previous maps such as Figure 12 and Figure 13 it can be seen that the stations lie within the mine influence polygons and are upwind of the major risk areas and as such can provide indicative information before pollution reaches the major population centres/risk areas in an emergency situation.

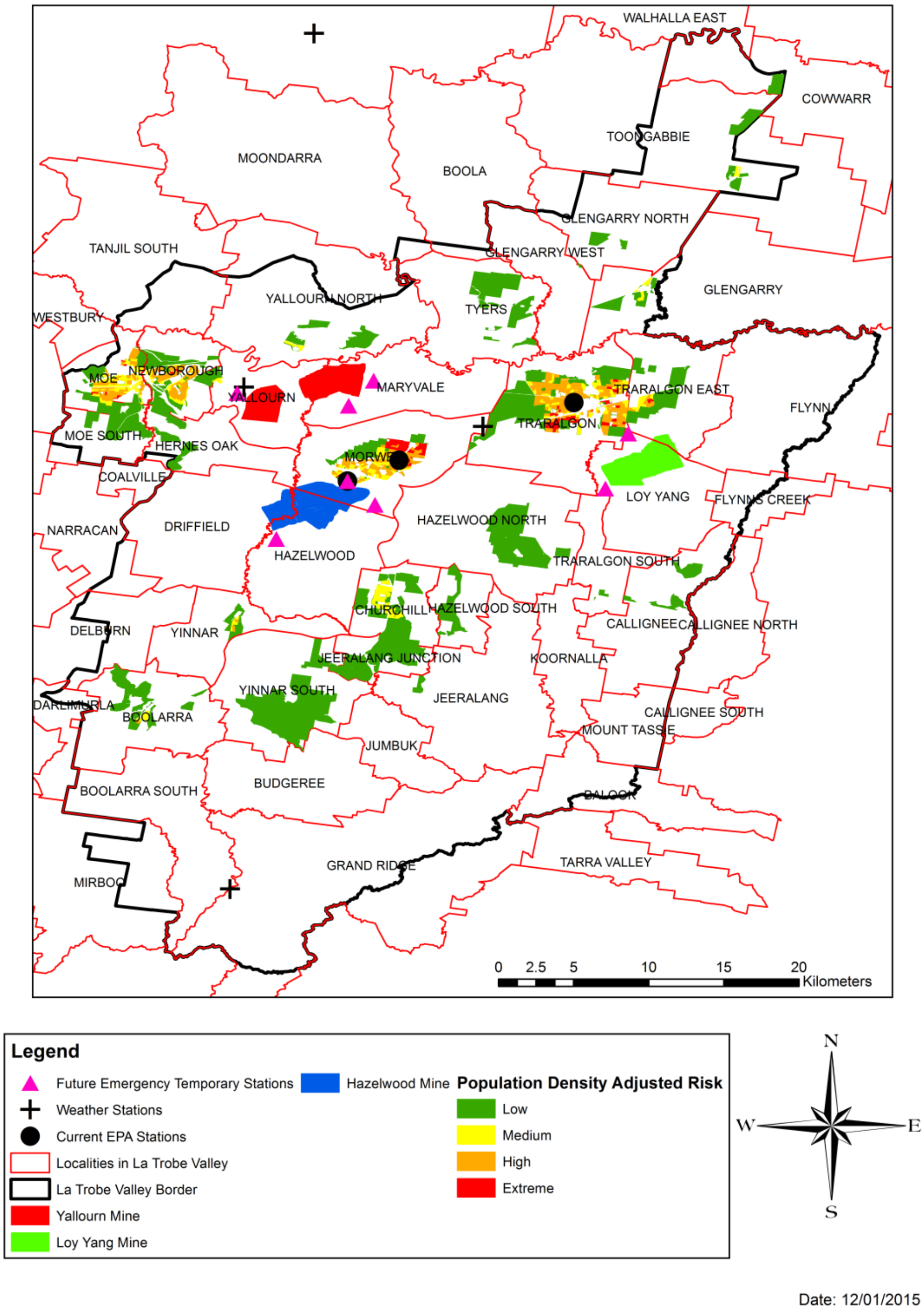

Figure 24 - Future emergency temporary monitoring station recommendations

5.6 The Adequate Network of Air Quality Monitoring Stations

In order to be deemed an adequate network, the stations needed to cover or eliminate areas of Extreme risk then High risk then Medium risk as much as possible without un-necessarily adding more and more stations to cover areas that were deemed Low risk. The stations displayed in Figure 23 covers every single area that has Extreme or High risk associated with it and also includes the Churchill area due to the size of the Medium risk area. There are a total of five proposed permanent stations sites.

Figure 24 is aimed not at the population centres but rather at the direction of the primary winds associated with the Latrobe Valley as seen in previously in Figure 6, Figure 12 and Figure 13. At any one time it is unlikely that more than one station would catch on fire so it is not expected that all temporary stations would need to be set up. As such it seems adequate to have only a few stand-by temporary stations that can be deployed in the event of one of the open cut coal mines being set alight. There are a total of eight proposed temporary station sites

Due to these stations requiring the EPA to install them, it stands to reason that they may be placed at any location in the nearby vicinity of the recommendation based upon personal land areas, commercial buildings and other site specific constraints that would inhibit or benefit the station installation. These recommendations are more of a guide of the specific locality areas as well as based upon the mine relationship in order to be appropriately maximised. In order to summarise, Figure 25 was created to show the combined proposal for permanent and temporary air pollution monitoring stations.

