

**Air pollution in Victoria
– a summary of the
state of knowledge
August 2018**

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Foreword

As Victoria's Chief Environmental Scientist, a key part of my role is to ensure Victorians have access to robust, science-based information about their environment. With the right information and knowledge, we can develop new and innovative ways for government, industry and community to protect the environment from the effects of pollution and waste.

Air pollution in Victoria – a summary of our current state of knowledge summarises our current knowledge about air quality, sources, trends and impacts in Victoria. The report also outlines some actions we need to take to inform decision making in the future to ensure we protect human health and the environment from air pollution.

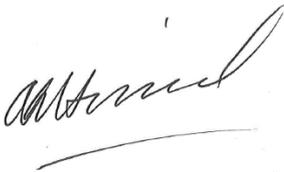
While Victoria's air quality is good by international standards, and has improved significantly over recent decades, there remain challenges ahead. We have a projected large population growth in Melbourne and regional centres. With this comes an associated increase in registered vehicles, infrastructure and industries which all impact air pollution sources and population's exposure to pollution.

Climate change is also predicted to impact future air quality by altering the meteorological variables that influence the development, chemical transformation, transport dispersion and deposition of air pollutants. Over the coming decades, we are likely to experience worsening heat waves and harsher bushfire seasons because of this changing climate, which all impact on the type and scale of exposure to air pollution.

We also have localised air pollution issues from point sources and diffuse sources which can affect communities around the state. We need the appropriate tools and knowledge to effectively assess and manage such issues.

The information provided in this report will be key in informing a comprehensive Victorian air quality strategy, a critically important program of work which will address prevention and actions to manage air quality into the future.

Environment Protection Authority Victoria has a proud history of using science to tackle environmental issues and I look forward to working with you all to protect the environment and human health to ensure a liveable and prosperous Victoria, now and always.



Dr Andrea Hinwood

Chief Environmental Scientist
Environment Protection Authority Victoria

Executive summary

Victoria's air quality has improved significantly over recent decades and is considered good by world standards. However, air pollution remains an important environmental and human health issue. Victoria's most common air pollutants are particulate matter, ozone, carbon monoxide, sulfur dioxide and nitrogen dioxide. Of these, particulate matter (PM_{2.5} and PM₁₀) and ground-level ozone are of greatest concern and are the focus of this report. This is due to their ongoing presence in the ambient air, the number of sources that contribute to these pollutants and their potential to increase in the future, as well as their potential environmental and human health impacts.

Environment Protection Authority Victoria (EPA) is responsible for the regulation, monitoring, assessment and reporting of air pollution in Victoria. Pollutant concentrations measured at EPA's ambient air monitoring stations are compared against the relevant national and state air quality standards. EPA also monitors air quality during major air pollution incidents when required. Most ambient air quality monitoring and reporting occurs in the Port Phillip Region due to the higher population density. EPA also monitors air quality at locations with localised pollution issues.

Air pollution in Victoria comes from a range of natural and anthropogenic sources. Primary pollutants are directly emitted through combustion activities, such as carbon monoxide, nitrogen dioxide, sulfur dioxide and PM_{2.5} from motor vehicles, or from mechanical processes, such as PM₁₀ in wind-blown dust. Secondary pollutants are produced from chemical reactions between other pollutants in the atmosphere, such as PM_{2.5} and ozone which is formed from volatile organic compounds and nitrous oxides in sunlight.

In Victoria, motor vehicles are a significant source of air pollutants. Important sources of particulate matter include smoke from bushfires and planned burns, wood heater smoke, and industry. Natural sources, such as sea salt and dust, are also major contributors of particulate matter.

High ozone concentrations are most likely to occur on days over 30 °C with light winds when there are sufficient concentrations of precursor pollutants to react in the atmosphere. Long-term trends based on EPA's data show that Melbourne's average ozone concentrations are below national standards. There has been an overall increase in annual average concentrations since 1996, however peak maximum one-hour concentrations have declined. Most exceedances of the ozone air quality standards in recent years have been attributed to large bushfires. Predictions for hotter, drier conditions increase the risk of higher ozone concentrations in the future.

Since 2009, EPA's data shows an overall reduction in the number of days when PM₁₀ has exceeded air quality standards. In most years, peaks of PM₁₀ has been attributed to wide-spread pollution events such as dust storms, bushfires and planned burns. At some monitoring locations, such Brooklyn in the west of Melbourne, peaks of PM₁₀ are often associated with localised dust issues.

In 2017, EPA's monitoring showed a significant increase in the number days when PM_{2.5} air quality standards were exceeded. These exceedances were mostly attributed to urban sources, such as wood fire heaters. In most years, smoke from bushfires and planned burns contributed to the majority of PM_{2.5} exceedances. Elevated PM_{2.5} concentrations on cool winter days with still conditions are generally associated with wood fire heaters combined with general urban air pollution from motor vehicles and industry, whereas PM_{2.5} exceedances on mild, still days with medium humidity are mostly attributable to planned burn smoke.

There is a large body of evidence that demonstrates that air pollution, even at concentrations below the current air quality standards, is associated with adverse health effects. At an individual level, the health impacts from air pollutants can vary considerably, depending on an individual's susceptibility to its effects.

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People generally more susceptible to experience health effects are those who have existing lung or heart disease, the young and those over 65.

Internationally, particulate matter is the individual pollutant estimated to be responsible for the largest burden of disease from outdoor air pollution. Evidence shows a clear association between increases in daily average PM_{2.5}, and effects on the respiratory and cardiovascular system, and premature mortality. However, there is now also evidence emerging of associations with adverse birth outcomes and diabetes.

Predictions for a drier, hotter climate, together with projected population increases, pose important challenges to Victoria's future air quality. EPA is responsible for providing Victoria with the necessary environmental knowledge to prevent air pollution and manage its impacts. To do this, EPA will continue to address knowledge gaps by utilising innovative technology and research methods and leveraging ever-increasing sources of data. Fit-for-purpose, accessible information about the present and future state of Victoria's environment is key to ensuring the continual improvement of Victoria's future air quality.

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Glossary of terms

Absorption	When one substance penetrates the body of another
Adsorption	The condensation of gases, liquids, or dissolved substances onto the surface of another
Aerodynamic diameter	Used to describe the behaviour of a particle as it moves around in the air; it compares the behaviour with that of a spherical particle of unit density
Aerosol	A mixture of particles suspended in the atmosphere
Air pollutant	Any substance in the air that could harm humans, animals, vegetation or other parts of the environment if present in high enough concentrations
Air pollution	The presence of one or more air pollutants in high enough concentrations to cause harm
Air pollution episode	A combination of events involving the presence of air pollution and meteorology that limits the dispersion of air pollutants
Air quality	Air quality is the degree to which air is suitable or clean enough for humans, animals, or plants to remain healthy
Air quality index	Score out of 100, based on dividing a pollutant concentration by a standard. Can be used to approximate relative impact of different pollutants
Airshed	Geographic area with sources of air pollutants, where air quality and dispersion is determined by topography, meteorology and sources of pollutants
Ambient monitoring	Monitoring of air pollutant concentrations to determine the background concentrations of an airshed
Background concentration	General concentration of air pollutants without the influence of local sources. In cases where there is insufficient data, a 70 th percentile value is sometimes used as a representation
Coarse particles	Particles which are between PM ₁₀ and PM _{2.5} , commonly measured in micrograms per cubic metre µg/m ³
Criteria air pollutants	Common air pollutants; includes carbon monoxide (CO), nitrogen dioxide (NO ₂), ozone (O ₃), sulfur dioxide (SO ₂), PM ₁₀ and PM _{2.5}
Equivalent instrument	Instruments that have been demonstrated under local conditions to perform and provide results consistent with the reference method
Fine particles	Particles with an aerodynamic diameter equal or less than 2.5 µm, commonly measured in µg/m ³
Local conditions monitoring	Monitoring of air pollutant concentrations to determine the influence of a local source on an airshed

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Mass concentration	Concentration of a substance (air pollutant) in air expressed as a mass per unit volume (commonly $\mu\text{g}/\text{m}^3$)
Meta-analysis	Statistical analysis for combining data from multiple studies in order to determine an overall trend
Morbidity	The state of having a disease
National Environment Protection (Ambient Air Quality) Measure	Sets national air quality standards and goals for common air pollutants; used by local jurisdictions to monitor and report against
National Environment Protection (Air Toxics) Measure	Sets national air quality standards and goals for toxic air pollutants; used by local jurisdictions to monitor and report against
National Environment Protection (National Pollution Inventory) Measure	Provides the framework for the establishment of the National Pollutant Inventory (NPI), which is an internet database designed to provide publicly available information on the types and amounts of certain substances being emitted to air, land, and water
Ozone (stratospheric)	More commonly known as the ‘ozone layer’, this is a beneficial layer of ozone located 10–50 km above sea level
Ozone (tropospheric)	Major component of photochemical smog; considered air pollution and tends to occur less than 10 km above sea level. Typically forms from precursor chemicals in the presence of sunlight during the summer months. Commonly referred to as ‘ground-level ozone’
Particle count	Alternative quantitative measure of particle concentration, generally used for ultrafine particles where mass concentration is difficult to measure due to low masses
Reference instrument	Instruments that have been assessed as the primary method for monitoring a pollutant that have the highest accuracy
State environment protection policies	Subordinate legislation made under the provisions of the <i>Environment Protection Act 1970</i> to provide more detailed requirements and guidance for the application of the Act to Victoria
State Environment Protection Policy (Ambient Air Quality)	Adopts the requirements of the National Environment Protection Measure (Ambient Air Quality) and sets air quality objectives and goals for the whole of Victoria
State Environment Protection Policy (Air Quality Management)	Establishes the framework for managing air emissions in Victoria from all sources of air pollutants
Synergistic	Where the response to two air pollutants together is greater than their individual responses
Systematic review	A type of literature review that uses systematic methods to identify, assess, select and synthesise high quality research evidence

Ultrafine particles

Particles with an aerodynamic diameter equal or less than 0.1 μm , commonly measured in particle counts per m^3

Acronyms and abbreviations

AQI	Air quality index
BAM	Beta attenuation monitor
BAP	Benzo(a)pyrene
CO	Carbon monoxide
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
GHG	Greenhouse gas
O₃	Ozone
µg/m³	Micrograms per cubic metre – 1 µg/m ³ is one millionth of a gram of the pollutant in a cubic metre of air
NATA	National Association of Testing Authorities
NEPMAAQ	National Environment Protection (Ambient Air Quality) Measure
NEPMAT	National Environment Protection (Air Toxics) Measure
NEPMNPI	National Environment Protection (National Pollutant Inventory) Measure
NO	Nitrogen oxide
NO_x	Oxides of nitrogen
NO₂	Nitrogen dioxide
PAH	Polycyclic aromatic hydrocarbons – measured as benzo(a)pyrene equivalents (BAP)
PM	Particulate matter
PM₁	Particles with an aerodynamic diameter equal or less than 1 µm
PM₁₀	Particles with an aerodynamic diameter equal or less than 10 µm
PM_{10A}	Daily concentration of PM ₁₀ , adjusted for the temperature difference between ambient conditions and sampling chamber of the TEOM
PM_{2.5}	Particles with an aerodynamic diameter equal or less than 2.5 µm
ppb	Parts per billion (1 ppb means the pollutant takes up 0.0000001 per cent of the air)
ppm	Parts per million (1 ppm means the pollutant takes up 0.0001 per cent of the air)
POP	Persistent organic pollutant

SAQI	Station air quality index
SEPPAAQ	State Environment Protection Policy (Ambient Air Quality)
SEPPAQM	State Environment Protection Policy (Air Quality Management)
SO₂	Sulfur dioxide
TEOM	Tapered element oscillating microbalance
VOC	Volatile organic compounds
WHO	World Health Organization

1 Introduction

Environment Protection Authority Victoria (EPA) is responsible for protecting human health and the environment from the effects of air pollution. EPA is also responsible for monitoring, regulating and reporting on Victoria's air quality. These responsibilities are legislated under the *Environment Protection Act 1970* (the Act) and the State's environment protection policies, which incorporate national standards on ambient air quality.

EPA currently monitors criteria air pollutants which include ground-level ozone, particulate matter (PM₁₀ and PM_{2.5}), carbon monoxide, sulfur dioxide and nitrogen dioxide. Lead, also a criteria pollutant, is no longer monitored. This report also provides information on other toxic pollutants (such as benzene, formaldehyde, toluene and xylene) which are found in trace amounts in the airshed, but for which there has been limited monitoring.

Air pollutants measured at EPA's air monitoring stations typically shows low concentrations relative to state and national standards. EPA's air monitoring data also shows a significant reduction in the concentrations of carbon monoxide, nitrogen dioxide and lead over the last few decades. Lead is now at such low ambient concentrations that monitoring is no longer required.

Despite its relatively good air quality, Victoria sometimes experiences air pollution at concentrations which can impact the environment and human health. Air pollution comes from a range of natural and anthropogenic sources. In Victoria, natural sources of pollution include windblown dust, sea salt and bushfires. Anthropogenic sources include major industry, commercial activities and motor vehicles. Particulate matter (PM₁₀ and PM_{2.5}) and ozone are the pollutants which most frequently exceed air quality standards.

There is now a strong evidence base that poor air quality can have serious impacts on human health, including effects on the respiratory and cardiovascular system. Poor air quality can affect the natural environment by impairing vegetation growth, acidifying soils and freshwater, and causing chronic health impacts in wildlife. Poor air quality can also have significant impacts on local amenity, reducing people's desire to engage in outdoor and community activities.

This report provides a summary of the current state of knowledge about air pollution in Victoria, with a focus on PM₁₀, PM_{2.5} and ground-level ozone. This is due to their ongoing presence in the ambient air, the number of sources that contribute to these pollutants and their potential to increase in the future, and their potential impact on human health and the environment.

2 Air pollution

Ambient air is a complex mixture of gases and particles which is constantly changing. This is due to a range of natural and anthropogenic activities which generate air pollutants. An air pollutant is any substance that can harm humans, animals, vegetation or other parts of the environment if present in the air in sufficiently high concentrations for specific periods of time. Air pollution, therefore, is defined as the presence of one or more air pollutants in concentrations high enough to cause harm.

2.1 Criteria air pollutants and air toxics

Criteria air pollutants can adversely impact the environment and human health. In Victoria, particulate matter (PM₁₀ and PM_{2.5}) and ozone are the pollutants of greatest concern due to the frequency of their occurrence, the concentrations they can sometimes reach in ambient air, and their potential for health and environmental impacts. Although lead is classified as a criteria pollutant, it has not been a pollutant of concern since its removal from petrol.

Air toxics include substances such as benzene, toluene, ethyl-benzene, xylene (BTEX) and formaldehyde. While they are generally less common than criteria pollutants and are usually present in very low concentrations, they are still considered to have significant impacts on human health and environment. In Victoria, guidelines for these substances are outlined in the National Environment Protection (Air Toxics) Measure.

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Table 1 shows the sources and most common known health effects associated with individual air pollutants, and the current Australian National Environment Protection (Ambient Air Quality) Measure standards (NEPMAAQ).

Table 1: Major air pollutants, health effects and current air quality standards (Adapted from Dennekamp & Cary 2010)

Pollutant	Sources	Health effects (most consistently reported)	The Australian NEPMAAQ standard
Particles < 10 µm in diameter (PM₁₀)	Motor vehicle engines (particularly diesel engines); burning solid fuel, fossil fuel and plant material; bushfires; coal and ore mining; windblown dust; paved and unpaved roads	<ul style="list-style-type: none"> - decreased lung function - increased respiratory symptoms - exacerbation of cardiac conditions, asthma and other respiratory conditions - premature mortality - lung cancer 	50 µg/m ³ over 24 hours 25 µg/m ³ over 1 year Note Victoria has a more stringent annual standard of 20 µg/m ³ for PM ₁₀
Particles < 2.5 µm in diameter (PM_{2.5})	Motor vehicle engines (particularly diesel engines); burning solid fuel, fossil fuel and plant material; bushfires	<ul style="list-style-type: none"> - decreased lung function - increased respiratory symptoms - exacerbation of cardiac conditions, asthma and other respiratory conditions - premature mortality - lung cancer 	25 µg/m ³ over 24 hours 8 µg/m ³ over 1 year
Ozone (O₃)	Secondary pollutant, formed when burning of fuels (motor vehicles or industry) occurs in sunny conditions	<ul style="list-style-type: none"> - decreased lung function - increased respiratory symptoms - exacerbation of asthma and other respiratory disease 	0.10 ppm over 1 hour 0.08 ppm over 4 hours
Sulfur dioxide (SO₂)	Mainly from fossil fuel combustion (especially energy generation)	<ul style="list-style-type: none"> - increased respiratory symptoms - exacerbation of respiratory disease 	0.20 ppm over 1 hour 0.08 ppm over 1 day 0.02 ppm over 1 year
Nitrogen dioxide (NO₂)	Motor vehicle engines; energy generation; mining and other industry	<ul style="list-style-type: none"> - increased respiratory symptoms - exacerbation of asthma and other respiratory disease 	0.12 ppm over 1 hour 0.03 ppm over 1 year
Carbon monoxide (CO)	Motor vehicle engines; energy generation; other industry; bushfires; and burning solid fuel	<ul style="list-style-type: none"> - Exacerbation of ischaemic heart disease - Decreased exercise capacity 	9.0 ppm over 8 hours

2.2 Primary and secondary generation of air pollutants

Air pollutants are either directly emitted into the air (primary pollutants) or are produced and formed in the atmosphere (secondary pollutants). Primary pollutants are generated through a mechanical or combustion process. For example, PM₁₀ in wind-blown dust from an unpaved road, PM_{2.5} from a bushfire, or sulfur dioxide from burning coal. Secondary pollutants are formed from chemical reactions in the atmosphere, rather than from a mechanical or combustion process. Both particles and ozone can be produced through chemical reactions. Ozone, for example, forms in sunlight from the reaction of volatile organic compounds (VOC) and nitrous oxides.

2.3 Particles as PM₁₀ and PM_{2.5}

Particle pollutants are a mixture of solid particles and liquid droplets; this mixture is commonly referred to as an aerosol. These particles are very small and are measured in microns or micrometres (µm). To demonstrate the relative size of these particles, they are often compared with fine beach sand and a strand of human hair as shown in Figure 1.

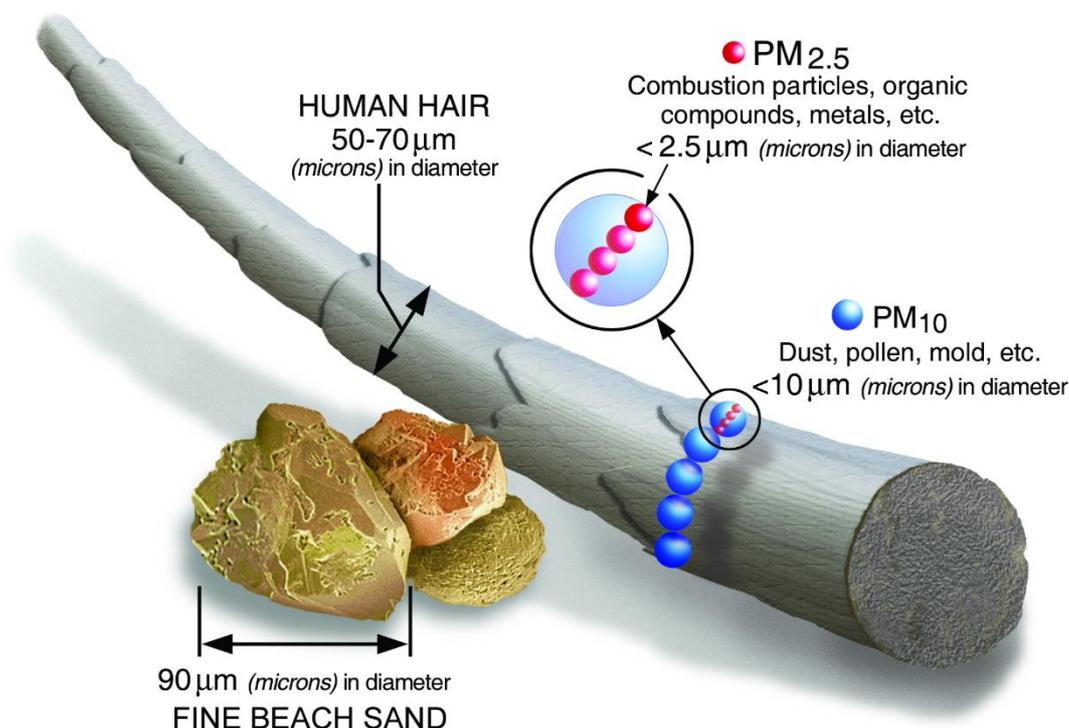


Figure 1: Comparison between fine beach sand (90 µm), human hair (50–70 µm), PM₁₀ and PM_{2.5} (US EPA 2018 <https://www.epa.gov/pm-pollution/particulate-matter-pm-basics>)

PM_{2.5} is equal to or smaller than 2.5 µm (0.0025 mm) in aerodynamic diameter. Often described as fine particles, they are up to 30 times smaller than the width of a human hair. PM_{2.5} is produced from the combustion of a range of materials such as fossil fuels, organic matter, rubber and plastic. Motor vehicles, power plant emissions and bushfires are all major sources of PM_{2.5} (Table 1).

PM₁₀ is equal to or smaller than 10 µm (0.01 mm) in aerodynamic diameter. Common sources of PM₁₀ include sea salt, pollen fragments and combustion activities such as motor vehicles and industrial processes. Dust from unsealed roads and non-exhaust vehicle emissions are a major source of PM₁₀.

PM₁ are particles with an aerodynamic diameter equal to or less than 1 µm. Ultrafine particles have an aerodynamic diameter equal to or less than 0.1 µm. Common sources are combustion activities. Due to their small size, they are usually measured using particle counts (expressed as number of particles per cm³) rather than mass concentrations (Heinzerling et al. 2016).

The chemical composition of particles will vary, depending on the source and dominant size fraction (Chow 1995, 1998; Liang et al. 2016; Seinfeld et al. 2016; Watson et al. 2016). Common indicator chemicals include sodium chloride from sea-spray ($PM_{10} > PM_{2.5}$); water soluble potassium, levoglucosan and semi-volatile organic decomposition products from biomass burning ($PM_{10} \approx PM_{2.5}$); crustal material from wind-blown soils (calcium, iron, manganese, aluminium and silica) ($PM_{10} > PM_{2.5}$); source specific elements from mining products (for example, iron, copper, manganese, chromium, nickel, vanadium, zinc, aluminium, cobalt, arsenic, strontium and uranium) ($PM_{10} \geq PM_{2.5}$); and high temperature elemental carbon, hopanes, and steranes from diesel engine exhaust ($PM_{10} < PM_{2.5}$) (Chan et al. 2008; Murillo et al., 2013; Pérez et al. 2008).

2.4 Ozone

Ozone is the primary constituent of photochemical smog. It is a colourless gas with strong oxidising properties which is found in different concentrations in both the stratosphere (10–50 km above sea level) and in the troposphere (sea level to 10 km). In the stratosphere, ozone is beneficial and reduces ultraviolet radiation. However, tropospheric ozone is considered a pollutant – its strong oxidising properties can harm human health, as well as sensitive vegetation and ecosystems.

As discussed in section 2.2, ozone is a secondary pollutant formed in the atmosphere by complex chemical reactions between nitrous oxides and VOCs. The chemistry of ozone formation is dependent on precursor emissions and on a variety of meteorological parameters, including ultraviolet light. This reaction is temperature dependent, which is why ozone formation tends to occur in Victoria during the summer months. The generation of these precursors are linked to many different natural and anthropogenic processes and occur over a wide area. The generation of the precursor emissions also vary during the day, such as peaks in emissions due to increased vehicle traffic at certain times of the day.

2.5 Carbon dioxide, nitrogen dioxide and sulfur dioxide

Carbon monoxide is a colourless, odourless and tasteless gas. It can be flammable in air and is dangerous in high concentrations as it binds preferentially to haemoglobin and reduces the body's ability to absorb oxygen. It is generally formed from combustion and is higher when the combustion is incomplete or inefficient. Domestic wood heaters are a potential source of carbon monoxide if not used efficiently. When oxygen is limited, fuel does not burn properly, which results in higher carbon monoxide emissions.

Nitrogen dioxide is an irritant gas which commonly forms from combustion processes. It can also be formed during the nitric acid manufacturing process. Nitrogen dioxide and VOCs play a part in the reactions associated with the formation of ozone in the atmosphere under certain conditions (Tory et al. 2000).

Sulfur dioxide is a colourless gas with a strong characteristic pungent odour. It can be an irritant at low concentrations. It generally forms from the combustion of fuels which contain sulfur, such as diesel and coal. Sulfur dioxide can be an important contributor to the formation of secondary particles.

2.6 Other air pollutants

Persistent organic pollutants are a group of chemicals which are known to be hazardous to human health and the environment. Twenty-one chemicals are regulated in Australia under the Stockholm Convention on Persistent Organic Pollutants. They include substances such as hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs), as well as dioxins and furans. The production, importation and use of these chemicals is not permitted in Australia. PCBs already in use in products, such as in large commercial power transformers, are being phased out as part of the National Strategy for the Management of Scheduled Waste (Department of the Environment and Energy 2011).

The State Environment Protection Policy (Air Quality Management 2001) lists additional air pollutants of concern as well as criteria to assess stack and ground level concentrations.

2.7 Sources of air pollution

Air pollution is always present in the environment as it is caused from many common sources. These sources include anthropogenic sources such as industry, motor vehicles and domestic wood burning. There are also natural sources such as windblown dust and smoke from bushfires.

2.7.1 Sources of particle pollution

Particles come from a range of natural and anthropogenic sources in the environment. Sources of particles are grouped into two categories: primary and secondary particles. Primary particles are generated directly through a mechanical or combustion process. Secondary particles are formed from chemical reactions in the atmosphere. The key precursor pollutants involved in the production of secondary particles includes gases and semi volatiles such as oxides of nitrogen, sulfur oxides, volatile organic compounds and ammonia.

Primary and secondary particles can also interact. For example, sometimes secondary particles can attach to and coat primary particles, such as occurs with wind-blown sea salts. In this case, the primary sodium chloride core can interact with and pick up secondary particles as it travels inland, away from the coast. For this reason, there can be a difference between fresh and aged sea salt as it travels.

2.7.2 Industrial sources of pollution

Emissions inventories are an important source of information when investigating sources of air pollution. The National Pollutant Inventory (NPI) is a collaborative program between the Commonwealth and states and territories. It is established under the National Environment Protection (National Pollutant Inventory) Measure and is mirrored by the Victorian Waste Management Policy (National Pollutant Inventory). The NPI reports on emissions of 93 substances to air, land and water. It includes particles as PM₁₀ and PM_{2.5} but doesn't include ozone emissions. This is due to ozone being a secondary pollutant, rather than being emitted directly from industrial and combustion processes. The NPI does report on precursors of ozone such as nitrogen dioxide and total volatile organic compounds; this information can be used in air pollution models to predict the formation of ozone.

Data in the NPI is reported as an annual emission, which can make it more difficult to use the data in models as the emission needs to be allocated across the year due to models having higher time resolution. As a result, assumptions need to be added to the NPI data to determine when emissions occurred during the year the data was reported in.

Data from the NPI indicates changes to industrial sources of pollution over the past few years. Changes include reductions of some pollutants due to the end of motor vehicle manufacturing, and changes associated with the closure of the Anglesea power station (www.npi.gov.au).

Not all emissions are included in the NPI as discrete air pollutant sources – there are many small to medium enterprises that don't meet the threshold for NPI reporting. Emissions from commercial premises and non-industrial pollutions sources such as motor vehicles and domestic emissions are also not included. EPA collects some of this data in its air pollutant emissions inventory which is aggregated and provides contextual data for the industrial emissions. EPA also uses this emissions data in partnership with other organisations, such as the CSIRO, to model air pollutants as they are discharged, mix and move in the environment. EPA is currently undertaking an update of its emissions inventory (last updated in 2006) – this update will be aligned with data from the 2016 Census undertaken by the Australian Bureau of Statistics.

2.8 Motor vehicles – exhaust emissions

Emissions from motor vehicles are widely distributed, with density of emissions generally linked to population size. In Melbourne, we have 4.8 million people, which is projected to increase to 5.6 million by 2026 and six million by 2031. We have 4.7 million cars registered in Victoria, which represents a 500,000 increase in registered vehicles over the last five years. This is likely to increase to 5.4 million registered vehicles by 2026 (EPA Victoria 2013). Unlike most industrial emissions, vehicle emissions are released in close proximity to where people live, work and do recreational activities (so called 'sensitive receptors') and are generally not as well dispersed. In Australia, the most common measure of vehicle activity level or traffic volume is vehicle kilometres travelled (VKT). It is the total kilometres travelled by vehicles on a given stretch of road over a period of time.

The key air pollutants of concern in exhaust emissions are PM_{2.5}, nitrogen dioxide, sulfur dioxide and volatile organic compounds. Particles as PM₁₀ are generally less likely to be present in vehicle exhaust compared with PM_{2.5}. PM₁₀ motor vehicle related emissions are mostly non-exhaust particle emissions which result from tyre, road and brake wear which are in the coarse fraction. The PM_{2.5} fraction make up the predominate

PM₁₀ component of vehicle exhaust. Sulfur dioxide concentrations in exhaust emissions are directly related to the amount of sulfur in the fuel.

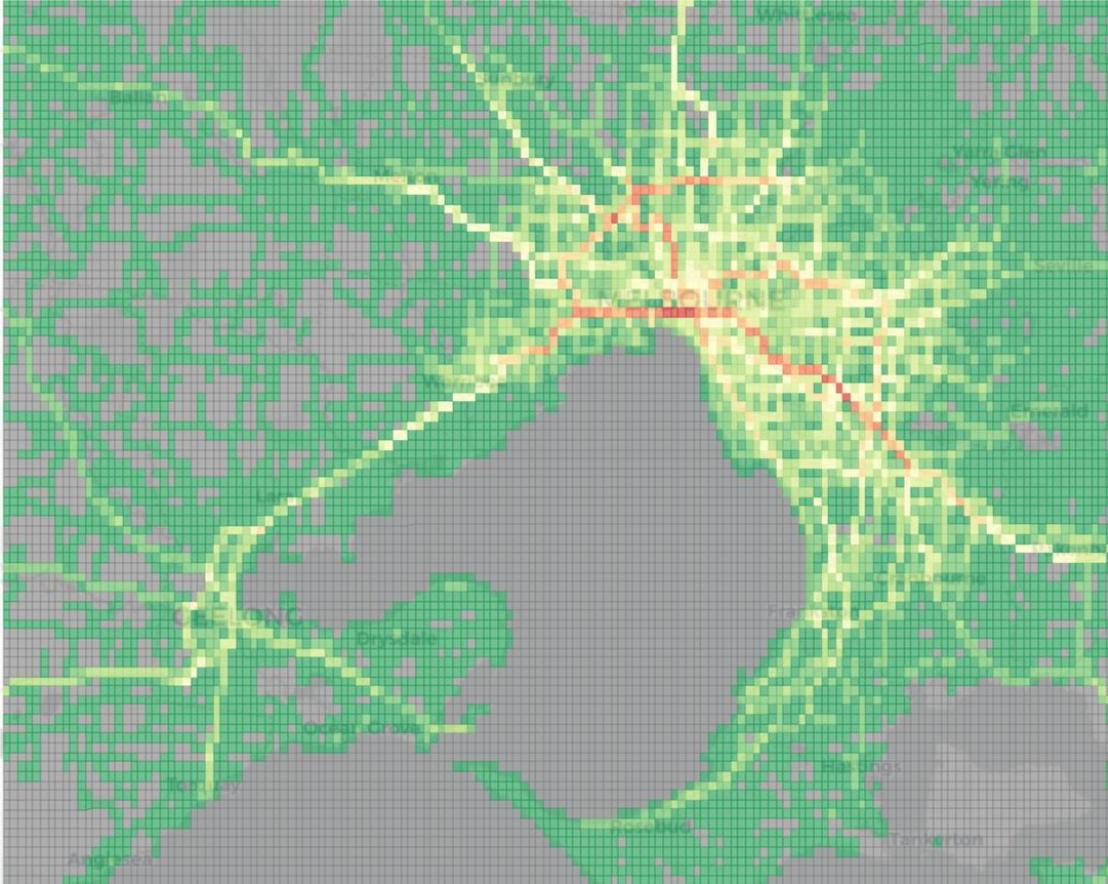


Figure 2: VKT distribution across Melbourne and Geelong in 2016 (1km x 1km grid)