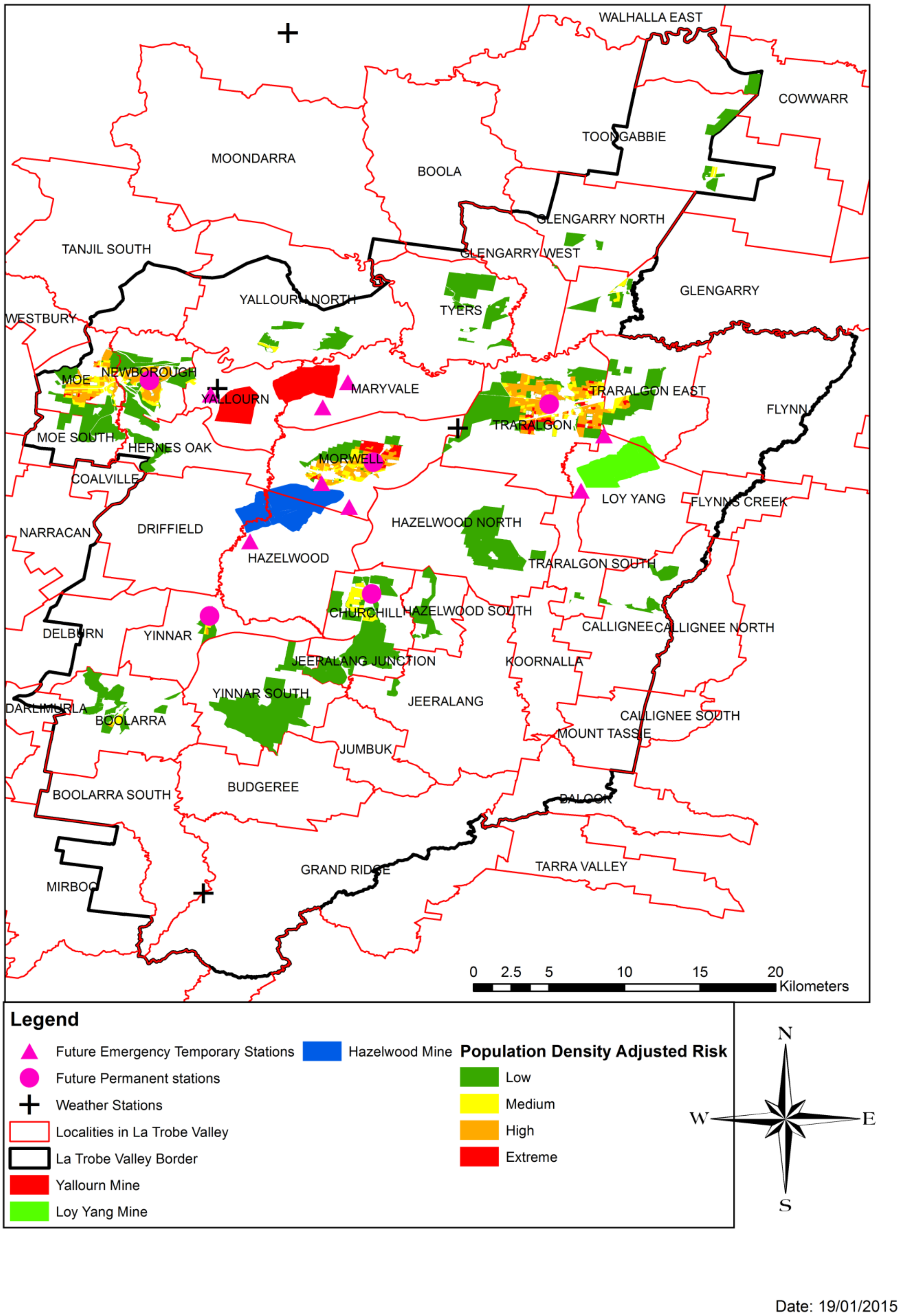

Figure 25 - Final proposed air pollution monitoring station network

5.7 Summary

The primary findings of this thesis are that although it is important for monitoring stations to be installed downwind of mine sites, it is more practical and important to install the stations at key hotspots of risk. These permanent stations in Traralgon, Morwell, Newborough, Churchill and Yinnar would benefit the community greatly during high pollution events specifically if a similar incident to the Hazelwood mine fire were to occur again.

It also means that these stations can be tuned to a higher accuracy than the temporary stations and have reliable data that can be actively streamed to the internet and hence be available for public information and use. Furthermore the installation of temporary stations to the West and East of Yallourn, North-West and South-West of Loy Yang, North-East, East and South-West of Hazelwood, would provide adequate information in an emergency situation by providing indicative data as the stations would not be required to constantly be assessed for their functionality due to their highly infrequent operation.

Chapter 6 Discussion and Conclusion

6.1 Introduction

Initially this study was going to utilise an atmospheric dispersion model to assess the potential impact the fire had on the surrounding areas. However during initial data collection it was determined that the output would be potentially erroneous due to an outdated 14 year old digital elevation model (created in the year 2000) which would have neglected almost 1-2km lengths within each of the mines which have been since excavated. In addition to this, there was also a lack of data for the emission rate of the fire which is a key piece of data that would determine the concentration levels likely for surrounding areas.

Without this information the resulting output had the potential to be misleading and give bad information about the likely concentration in surrounding areas. It also had the potential to be drastically different based upon small changes in the coding of the variables in the model itself. As a result it is more appropriate to consider the actions that took place on a public scale and assess if the monitoring stations were appropriately set up based upon the actual wind directions exhibited in the Latrobe Valley and real world observations rather than through the use of computational modelling and theoretical measurements that were never officially measured and could change the output drastically depending on their initial inputs.

6.2 Conclusions

The Latrobe Valley has numerous populated towns centred around three mine complexes.

A fire which occurred in the Hazelwood mine prompted the installation of two new temporary monitoring stations in the Morwell township in order to measure pollutants and forewarn residents of what to expect. However the setting up of the stations took too long and the population was likely put at unfair risk due to poor monitoring schemes in the area. To compound this lack of information, the sites were not directly comparable which is inexcusable.

As a result this paper has investigated information and data on the situation that occurred and taken into consideration average conditions in the area at the highest risk periods for fire during the year, in order to suggest improvements.