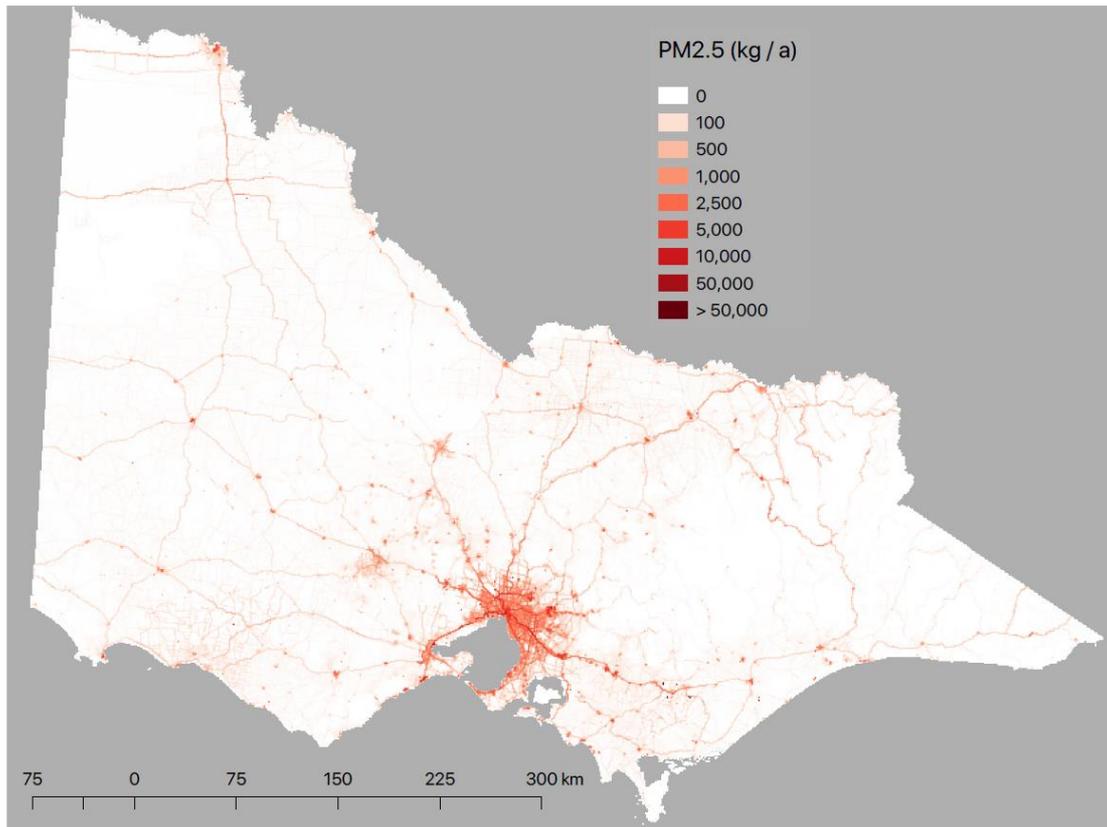


Figure 3: 2016 Emissions Inventory PM_{2.5} kg/m²/annum

The distribution of VKT for Melbourne and Geelong in 2016 is shown in Figure 2, with the main highways and arterial roads clearly visible, and data aggregated into a 1 km by 1 km grid. Different fleet distributions (the mix of vehicles, cars and trucks) and emission factors are used to determine emissions in each grid square. Across Victoria, the influence of motor vehicles on emissions of PM_{2.5} is clearly shown in emissions inventory data (Figure 3). Additional inventory maps are shown in Appendix 2.

2.9 Motor vehicles – non-exhaust emissions

Non-exhaust motor vehicle emissions are generally associated with particles as PM₁₀. Improvements to vehicle engines are unlikely have an impact on these types of emissions, except in instances when vehicles become lighter. Heavier vehicles will have increased tyre and brake wear, which may be a factor with electric and hybrid vehicles over the short term, as batteries can add significant weight to these vehicles until lighter energy storage is available. In the future, it is possible that an increase in the number of electric and hybrid vehicles could result in non-exhaust emissions becoming a more dominant emission source than exhaust emissions (Timmers & Achten 2016).

Another source of non-exhaust PM₁₀ is clutch wear in the engine, and road surface wear, which includes both the erosion of road surfaces and vehicle wear. The repair and maintenance of roads is also a source of air emissions, including volatile organic compounds from bitumen.

2.10 Urban sources of pollution

2.10.1 Domestic wood heaters

In Victoria, wood heaters are commonly used to provide home heating and are spatially well distributed across Melbourne and Victoria. Figure 4 shows a spatial distribution of wood heaters across the Port Phillip region based on data collected from real estate listings. The policy impact assessment for the proposed

variation to the Waste Management Policy (Solid Fuel Heating) estimated that there are 96,900 wood heaters in the Port Phillip region and 142,800 in total across Victoria (Regulatory Impact Solutions 2017).

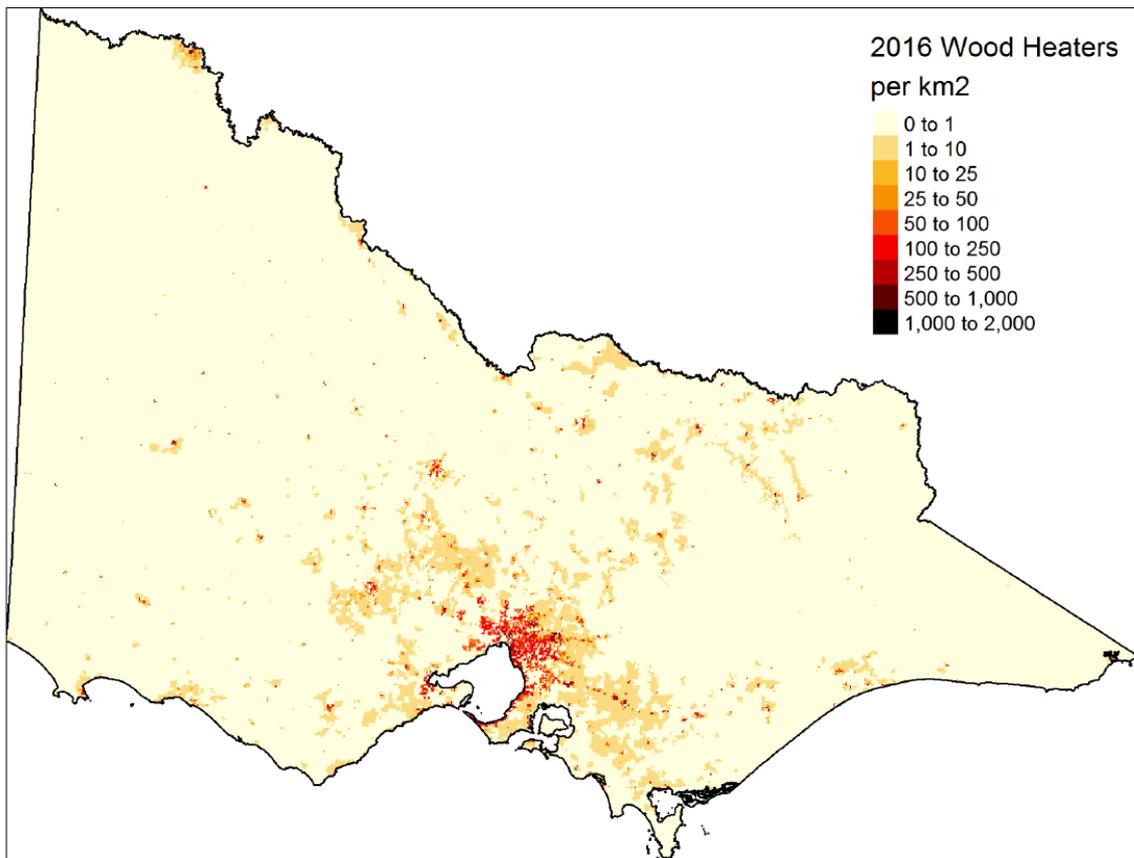


Figure 4: Spatial distribution of wood heaters in Victoria

In some instances, wood heaters are the primary source of heat and cannot be easily replaced as there is no access to natural gas heating. In other areas, there are alternatives available, such as natural gas heating and heat pumps, as well as electric heating, which produce less PM_{2.5}. Individual wood heaters also vary in performance, depending on their design and how they are operated (Figure 5).

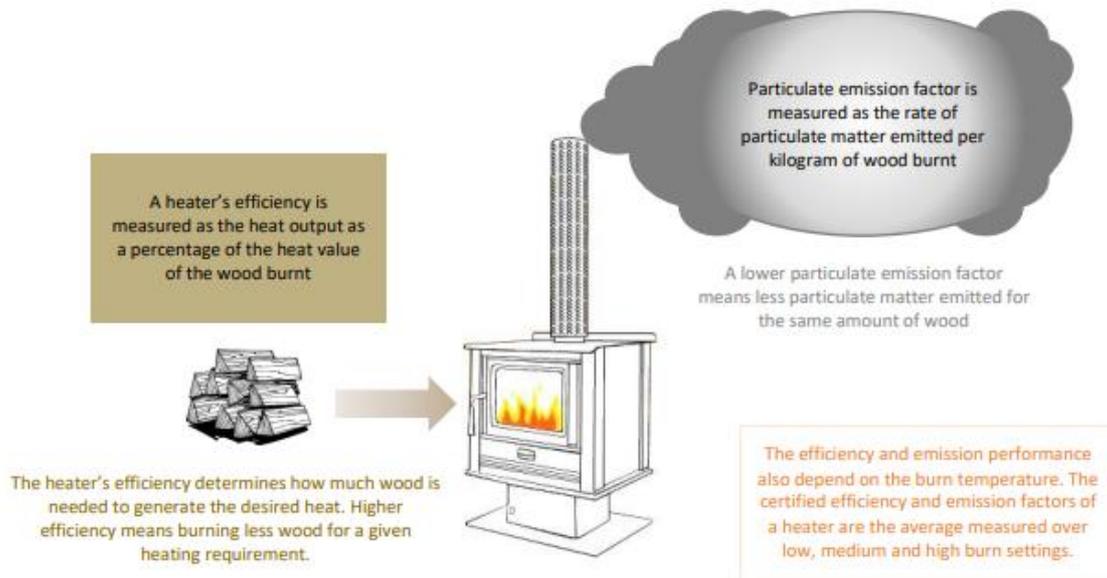


Figure 5: Emissions from wood heaters (Regulatory Impact Solutions 2017)

In addition to domestic wood heater emissions, combustion activities in commercial premises, such as in the restaurant and catering sectors, also contribute to PM_{2.5} pollution. This includes premises such as charcoal chicken, steak and wood fired pizza premises. These premises generally have lower individual discharges compared with industrial emission sources. However, emissions tend to be closer to sensitive receptors, which increases their potential for impacts. These sectors are not regulated by EPA; air pollution concerns from these types of premises are generally managed by local councils.

2.11 Bush fire and planned fuel reduction burn emissions

Planned fuel reduction burns involve lighting fires under carefully managed conditions to reduce fuel load, which lessens the risk of bushfire. Agencies use a range of tools to reduce smoke impacts on communities. This includes the use of specialised models to predict the concentration and movement of smoke with the aim of planning and guiding burning programs. There are a number of factors which influence the potential impact of smoke on communities, including:

- type of combustion and fuel loading in the area
- moisture content of the fuel
- size of the area consumed
- meteorology, dispersion and proximity of the community to the area.

The 2009 Victorian Bushfires Royal Commission highlighted the difference in size between major bushfires and planned burns (Victorian Bushfires Royal Commission 2010). It estimated that planned burns accounted for 130,000 hectares burnt, compared with the 2009 bushfires which were greater than 400,000 hectares. This difference is likely to be greater now, as planned burns are more targeted at high risk areas rather than focused on burning a set area. Based on these figures alone, the total emissions of particulate matter and carbon monoxide could be greater from total bushfires (non-planned burns) compared with planned burns in some years. However, the actual smoke impacts will vary greatly depending on conditions and location.

Recent work carried out by CSIRO for the Department of Environment, Land, Water and Planning (DELWP) indicates that the emission factors for particulate matter and carbon monoxide from smouldering combustion (characteristic of planned burns) would be about three times higher than emissions produced by the flaming combustion typical of a bushfire. These emission factors are based on pollutant per weight of fuel. The smoke from a planned burn may also be more visible due to a higher level of moisture in the fuel and have increased concentrations of volatiles due to incomplete combustion (CSIRO 2017). Monitoring conducted in townships in southern Western Australia and Victoria found that higher concentrations of PM_{2.5} and carbon monoxide for bushfires compared with planned burns (Reisen 2011).

Although smouldering combustion produces more carbon monoxide and particulate matter than flaming combustion, there are other factors which can affect the overall production of emissions in planned burns and bushfires. Planned burns also target different fuel sources to those often consumed by bushfires.

Bushfires tend to occur during periods of low humidity, high winds and temperatures. Conversely, planned burns are carried out during conditions with high humidity, low winds and temperatures. Another difference between these different types of fires is that smoke plumes from planned burns are cooler and less buoyant than bushfire plumes. As a result, planned burn plumes may travel shorter distances and are more likely to be concentrated in the nearby area (Reisen et al. 2013). Topography is also a major influence on smoke dispersion. If smoke is generated in or enters a valley, it can become trapped and will linger, which can lead to extended periods of smoke impacts.

2.12 Natural sources

Natural sources are major contributors to air pollution and include PM₁₀, PM_{2.5}, and volatile organic compounds. While natural sources cannot be regulated or controlled, their contribution to air quality impacts need to be understood. While dust and PM₁₀ tend to have local impacts on air quality, there are times when wind-blown dust can also cause impacts over a large area. The dust storm that occurred in Melbourne on 8 February 1983 is a well-known example of this type of event. These dust events are commonly caused by strong winds after prolonged periods of drought conditions. El Niño cycle years present an increased risk of dust events occurring.

Sea salts can be a major source of PM_{2.5} and PM₁₀, particularly near the coast. They can also be found inland. A study in 2015 collated source apportionment studies from around the world and indicated that 15 per cent of PM_{2.5} measured comprised of sea salt (Karagulian et al. 2015). Sea salts are released to the air when foam bubbles along the shoreline burst and are transported inland by wind. Although there are no mechanisms to control or contain sea salt in the air, its presence needs to be considered when assessing particle movements as they can carry other air pollutants by adsorbing them onto their surface.

VOC emissions can also come from a range of biogenic or natural sources, a common source of biogenic VOC emissions are eucalypt trees (Keywood et al. 2016). A major component of biogenic VOC is isoprene, which is highly photochemically reactive (Carter 1994). As a result, the inclusion of biogenic emissions is important when modelling the formation of ozone (Bannister et al. 2011).

2.13 Major pollution incidents

Air pollutants from emergency events, such as industrial fires, can have a large impact on local communities. Pollution generated from emergency events also has the potential to cause impacts over a broad geographical region. Since the 2014, EPA has been involved in emergency response efforts by monitoring and forecasting air pollution for several large peat fires, and industrial fires at recycling plants and tyre stockpiles. These types of fires can produce emissions containing significant concentrations of PM₁₀, PM_{2.5}, carbon monoxide, nitrogen dioxide and sulfur dioxide. Each emergency event is different due to the mixture of different fuels involved and local meteorological conditions. This makes it difficult to predict the emission rate of air pollutants being generated.

Data from air monitoring during these incidents has at times resulted in incident controllers recommending the relocation of residents for periods of time. While these emergency events tend to be of short duration, their ability to have large impacts on air quality over short time periods necessitate their consideration and inclusion in the broader context of air pollution in Victoria.

A recent example of air pollution from an emergency incident was the peat fires in south west Victoria in early 2018. EPA monitored carbon monoxide and PM_{2.5} concentrations, reporting air quality data via [EPA AirWatch](#), its air quality website. This pollution event lasted for over forty days. During this period, air quality was also impacted by smoke from planned and agricultural burns.

3 Regulation of air pollution in Victoria

The *Environment Protection Act 1970* provides a legal framework to protect the environment in Victoria. It applies to air, water, land and noise emissions. The Act also establishes the Environment Protection Authority Victoria and its powers, duties and functions. The Act is supported by other regulations and policies as discussed below.

3.1 National Environment Protection (Ambient Air Quality) Measure

Established in 1998, the National Environment Protection (Ambient Air Quality) Measure (the NEPMAAQ) sets standards for seven key air pollutants: carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, lead, and particles as PM₁₀ and PM_{2.5}. The purpose of the NEPMAAQ is to set standards that provide adequate protection of human health and wellbeing. The NEPMAAQ standards are outlined in Table 2.

Table 2: National Environment Protection (Ambient Air Quality) Measure standards for pollutants

Pollutant	Averaging period	Maximum concentration	Exceedances allowed
Carbon monoxide (CO)	8 hours	9.0 ppm	1 day a year
Nitrogen dioxide (NO₂)	1 hour	0.12 ppm	1 day a year
	1 year	0.03 ppm	None
Photochemical oxidants (as O₃)	1 hour	0.10 ppm	1 day a year
	4 hours	0.08 ppm	1 day a year
Sulfur dioxide (SO₂)	1 hour	0.20 ppm	1 day a year
	1 day	0.08 ppm	1 day a year
	1 year	0.02 ppm	None
Lead (Pb)	1 year	0.5 µg/m ³	None
Particles as PM₁₀	1 day	50 µg/m ³	None**
	1 year	25 µg/m ³ ***	None
Particles as PM_{2.5}	1 day	25 µg/m ³	None**
	1 year	8 µg/m ³	None
Particles as PM_{2.5} by 2025*	1 day	20 µg/m ³	None**
	1 year	7 µg/m ³	None

*The goal of the NEPM is for the maximum concentrations for PM_{2.5} to decrease by 2025.

**Excludes exceptional events where exceedance is caused by bushfires, authorised hazard reduction burns or continental scale windblown dust in excess of normal historical fluctuations and background levels.

***Note Victoria has a more stringent annual standard of 20 µg/m³ for PM₁₀.

Under the National Clean Air Agreement Workplan, Victoria is leading a review of the NEPMAAQ standards for sulfur dioxide, nitrogen dioxide and ozone (Department of Environment and Energy 2018). This work is currently underway with the aim to present proposed standards to the National Environment Protection Council for consideration, followed by public consultation, with a view to strengthen the standards by the end of 2019 (Australian Government n.d.).

3.2 State Environment Protection Policy (Ambient Air Quality)

State Environment Protection Policies (Ambient Air Quality – SEPPAAQ and Air Quality Management – SEPPAQM) are subordinate legislation made under the provisions of the Act to provide more detailed requirements and guidance for the application of the Act to Victoria. The SEPPAAQ incorporates the air

quality standards from the NEPMAAQ. The two key differences between the SEPPAAQ and NEPM is the SEPPAAQ includes visibility as a measure of air quality and has adopted a more stringent annual standard of 20 µg/m³ in SEPPAAQ (Table 3).

Table 3: State Environment Protection Policy (Ambient Air Quality) 1999

Pollutant	Averaging period	Maximum concentration	Exceedances allowed
Visibility reducing particles (minimum visual distance)	1 hour	20 km	3 days a year

Visibility correlates well with fine particles and is a useful surrogate for PM_{2.5} when no dedicated PM_{2.5} monitoring is available. EPA reports visibility as ‘airborne particle index’ (API). EPA utilises API instead of visibility as it can be used to calculate a corresponding AQI value (see Appendix 5 for example).

API is inversely related to visibility according to the following formula: $API = 47 / \text{Visibility (in km)}$

3.3 State Environment Protection Policy (Air Quality Management)

The State Environment Protection Policy (Air Quality Management) 2001 (SEPPAQM) sets out a framework for the regulation and management of air emissions into the environment. The policy does this by setting out stack emission limits and design ground level concentrations for air pollution emission discharges from licensed premises to ensure the air quality standards in the NEPM and SEPPAAQ are achieved. In addition, the SEPPAQM aims for the cleanest air possible, while also considering the economic and social development of Victoria.

In addition to setting standards around the discharges from facilities, the SEPPAQM also allows for Protocols for Environmental Management (PEM) – these currently include the following:

- [Greenhouse gas emissions and energy efficiency in industry](#) (publication 824)
- [Minimum control requirements for stationary sources](#) (publication 829)
- [Mining and extractive industries](#) (publication 1191).

3.4 Environment Protection (Vehicle Emissions) Regulations 2013

The Environment Protection (Vehicle Emissions) Regulations 2013 aim to minimise the negative impacts of air and noise emissions from motor vehicles, and the release of petrol vapours related to the production of fuel. The regulations also prescribe air emission and noise standards for in-service vehicles (under 4.5 tonnes). A Heavy Vehicle National Law (HVNL) regulates emissions, noise and safety of in-service vehicles over 4.5 tonnes gross vehicle mass (GVM) and has been adopted in Victoria (National Heavy Vehicle Regulator 2013).

3.5 Works approvals

In Victoria, new processes that discharge a waste (including air pollutants) to the environment that increase or alter an existing discharge may be subject to a works approval. These are issued by EPA under the Act. The works approval process is designed to ensure a mix of approaches is used to manage pollution sources so that best environmental practice can be achieved, using the best available technology possible. There is also a requirement for air pollutants that are classified as highly toxic (and designated as class 3) substances in the SEPPAQM to be reduced to the maximum extent achievable prior to discharge. Compliance with the works approval process is also intended to ensure that there are suitable separations between industrial emissions. This means that suitable separations between industrial emissions and nearby sensitive receptors are in place to ensure the dispersal of pollutants.

3.6 Regulating motor vehicle emissions and fuel quality

At a national level, fuel type and quality influence vehicle exhaust emissions. Fuel standards are regulated at a Commonwealth level by the Department of the Environment and Energy under the *National Fuel Quality*

Standards Act 2000 (the Fuel Act) and the Fuel Quality Standards Regulations 2001 (the Fuel Regulations). The Fuel Act and the Fuel Regulations determine the concentrations of sulfur in fuel that is imported and manufactured in Australia. The reduction of sulfur in petrol and diesel is key to ensure the sulfur dioxide levels remain low. The current fuel standards are being reviewed to determine if Euro 6 standards are suitable with current fuel standards (IHS Advisory Services 2016).

The Commonwealth is also responsible for vehicles entering the Australian fleet. This is implemented by the Department of Infrastructure, Regional Development and Cities using the Australian Design Rules (ADR) under the *National Motor Vehicle Standards Act 1989*. ADR are national standards that includes standards for air pollutant emissions. These standards ensure that newer vehicles entering the fleet have improved fuel efficiency and have lower emissions.

VicRoads is responsible for ensuring that roads are maintained and the network is developed so that vehicles can travel efficiently, thus reducing the time that they are active and generating emissions.

3.7 Regulating wood heaters

In Victoria, the Waste Management Policy (Solid Fuel Heating) incorporates the Australian Standard AS/NZS 4013:2014, which sets the emission factor of wood heaters (the amount of PM_{2.5} emitted per kilogram of wood burnt). While the impacts of an individual wood heater may be localised, the accumulative impact of large clusters of wood heaters with relatively low discharge heights can be significant. Wood heater usage also tends to occur during winter when conditions are cold and wind speeds are generally low, which can exacerbate air quality issues (EPA Victoria 2007b).

The National Clean Air Agreement established by Australian government environment ministers in December 2015 identified health impacts of PM_{2.5} from wood heaters as a priority issue that requires addressing (Australian Government n.d.).

4 Monitoring Victoria's air quality

In Victoria, EPA uses different types of air monitoring systems for different purposes:

- General condition monitors provide EPA with information on general air quality and pollution and the assessment of trends over time and space.
- Local condition monitors are used to investigate local air quality and pollution issues.
- Incident air monitors are set up to respond to major pollution events (incidents).

Monitoring can also be used to assess changes to air pollutants because of chemical and physical processes in the atmosphere. This includes the formation of ozone as well as the formation or transformation of secondary aerosol particles such as sulfur dioxide to sulfates and oxides of nitrogen to nitrates.

4.1 General and local condition monitoring

General and local condition monitoring are used to determine long-term trends in air quality, EPA uses reference or equivalent tier methods to monitor air pollutants in its network. These methods have been tested to determine a certain level of performance and consistency across different airsheds and conditions. These methods are also generally covered by a suitable Australian Standard which defines how they should be setup and operated. Suitable methods are listed in the Schedule 3 of the NEPMAAQ.

4.2 Incident air monitoring

During air quality incidents, EPA can deploy a range of instruments. Reference and equivalent instruments can be used. However, these types of instruments often need larger, purpose-built shelters and mains power to operate, which may not be available in the first few days of an incident. As a result, incident air monitoring equipment is often designed to be operated on solar or battery power, with built in data collection and telemetry. Because of the limitation of lower power requirements, smaller sensors and light scattering techniques are often used. These smaller sensors can have a greater level of uncertainty associated with their measurements and require calibration with reference and equivalent grade instruments.

4.3 Data accessibility

The expectations of the community regarding the accessibility of air quality information in their local area have increased significantly since the start of electronic air monitoring in 1979. To be responsive to the public, EPA provides air monitoring network data on an hourly basis on EPA's website ([EPA AirWatch](#)). Data collected during an air pollution incident is also shared on EPA's website.

In Victoria, EPA does most of the air quality monitoring. However, there is an industry-run monitoring network in the Latrobe Valley, which is supported by the local power generators and Australian Paper (Latrobe Valley Air Monitoring Network n.d.). Data from this network is available at [Latrobe Valley Air Monitoring Network](#).

Data accessibility is also important for communities to be able to download and view data for themselves. EPA has started making annual datasets available on the www.data.vic.gov.au web-portal, along with other Victorian Government datasets for public viewing (data.vic.gov.au n.d.).

As part of EPA's current transformation program, it is currently undertaking a review of all its environmental monitoring programs. The outcome of this review will determine how the network can be improved to ensure Victoria's airsheds are monitored effectively and that the network continues to provide fit for purpose information to stakeholders.

4.4 Assessing and reporting air quality in Victoria

In Victoria, air quality is assessed against a set of legislated air quality standards as outlined in the NEPMAAQ and SEPPAAQ. These standards are defined by an ambient concentration and an averaging time period, which can be hourly, eight-hourly, daily or yearly. As the science and understanding of air pollution and its impacts improves, these air quality standards change over time.

The ambient air quality standards (Table 2) can be used to calculate air quality index values. The air quality index (AQI) is used to determine air quality categories. There are five AQI categories, ranging 'very good' to 'very poor'. As an index, a lower number indicates better air quality compared with a higher number. It is also possible to have an index of greater than 100 – this occurs when an air pollutant's concentration is greater than its corresponding air quality standard. The highest pollutant AQI score at an air monitoring station is taken as the station's overall air quality index.

In Victoria, a second set of PM_{2.5} categories have been developed and adopted by EPA, Department of Health and Human Services, and Emergency Management Victoria (Emergency Management Victoria 2017). These categories, often referred to on EPA's website as 'health categories', use 24-hour average concentrations rather than an index value to determine air quality. The categories also cover a greater range of high concentrations. See Appendix 1, Table 7.

The 'health categories' describe the potential health impact of PM_{2.5} pollution at different concentrations and provides advice for community and agencies to guide decision making during major smoke events or incidents. Each health category has set messaging which provides cautionary advice with suggested actions people can take to reduce their exposure to PM_{2.5} in smoke. The advice changes, depending on the category's PM_{2.5} concentration.

In Victoria, EPA reports air monitoring data in annual compliance reports as per the requirements of the NEPMAAQ. These reports provide an annual summary of air quality performance and includes the number of exceedances of the air quality standards and long-term trends. Reports are available on [EPA's website](#).

EPA uses transverse element oscillating microbalance monitors (TEOMs) to measure PM₁₀ concentrations in the ambient air. The TEOM measurement chamber is heated to 50°C to remove moisture from the sample (this can also lead to the loss of volatile and semi-volatile compounds from the sample). Hourly data is reported directly from the instrument, although the daily or 24-hour average data is sometimes corrected. This correction is applied on cold days, as this is when the loss of volatiles occurs, which increases the reported concentration. Data in this report has been corrected as per the method outline by NEPC (National Environment Protection (Ambient Air Quality) Measure Peer Review Committee 2001).

4.5 Air quality in Melbourne and Geelong

The Port Phillip airshed is nominated as the main region for monitoring and reporting for NEPMAAQ purposes; this includes the greater Melbourne and Geelong areas. The Port Phillip region covers approximately 24,000 km² and extends from Creswick (NW corner) to Buxton/Marysville (NE corner) in the north, and from Kennett River (SW corner) to Inverloch (SE corner) in the south. Figure 6 shows the location of EPA's NEPM air monitoring stations, along with population distribution.

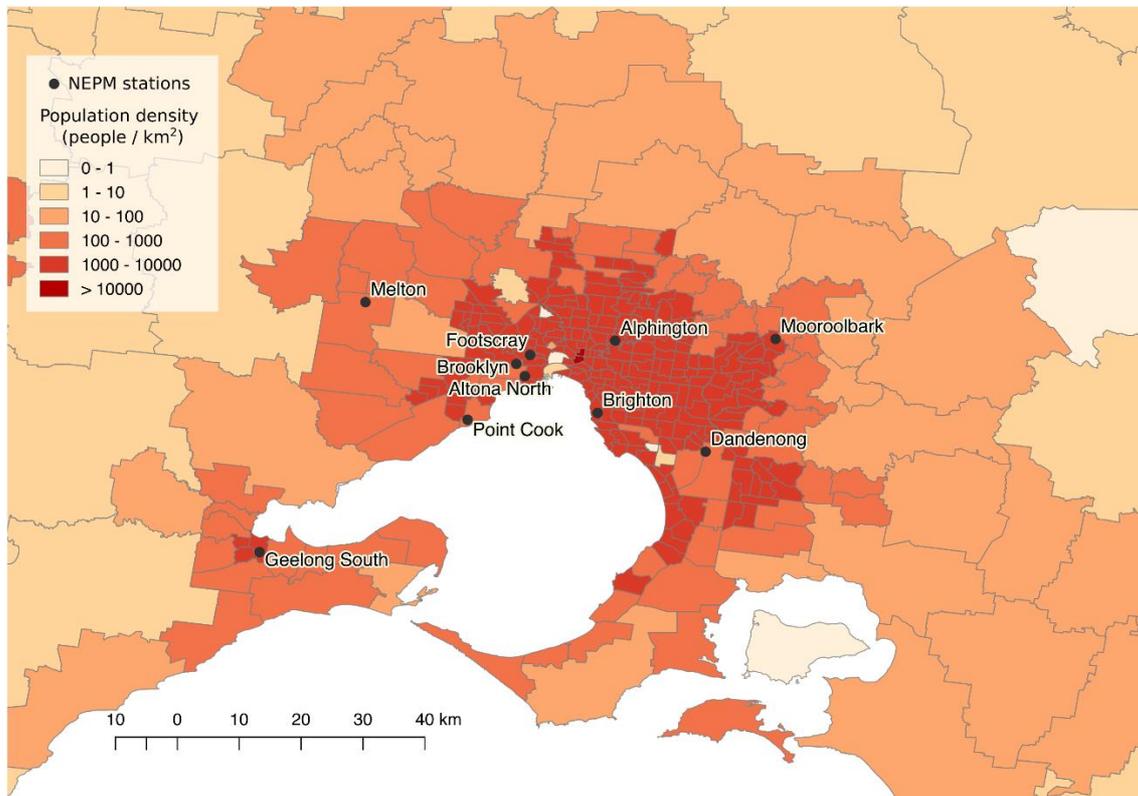


Figure 6: Population density in Greater Melbourne and Geelong with NEPM monitoring stations

Port Phillip Bay is the main geographic feature in the Port Phillip region. The region includes coastal areas, including the city of Melbourne and some plains, parts of which are bordered by mountains. The Dandenong Ranges are 30 km east of Melbourne and rise to about 700 m as shown in Figure 7. This topography allows down-slope (katabatic) winds to develop in the morning and up-slope (anabatic) winds with bay and sea breezes in the afternoon, when the regional scale pressure gradient is weak. The topographic features of the Port Phillip region can result in recirculation of air due to offshore breezes followed by onshore breezes; on rarer occasions an eddy, commonly referred to as the Spillane Eddy (Spillane 1978), may form.