From this analysis of meteorological/climatological conditions and population distribution, recommendations have been made to rectify data gaps in monitoring the air quality for Latrobe Valley residents with the aim to safeguard residents from potential hazardous situations in the future.

New stations should be set up on the outskirts of any township bordering a coal mining area.

According to the hypotheses proposed in the introduction to the results, the Traralgon station did in fact appear to be too far from the Morwell township in order to provide useful information to the residents there. The temporary stations were set up far too late and important information was not able to be determined for almost two weeks after the start of the fire. However it was discovered that it would be more appropriate to have three temporary emergency stations on standby in the event of a future fire so a similar scenario does not reoccur.

Contrary to the initial hypothesis, the permanent stations should not be set up on the flanks of the mines. Instead they should be set up within the townships themselves where the highest risk of mine influence occurs. This is because it is important to know information at the area of importance rather than try to assume what the dispersion rate might be based on wind speed.

6.3 Discussions

The fire danger period for the southern half of Australia starts in November and proceeds through to March (Williams, Karoly & Tapper 2001). Prolonged periods of dry hot weather can exacerbate the drying of moisture content from exposed coal piles and mine faces. This coupled with predicted rises in Fire Danger Index due to climate change (Williams, Karoly & Tapper 2001), poses a significant risk of re-occurrence of a similar event in the future. Two of the key points made in the finalisation of the Hazelwood Mine Fire Inquiry by Teague, Catford and Petering (2014) was that:

“Recommendation 5: The State equip itself to undertake rapid air quality monitoring in any location in Victoria, to:

Collect all relevant data, including data on PM 2.5, carbon monoxide and ozone; and

Ensure this data is used to inform decision-making within 23 hours of the incident occurring.”

“Recommendation 6: The State take the lead in advocating for a national compliance standard for PM2.5”

This thesis has attempted to highlight the importance of permanent monitoring stations being set up in nearby populations which would assist in improving the notification of dangerous smoke to nearby communities and by extension appropriately equip the Victorian State Government to be able to handle future emergencies adequately. If in case a similar situation arose whereby faults, errors and other unforseen problems occurred with the temporary stations being set up when a mine fire is active, the establishment of the permanent monitoring stations earlier as suggested in Figure 23 would be adequate in the meantime for notifying local communities of the hazard whilst the temporary stations are properly set up. This would avoid the knowledge gap which was experienced for almost two weeks by Morwell residents whereby they had no idea what was affecting them as they could only rely on the Traralgon station which was downwind and much further from the mine than they were.

6.4 Areas for Further studies

This study was done without the use of any atmospheric modelling programs. In the future it may be useful, especially for specific fire events, to give an approximation of where and what concentration of pollutants were blown/deposited over what areas. These computer models can be very technical and can be used for many different pollutant types (for example SO_2, PM2.5, PM10, CO, NO_2 etc). The computer models would not likely be useful in order to predict future pollution distribution, more so they would be useful in assisting authorities to determine what areas need assistance in the wake of such a technological disaster, such as who needs compensation, do any health centres need to be relocated, do any schools need to be relocated, which areas should cleaning kits be distributed to etc.

By installing permanent stations at the recommended sites, it enables a vast amount of information to be available for potential future studies. Examples of future studies could involve analysis of the health impacts of coal mining and/or coal fires on nearby populations, how pollution is dispersed in the valley on a diurnal and seasonal scale and also there could be studies done of the impact that the implementation of these stations have on the local populous in terms of if they take more notice of the coal impacts. This could also set the basis for a warning system whereby the stations automatically send out notifications via mobile phone applications such as the recently implemented Vic Emergency website that was set up in response to the 2009 Victorian Bushfires.

This monitoring system could set a precedent for other townships throughout Australia that are located within close proximity to coal mining operations that have the risk of catching fire. It would start to highlight the importance of knowing how dangerous the pollution from these sources truly are and assist with more appropriate management by the local and state governments as well as the companies which operate the mine sites.

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