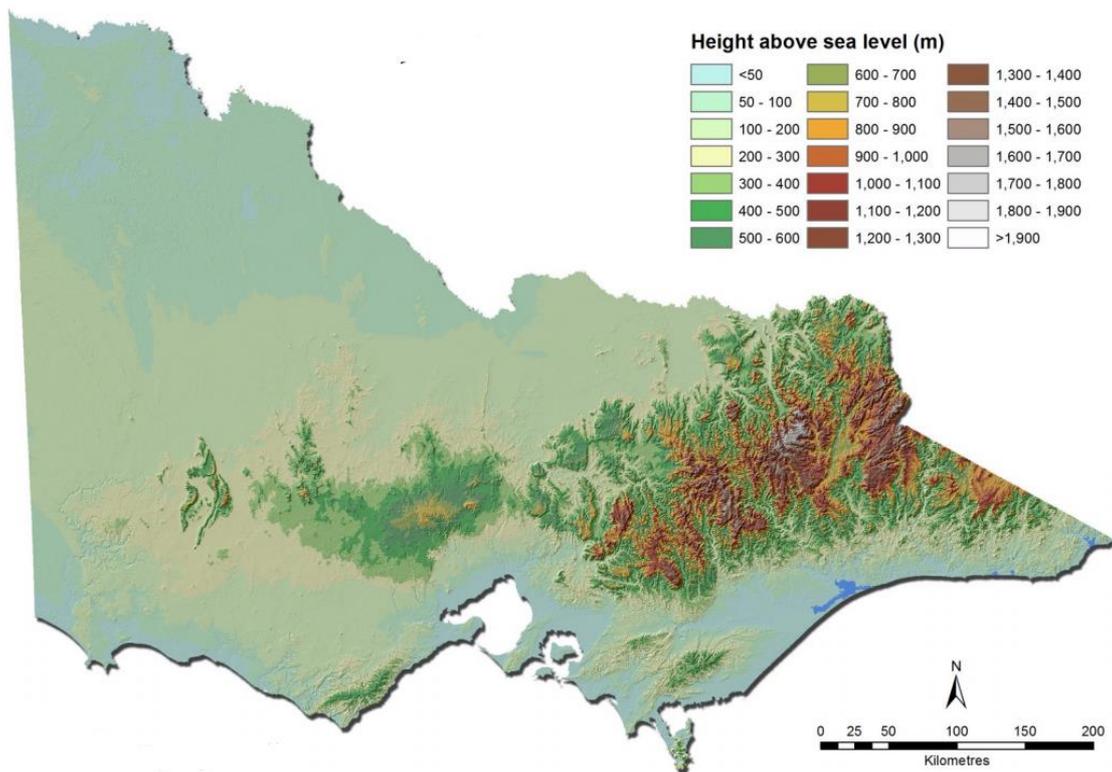


Figure 7: Elevation about sea level in Victoria (Source Victorian Resources Online www.depi.vic.gov.au/vro)

Air dispersion patterns are strongly influenced by Port Phillip Bay and the surrounding hills. Night-time katabatic flows can move pollutants towards Port Phillip Bay and restrict the extent they disperse vertically. During summer and autumn, ozone generated from these pollutants can be carried to Melbourne suburbs by afternoon sea breezes. These air flow patterns are a major mechanism for ozone events.

Despite Melbourne's population growth, Australian cities and urban centres are isolated by world standards, which means that long-range transport of air pollutants from other locations tend not to be a significant source (Tory et al. 2000). However, there have been episodes of smoke from fires reaching adjoining states. For example, smoke from fires in north-west Tasmania in January 2016 were transported across the Bass Strait and affected Melbourne's air quality.

The results of monitoring conducted at four monitoring stations across the Melbourne region during 2016 is shown in Figure 8 and also in Appendix 1, Table 8 and Table 9. In general, air quality at EPA's monitoring stations has been in the 'good' to 'very good' air quality categories at least 75 per cent of the time, meaning air quality is typically good. However, the results also show that at some air monitoring stations, there are up to 38 days in a year where there is an hour or more when air quality does not meet the 'good' air quality category.

Air pollution in Victoria – a summary of the state of knowledge

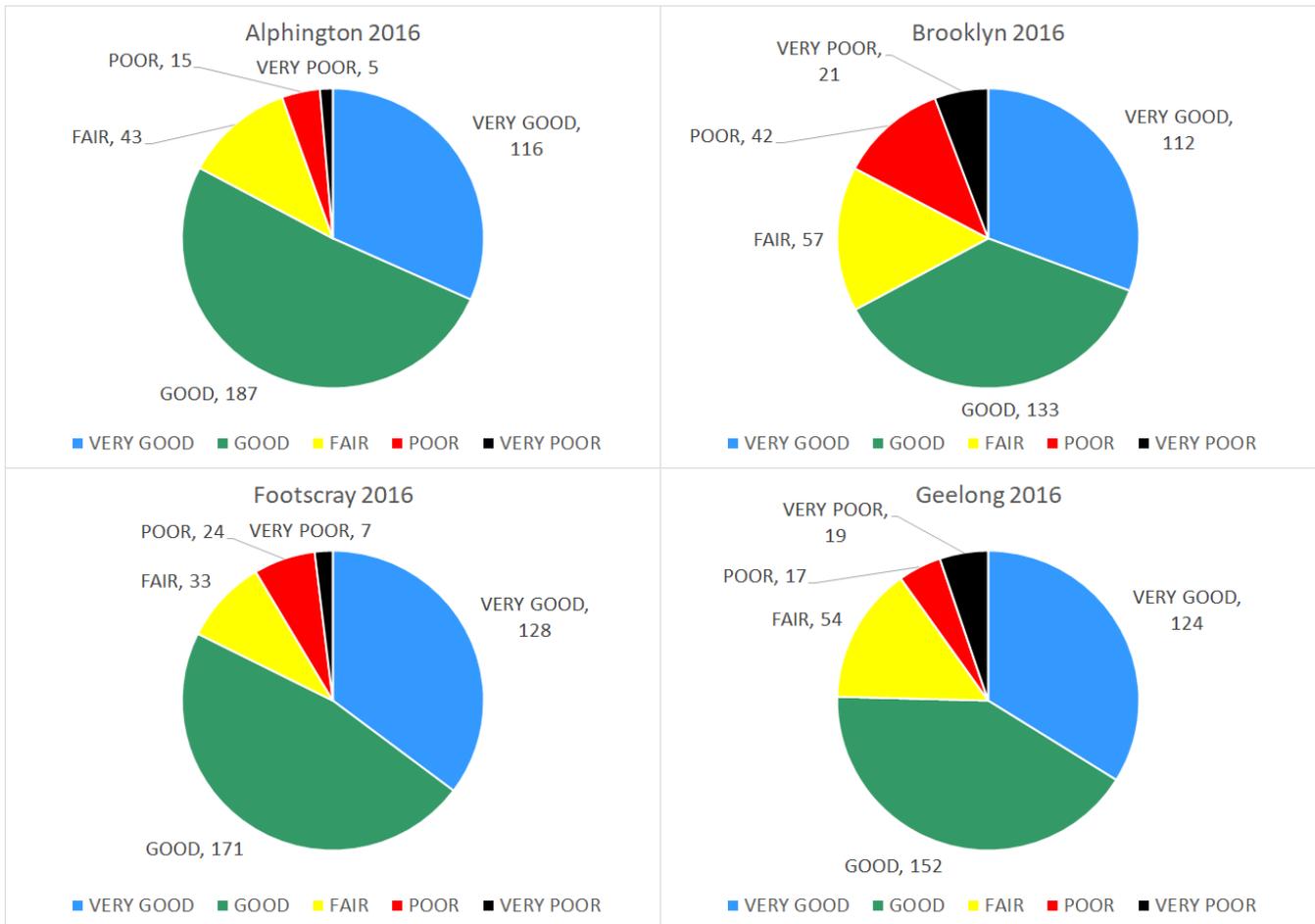


Figure 8: Number of days in different air quality categories at Alphington, Brooklyn, Footscray and Geelong monitoring stations in Port Phillip Region 2016

Local sources of pollution can have a significant influence on the data collected. This is particularly true for PM₁₀ where local dust sources can dominate measured concentrations. Dust generation activities on sites, such as crushing, digging, truck and earth moving machinery traffic on unsealed roads, and traffic from unsealed carparks can reduce air quality; this leads to an increase in days where air quality does not meet the ‘good’ air quality category. The Brooklyn air monitoring station was set up in response to community concerns about dust and PM₁₀ from an industrial estate to the north of the area. Monitoring indicated that two heavily used unsealed roads in the estate were major sources of dust pollution. Although these roads have now been sealed, there continues to be other unsealed surfaces and activities which contribute to dust and PM₁₀ in the area, necessitating continued monitoring in the area.

The Geelong monitoring station is adjacent to an unsealed carpark in the Geelong showgrounds. As a result, there is a strong association between days of high activity at the showgrounds and days when air quality at the station is impacted by raised dust and PM₁₀. The location of the station represents a challenge as it is sometimes not representative of air quality in the broader Geelong area. The data from the station does indicate, however, that localised pollution issues sometimes affect the site and that people near the showgrounds may be exposed to high levels of PM₁₀ pollution.

4.6 Latrobe Valley

The total population of the Latrobe Valley airshed, which includes the urban centres of Traralgon, Moe and Morwell was 275,000 in 2016 (Australian Bureau of Statistics 2016). The western end of the southern boundary is defined by the boundaries of the shires of Baw Baw and Latrobe and follows the ridge of the Strzelecki Ranges, which forms a natural boundary for the airshed. The airshed extends to the north-west corner (AMG 402E, 5800N), extending 129 km to the east and 54 km to the south at the eastern end.

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Air dispersion patterns are strongly influenced by the shape and topography of the area which is defined by a valley. There is a generally westerly air flow through the valley, although night-time katabatic flows can move pollutants towards the towns of Moe, Morwell and Traralgon.

Air quality at EPA’s monitoring stations in the Latrobe Valley has been in the ‘good’ to ‘very good’ air quality categories for at least 75 per cent of the time (Figure 9), which is similar to air quality in the Melbourne and Geelong region (Appendix 1 Table 10 and Table 11).

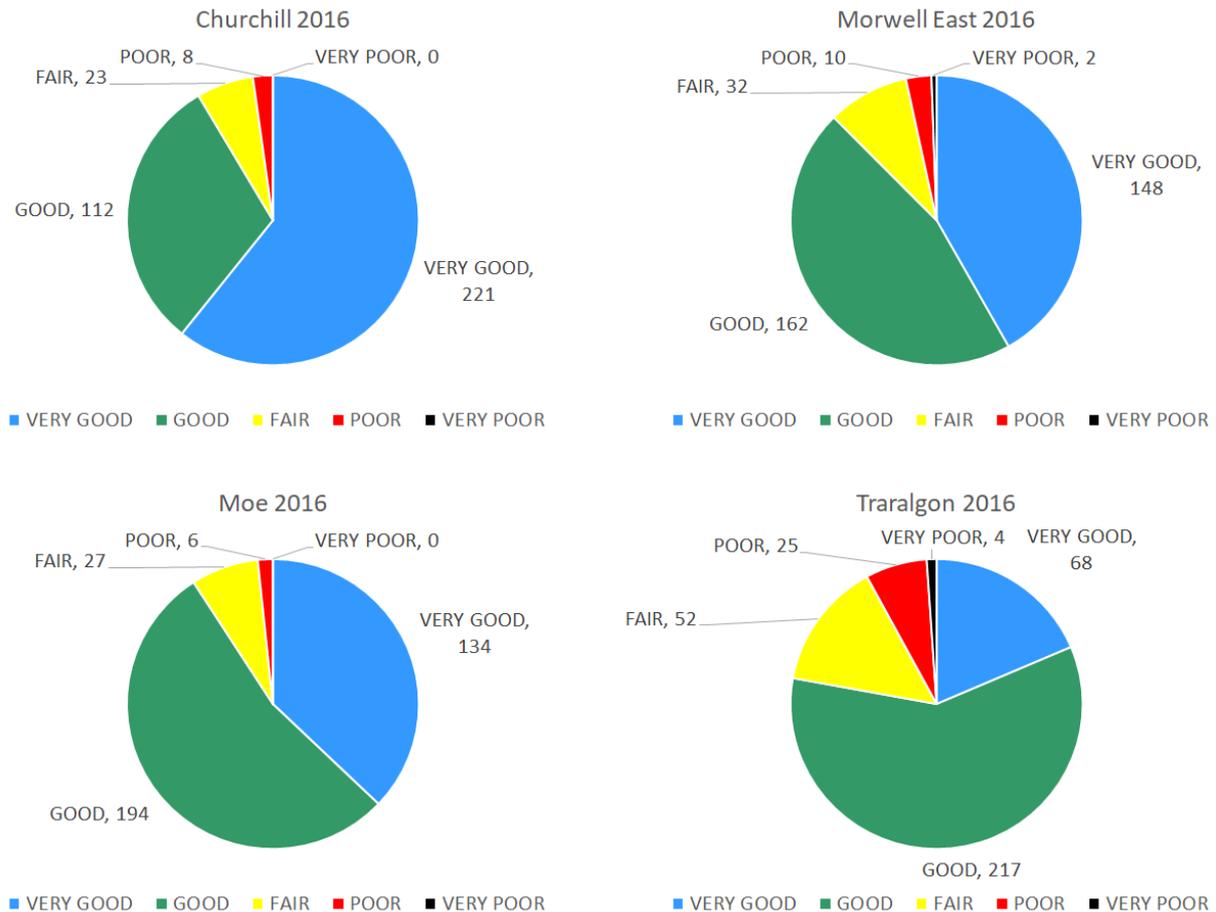


Figure 9: Number of days in different air quality categories at Churchill, Moe, Morwell East and Traralgon monitoring stations in Latrobe Valley region 2016

4.7 Regional Victoria

Regional air quality is currently not extensively monitored, however various regions have had limited monitoring during discrete periods. Since 2003, EPA has carried out some local conditions monitoring in some regional locations. PM_{2.5} is currently monitored at Wangaratta. Population densities around Victoria are shown in Figure 10.

4.7.1 Wangaratta

EPA monitors at Wangaratta using a light scattering technique which is of the same type used to measure pollution during incident response monitoring. A significant difference in PM_{2.5} concentrations in Wangaratta between 2016 and 2017 was observed, with a much higher number of days reaching the ‘poor’ to ‘very poor’ air quality categories in 2017. As a result, only 57 per cent of days in 2017 were consistently in the ‘good’ to ‘very good’ air quality categories. Most of these days of poor air quality have been attributed to planned burns and domestic wood heaters in winter (Appendix 1 Table 10 and Table 11).

4.7.2 Warrnambool, October 2006 to October 2007

PM₁₀, ozone and visibility at Warrnambool from October 2006 to October 2007 were measured. The PM₁₀ standard was exceeded on three days and the visibility standard on 13 days. The ozone standard was met during the 12-month period. One day of poor visibility was attributed to winter wood heater smoke and the others were attributed to bushfires. At other times, air quality was comparable with other parts of Victoria (EPA Victoria 2008a).

4.7.3 Mildura, December 2004 to June 2006

PM₁₀ at Mildura was measured between from December 2004 to June 2006. Over 18 months, the PM₁₀ standard was exceeded on 38 occasions – 26 days were attributed to dust storms; six days attributed to winter wood heater smoke; and three days were attributed to bushfires. There were also three days of PM₁₀ exceedances which could not be attributed to a specific source. The high frequency of dust events is related to Mildura's proximity to desert areas and strong winds associated with cold fronts which travel west to east across southern Australia (EPA Victoria 2008b).

4.7.4 Ballarat, August 2005 to August 2006

Visibility was measured in Ballarat using nephelometry from August 2005 to August 2006. Over the 12-month period, the visibility standard was not met 30 times – 23 days were attributed winter wood heaters; five days were attributed bushfires; and two days could not be attributed to a specific source (EPA Victoria 2007a).

4.7.5 Bendigo, May 2004 to July 2005

EPA monitored PM₁₀ at Bendigo from May 2004 to July 2005 and during this period, the PM₁₀ standard was exceeded four times – three days in winter were attributed to wood heater smoke and one day was attributed to wind-blown dust due to dry conditions and elevated temperatures (EPA Victoria 2006).

4.7.6 Shepparton, December 2003 to December 2004

PM₁₀ at Shepparton was monitored from December 2003 to December 2004. The PM₁₀ standard was exceeded on one day during this period. This was attributed to widespread wind-blown dust as elevated PM₁₀ was also detected the same day at EPA's monitoring stations in Collingwood and Geelong (EPA Victoria 2005).

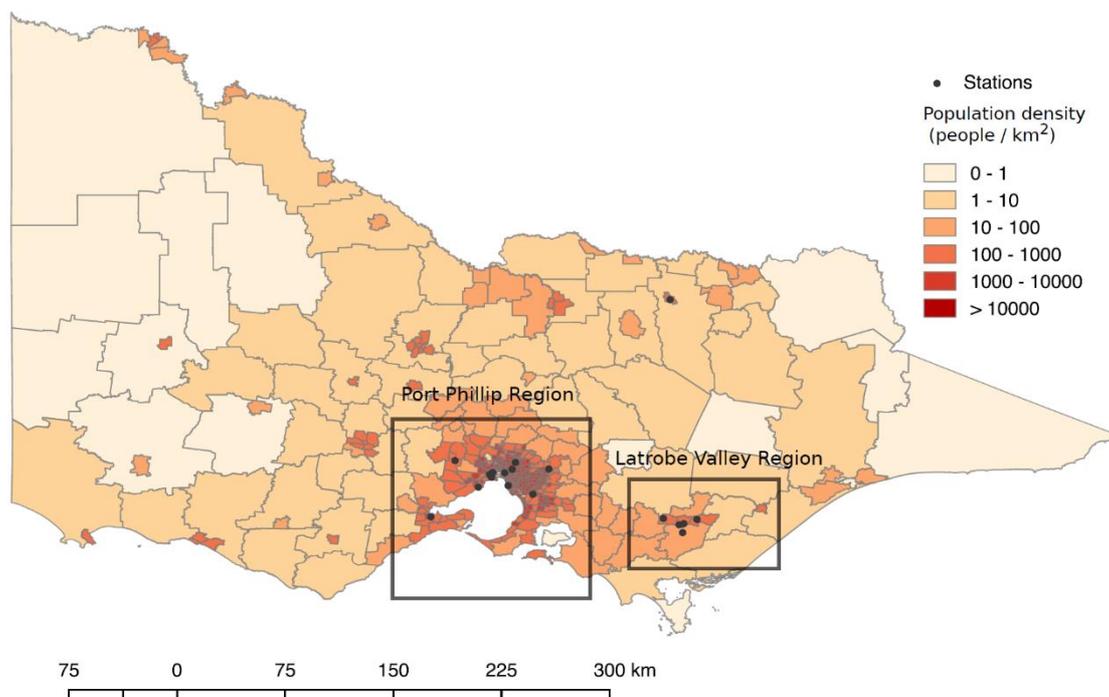


Figure 10: Location of monitoring stations and population density

5 Trends in air quality

5.1 Particles as PM₁₀

Since 2009, there has been a reduction in the number of days where PM₁₀ has exceeded standards at NEPMAAQ air monitoring stations. This trend excludes data from Brooklyn, which is strongly influenced by a local source of PM₁₀ pollution. The years 2003 and 2006–2009 were heavily impacted by major bushfires and planned burns (Figure 11). These years were also associated with prolonged drought conditions (Albert et al. 2013) which contributed to PM₁₀ associated with dust events.

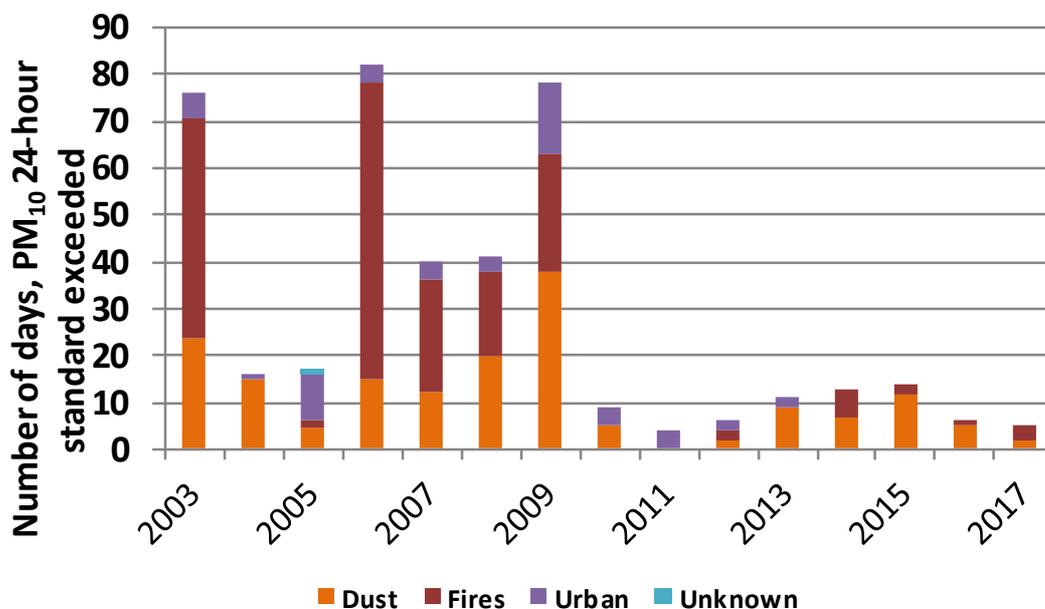


Figure 11: Source attribution of PM₁₀ events at Port Phillip NEPM monitoring sites (2002–2017)

Source attribution can be used to determine likely sources of particles, which helps determine the most suitable interventions to reduce particles in the atmosphere. In general, where the monitoring measurements are greater than two standard deviations from the long-term average at the Footscray monitoring station (Figure 12), elevated concentrations are more likely. PM₁₀ concentrations tend to be elevated during in summer due to lower rainfall and strong winds. As PM₁₀ also includes the PM_{2.5} fraction, PM₁₀ concentrations will also be elevated during pollution events such as bushfires (Figure 11).

Source attribution can also be used to compare monitoring data from different locations using network stations. Footscray and Brooklyn are located to the west of Melbourne and are approximately 3 km apart. Footscray is a long-term ambient monitoring station. Brooklyn was installed as part of local conditions monitoring to monitor and address dust and odour issues from the industrial estate to the north west of the monitoring station. The results of monitoring from the two locations show a substantial difference, despite being only 3 km in distance from each other (Figure 12 and Figure 13). In Figure 13, elevated PM₁₀ concentrations detected at Footscray which coincide with high readings at Brooklyn have been highlighted in purple. These occurrences of elevated PM₁₀ are likely to be associated with broader scale air quality issues due to dust or fires. Footscray has fewer concentrations of PM₁₀ above 50 µg/m³, whereas Brooklyn has many readings exceeding the 50 µg/m³ concentrations. This demonstrates the importance of local sources to airshed concentrations and supports the need for well-designed and agile air monitoring networks that can adapt to these local pollution impacts.

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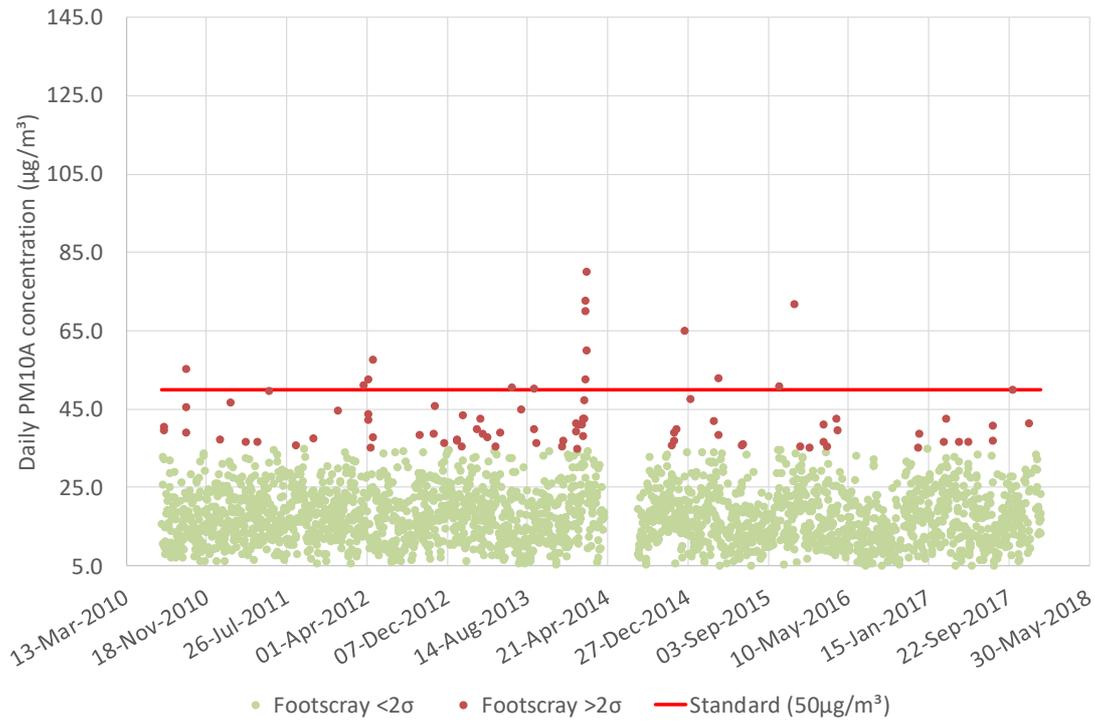


Figure 12: Seasonal Variation in PM₁₀ at Footscray highlighting values greater than 2 standard deviations (σ) away from the mean concentration (µg/m³)

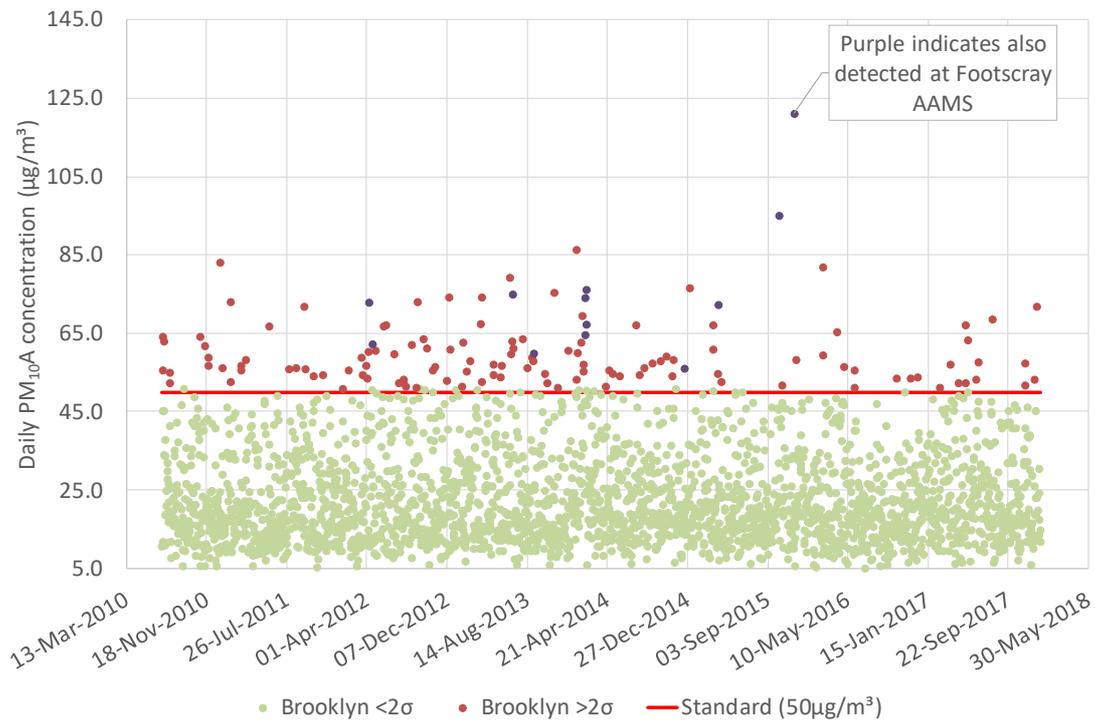


Figure 13: Seasonal Variation in PM₁₀ at Brooklyn highlighting values greater than 2 standard deviations (σ) away from the mean concentration (µg/m³)

5.2 Particles as PM_{2.5}

Victoria experienced an increase in the number of days where the PM_{2.5} daily standard of 25 µg/m³ was exceeded in 2017, with most exceedances attributed to urban sources (Figure 14).

When comparing PM₁₀ sources in Figure 11 with PM_{2.5} sources in Figure 14, a discrepancy in source attribution is observed. This is due to different sources contributing PM₁₀ compared with PM_{2.5}, the latter being produced principally by combustion processes. Other factors which may explain the results are that there have historically been more stations in the NEPMAAQ network monitoring PM₁₀ compared with PM_{2.5}, with only the Partisol manual reference method available for measuring PM_{2.5} prior to 2015. This instrument ran on a one-in-three-day sampling schedule, which means sampling did not occur some days. See Appendix 4 for information on the different monitoring methods.

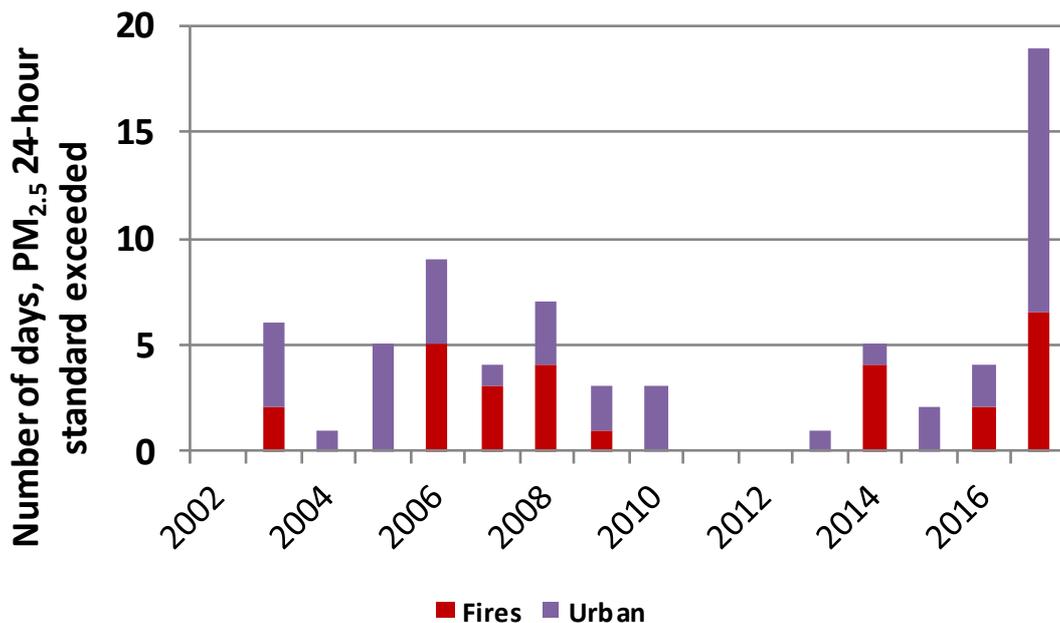


Figure 14: Source attribution of PM_{2.5} events at NEPM monitoring sites (2002-2017)

Source attribution is based on additional sources of information (including time of year, local meteorological conditions, proximity to local sources) to determine likely PM_{2.5} sources. For example, it is unlikely that domestic wood heaters would contribute to PM_{2.5} pollution in the middle of January. However, different sources of PM_{2.5} can occur concurrently. For example, in late June 2017, it is possible that both planned burns and domestic wood heaters could contribute to PM_{2.5} pollution. Domestic wood heaters are estimated to be the primary urban source of PM_{2.5} during winter, noting that there is limited particulate matter characterisation verification available. This source attribution was determined by comparing hourly PM_{2.5} data with average and minimum temperatures and looking for concentration patterns consistent with that shown in Figure 14.

Monitoring results greater than two standard deviations from the long-term average at the Alphington monitoring station is shown in Figure 15. Excluding days which are greater than two standard deviations from the mean, the data indicates that there has been little change in PM_{2.5} concentrations in recent years, although the increase in PM_{2.5} events in 2017 could signal an increase in the future.

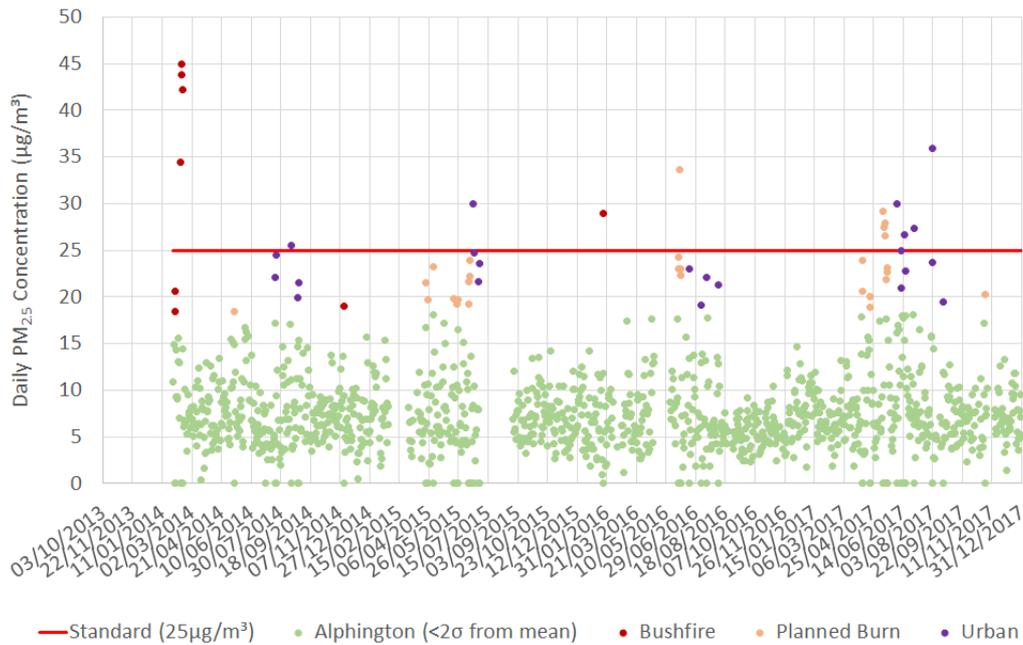


Figure 15: Source Attribution of PM_{2.5} at Alphington 2014–2017 highlighting values greater than 2 standard deviations (σ) away from the mean concentration (µg/m³)

Elevated PM_{2.5} concentrations on days with low winds, medium humidity and mild temperatures can often be attributed to planned burns, as these are the optimal weather conditions used to conduct planned burns. If hourly data is available, it can also be used to help determine likely sources of PM_{2.5}. For example, planned burns tend to occur in the late morning and early afternoon, so increases of PM_{2.5} during these periods can indicate that the likely source is planned burns. Hourly data can also be used to identify urban sources of PM_{2.5} such as domestic wood heating. An example is shown in Figure 16 where the hourly concentrations at Alphington peaked in the evening and decreased during the day. The determination of likely sources is a qualitative process which considered a range of potential indicators. Meteorological indicators associated with wood heater use are cold, low wind conditions where the ambient temperature is less than 8 °C. The timing of peaks can be another indicator that the source is from wood heaters, as early morning and late evening peaks correspond to times when people are more likely to be at home and using their wood heaters.

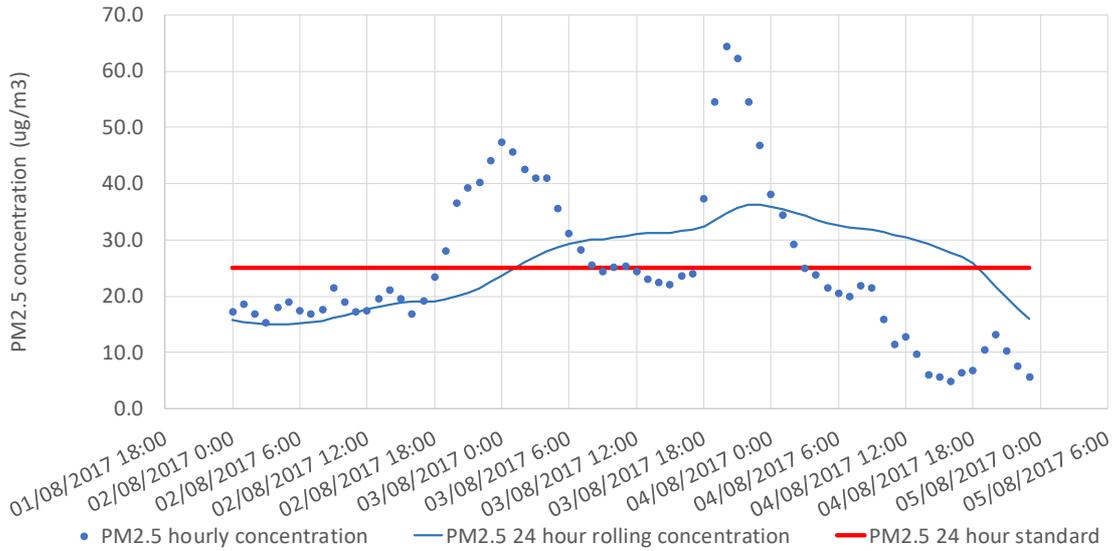


Figure 16: Source attribution of PM_{2.5} based on hourly data collected at Alphington for wood heater source

5.3 Ozone

In the Port Phillip Region, there are several events and meteorological patterns that lead to high ozone events and concentrations. These include:

- sufficient concentrations of precursor chemicals (total volatile organic compounds and oxides of nitrogen)
- multiple days where the maximum daily temperature greater than 30 °C (Figure 17)
- light N-NE wind (either synoptic or katabatic), followed by a bay or sea breeze, sometimes compounded by the Spillane Eddy.

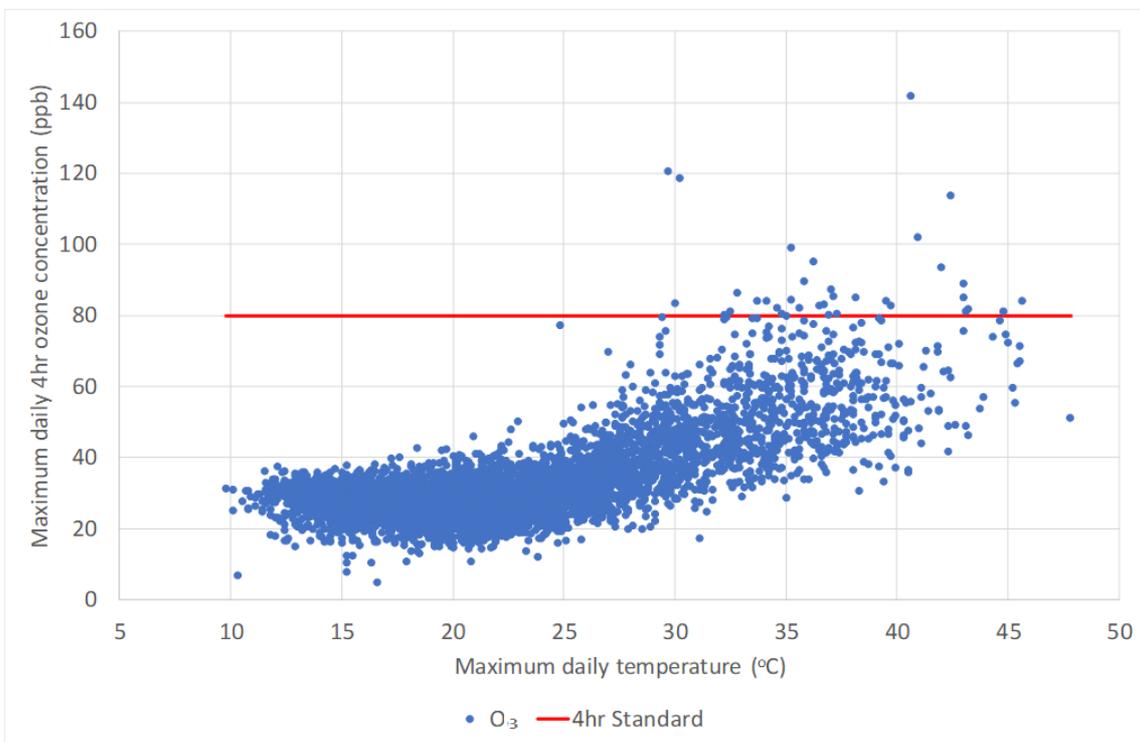


Figure 17: 4hr Ozone maximums versus daily temperatures 2002–2017

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An indicator of the formation of ozone is daily maximum temperature, as exceedances of the four-hour ozone standard tend to only occur when the maximum temperature is greater than 30 °C (Figure 17). Higher concentrations of ozone have also been observed when there are very light winds. This is caused by a direct balance between synoptic and sea-breeze effects, leading to the trapping of precursor chemicals; this forms ozone that stagnates in the air. Occasionally, light synoptic winds, and bay and sea breezes result in the Spillane Eddy, which can increase ozone concentrations, but this is a less common cause of elevated ozone.

Between 1980 and 2017 (Figure 18) ozone concentrations annual average ozone concentrations have increased. At the same time, the maximum one-hour concentrations are decreasing (Figure 19).

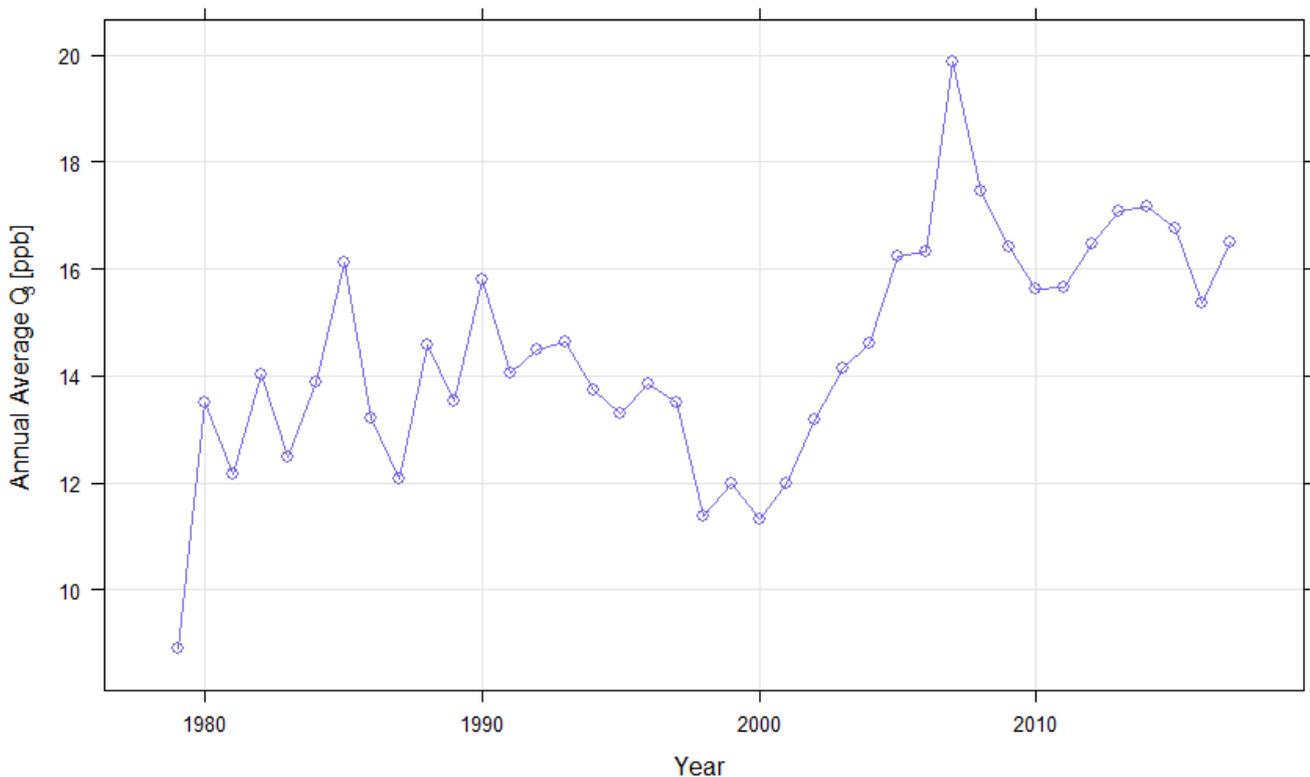


Figure 18: Ozone – annual average of long-term Melbourne sites has slowly increased from 1979–2017

During 2007, average ozone concentrations were higher than expected with several factors likely to explain the results:

- Melbourne was unusually hot during 2007 – higher temperatures generally lead to increased formation of ozone.
- Less cloud cover during the year – increased sunlight is typically associated with increased formation of ozone.
- Major bushfires in Victoria and Tasmania during January and February 2007 – these bushfires produced additional precursor air pollutants which would have contributed to the increase of ozone (EPA Victoria 2013).

Despite an increase in annual average ozone concentrations in Melbourne from 1979 to 2017, there has been a general decrease over time of the maximum peak 1-hour concentrations of ozone measured in Melbourne since the 1980s (Figure 19). Peak summer smog ozone events have decreased due to fewer precursor air pollutants being emitted by industry and transport sources. However, as the annual average ozone concentrations are increasing, there continues to be a need for ozone monitoring and increased understanding of the sources which contribute precursors to ozone formation into the future.

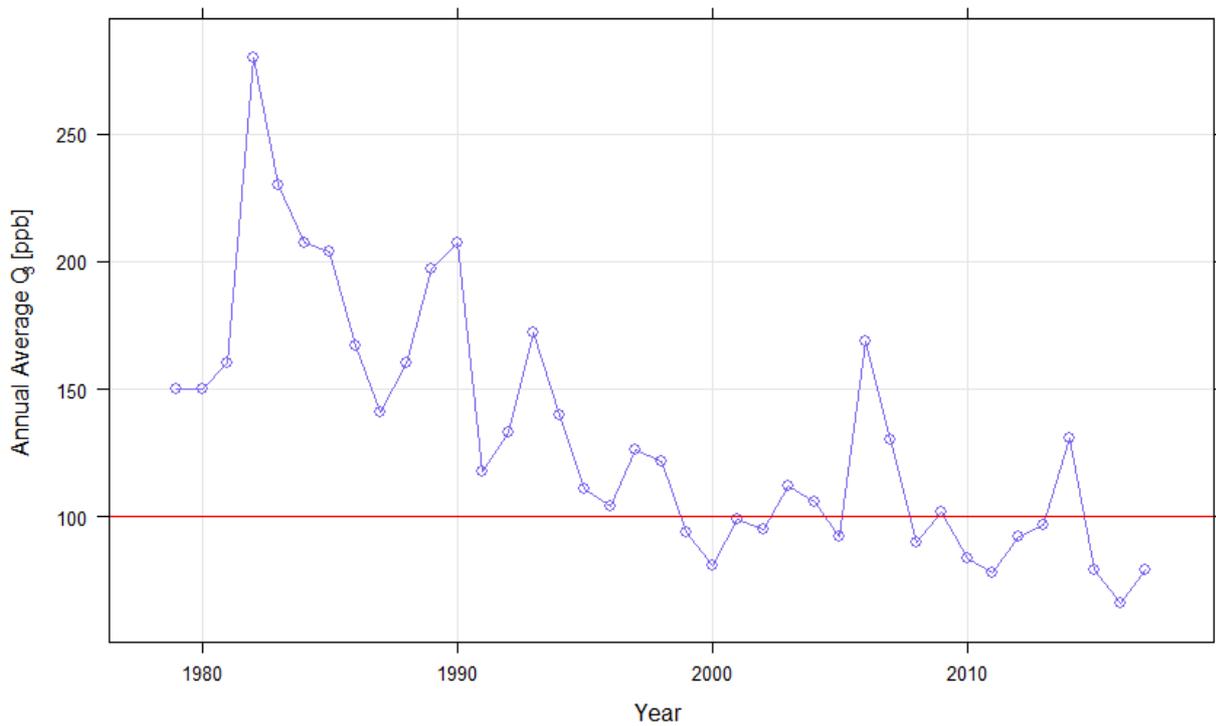


Figure 19: Ozone – highest 1-hour average ozone measured in Melbourne each year since 1979

There have been few exceedances of ozone over the last few years and most have been associated with large bushfires (Figure 19). As a result, despite relatively low ozone concentrations, ozone continues to be an air pollutant of concern for Victoria in most years. With predictions of higher temperatures and less rain increasing the risk of bushfires (Commonwealth of Australia 2016a), there is the potential risk for higher ozone concentrations in the future.

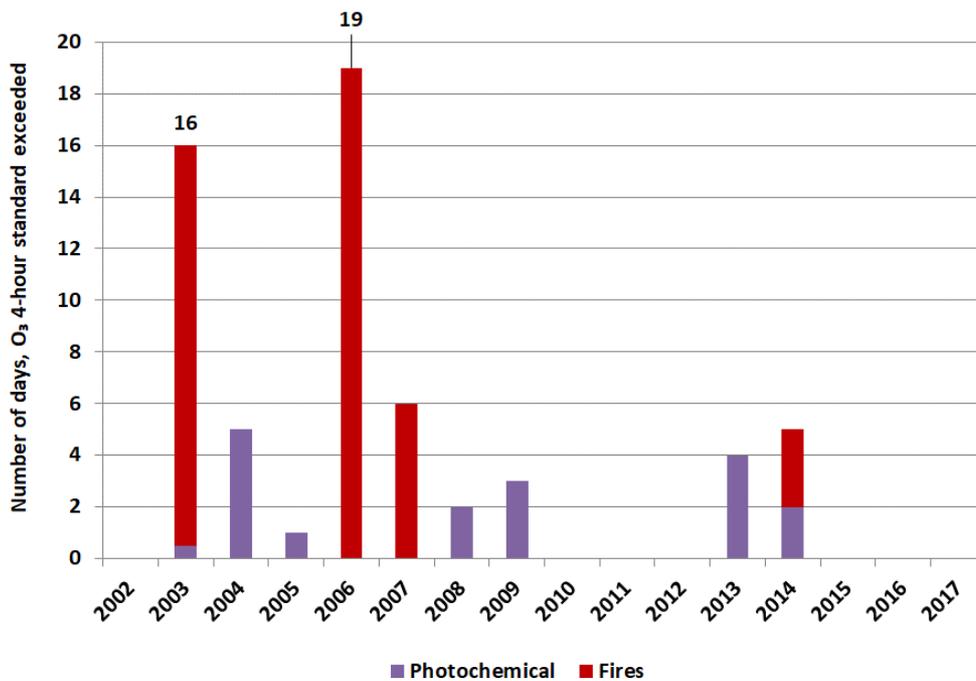


Figure 20: Source attribution of ozone events at Port Phillip NEPM monitoring sites (2002–2017)

5.4 Other pollutants

EPA's monitoring as reported in the annual NEPMAAQ compliance reports indicate that concentrations of carbon monoxide, nitrogen dioxide and sulfur dioxide occur at low levels. The review of the ozone, nitrogen dioxide and sulfur dioxide air quality standards will consider a range of factors including health effects and achievability against current and proposed standards in making recommendations for final standards.

While nitrogen dioxide concentrations have increased marginally over the last five years, the long-term trends indicate an overall decrease since 1996. Annual average concentrations of nitrogen dioxide continue to be significantly below the current air quality standard (Figure 21).

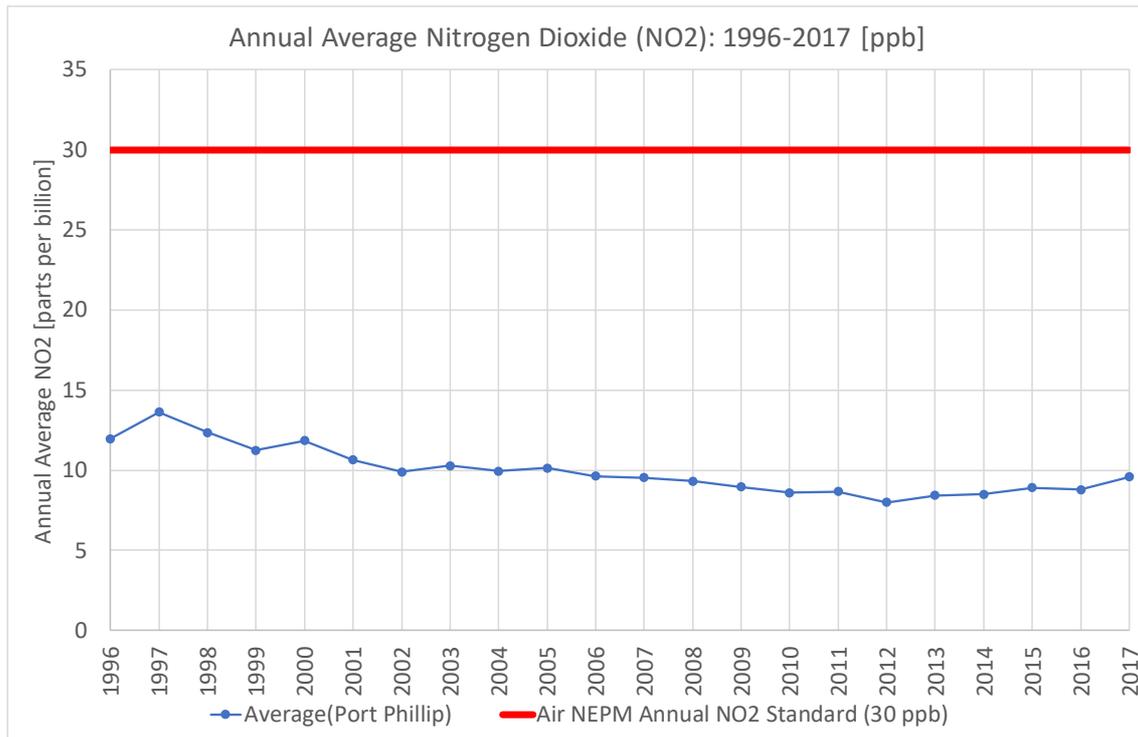


Figure 21: Nitrogen dioxide – average of long-term Melbourne sites

Ambient concentration of sulfur dioxide is also typically very low in Melbourne (Figure 22). However, at locations where there are local sources of sulfur in processes such as fuel refining, such as at Altona North (Figure 22), there can be higher concentrations of sulfur dioxide than ambient background levels. Nonetheless, concentrations at Altona North are still low compared with the AAQNEPM sulfur dioxide annual standard.

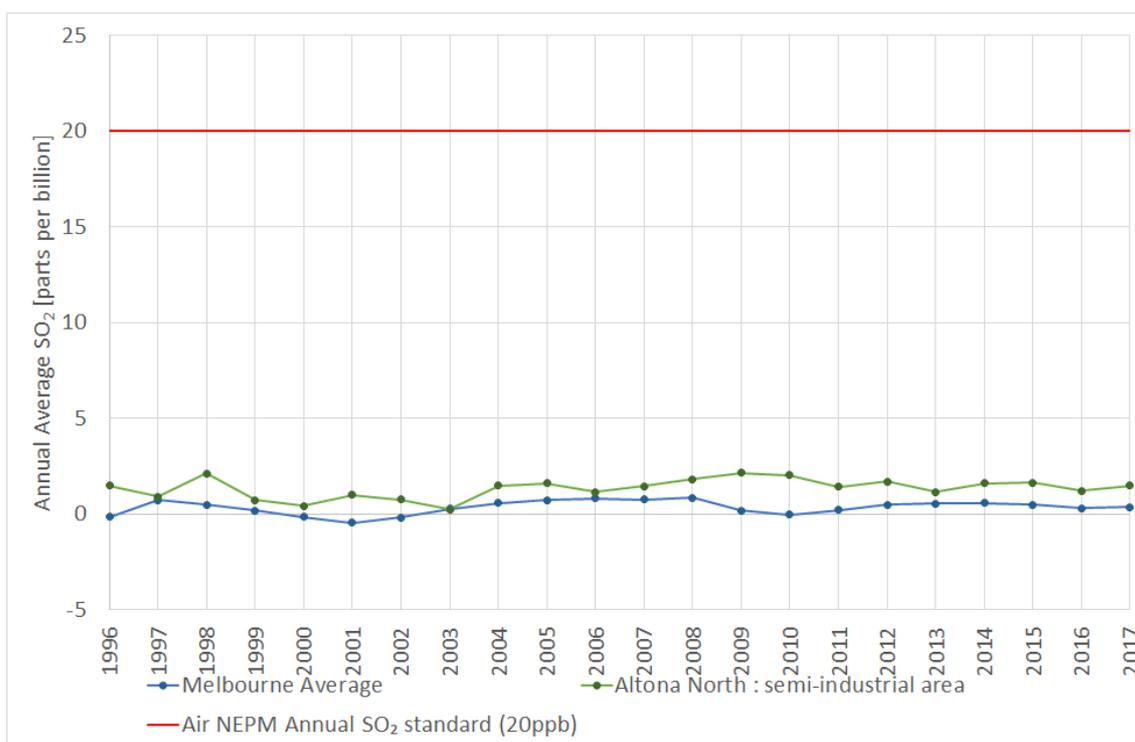


Figure 22: Sulfur dioxide – annual average of long-term Melbourne sites and Altona North which has a local source of SO₂, 1996–2017

6 Air pollution and health

6.1 Introduction

This chapter presents a summary of the epidemiological evidence in relation to air quality and health, and outlines some of the new evidence about exposure to air pollutants and health effects that has emerged in the last few years. It also discusses studies that have investigated potential health benefits of interventions aimed at reducing air pollution. Health effects of indoor air pollution (from sources such as cooking, heating, and incense burning) are not included.

There is a large body of evidence that demonstrates that air pollution, even at concentrations below the current air quality standards, is associated with adverse health effects (Brook et al. 2014; WHO 2006; Lim et al. 2012; US EPA 2009; Burnett et al. 2014). The strongest evidence relates to premature mortality and effects on the respiratory and cardiovascular system. In 2013, the International Agency for Research on Cancer classified outdoor air pollution and particulate matter as carcinogenic to humans (IARC 2016).

Particulate matter is estimated to be the individual pollutant responsible for the largest burden of disease from outdoor pollution (GBD Risk Factors Collaborators 2017). This is mainly due to its effects on the cardiovascular and respiratory system as the small particles can penetrate deep in to the lung (GBD Risk Factors Collaborators 2017). In fact, on a global scale, ambient particulate matter is estimated to be responsible for approximately 4.1 million premature deaths (7.5 per cent of global deaths). These deaths are largely caused by chronic lung diseases and lung cancer, heart disease and stroke, and respiratory infections. Ozone was estimated to be responsible for 234,000 deaths from chronic lung disease. Ambient particulate matter (PM₁₀ and PM_{2.5}) was the sixth highest risk factor for global mortality in 2016. The first five risk factors were high blood pressure, smoking, high-fasting plasma glucose, high body mass index, and high total cholesterol. Ozone was 33rd on this ranked list of risk factors of mortality (GBD Risk Factors Collaborators 2017).

In Victoria, the main sources of pollution are from traffic, power generating industries, and smoke episodes from bushfires. On a more local scale, planned burns, peat fires, coal mine fires and emissions from local industry can result in large exposures of nearby communities (Table 1, section 2.1).

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Outdoor air pollution is a complex mixture of pollutants that often have similar sources which generally result in a high correlation between pollutants. This can make it difficult to determine the health effects attributable to individual air pollutants. However, PM₁₀, PM_{2.5} and ozone are of most concern in Victoria, as these pollutants present in the highest concentrations with relation to the air quality standards (EPA Victoria 2017) (see section 3.1), and they have well-documented adverse health effects such as premature mortality, and acute and chronic respiratory morbidity (WHO 2006; Jerrett et al. 2009; Peng et al. 2013).

6.2 Population level impacts and susceptibility

Most epidemiological studies that investigate the association between air pollution and health have used existing health registries, such as mortality registries, and registries of hospital admissions and emergency presentations to establish an association. These are all high-level health outcomes in the pyramid of health effects (Figure 23), meaning they are the least common but have the most severe health effects. There are a whole range of effects that are less severe and are generally not captured by existing health registries, such as symptoms, and sub-clinical health effects. Generally, the only way to measure these less severe health effects are by collecting information on individuals, such as blood markers of inflammation or coagulation which can indicate an effect on the heart, or exhaled nitric oxide which can indicate lung inflammation. Therefore, the studies of the higher-level health outcomes are very informative, but it is important to consider that these only include a small part (the tip of the pyramid) of the wide range of health effects of air pollution.

The impacts on individuals exposed to similar levels of air pollutants can vary considerably, depending on their susceptibility to the effects of air pollutants. Individuals that are generally considered to be more susceptible are those who have existing lung or heart disease, the young and the elderly (Pope et al. 2006).

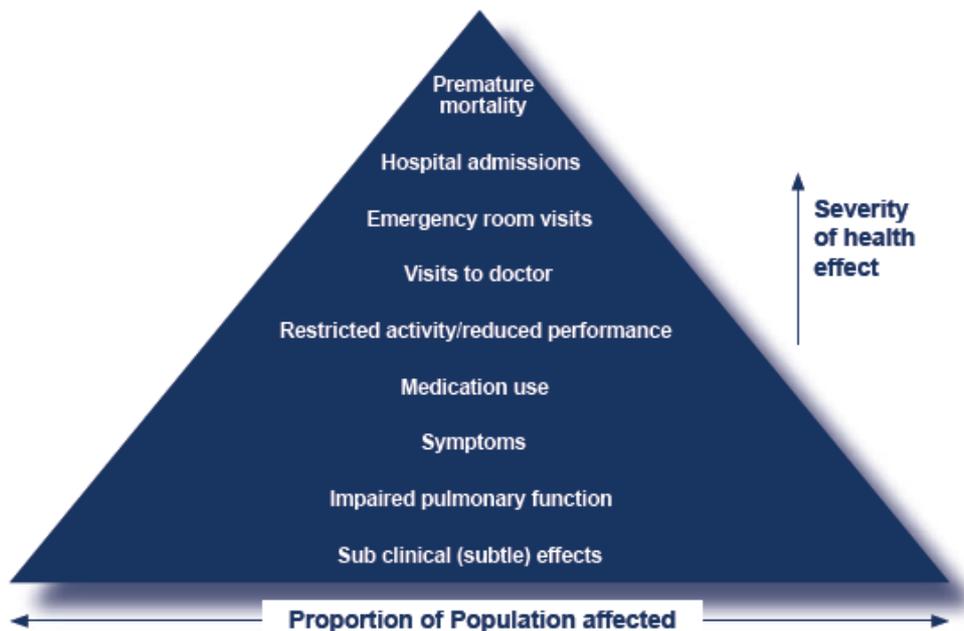


Figure 23: The air pollution health effects pyramid (Dennekamp & Abramson 2011; adapted from ATS 2000)

6.3 Ambient particulate matter

PM_{2.5} is a component of PM₁₀ and both size fractions show clear evidence of being associated with health effects, with PM_{2.5} generally showing stronger associations. Ultrafine particles (UFP), which are a subset of PM_{2.5}, are much smaller and can therefore penetrate further into the lungs. They can only be measured by number due to their small size and are therefore more difficult to measure. Unlike PM_{2.5} and PM₁₀, UFPs are not regulated. A smaller number of studies have investigated the health effects of UFPs. There is some evidence that there is an association of UFPs with cardiovascular health effects (HEI 2013; Pieters et al. 2015; Stone et al. 2017). In epidemiological studies, it is difficult to determine whether UFPs have

independent effects, with more research needed. This section will therefore focus on the health effects of PM_{2.5}.

Systematic reviews and meta-analyses investigating the association between PM_{2.5} and effects on health have mainly focused on effects on the respiratory and cardiovascular system. There is clear evidence that there is an association between increases in daily average PM_{2.5}, and emergency presentations and hospital admissions for respiratory and cardiovascular conditions and mortality (Katsouyanni et al. 2009; Simpson et al. 2005; Atkinson et al. 2014; WHO 2006; WHO 2013). There is now also evidence from a meta-analysis of an association between increased PM_{2.5} with increased out-of-hospital cardiac arrest using data from Europe, North America, Asia and Australia (Zhao et al. 2017). This included a study conducted in Melbourne (Dennekamp et al. 2010). In addition, many studies have also shown an association between exposure to PM₁₀ and PM_{2.5}, and reduced lung function, respiratory symptoms, and physiological and sub-clinical changes, such as heart rate variability, blood markers of inflammation and coagulation (Gold et al. 2000; Brook et al. 2010; Götschi et al. 2008; WHO 2013). It is generally accepted that there is a linear relationship between exposure to particulate matter PM₁₀ and PM_{2.5}, and health outcomes, and that there is no safe PM₁₀ and PM_{2.5} level below which no effects are expected (Pope et al. 2006).

Studies investigating long-term exposure to PM_{2.5} have also shown associations with effects on the respiratory and cardiovascular system, in particular cardiopulmonary mortality (WHO 2013). A comprehensive review by the American Heart Association concluded that long-term exposures increased the risk of cardiovascular mortality to an even greater extent than exposures over a few days (Brook et al. 2010). They also concluded that reductions in PM_{2.5} levels were associated with decreases in cardiovascular mortality. These conclusions have been confirmed by more reviews and meta-analyses published subsequently (Cesaroni et al. 2014; Hoek et al. 2013). A critical review by the Health Effects Institute (2010) concluded that exposure to traffic air pollution adversely affected lung development in childhood. A recent meta-analysis supported the hypothesis that childhood exposure to traffic air pollution contributes to the development of childhood asthma (Khreis et al. 2017).

Using the results from a large meta-analysis done for the WHO (Henschel and Chan 2013; WHO 2013), a study by Hoek et al. (2013) concluded that for every 10 µg/m³ increase in PM_{2.5}, the risk of all-cause mortality increased by 6.2 per cent (95 per cent confidence interval 4.1–8.4 per cent). This is similar to results from the earlier American Cancer Society Study (Pope et al. 2002). This estimate is most commonly used in health impact assessments. However, a more recent analysis using data from European Cohorts found an even greater increase in all-cause mortality of 13 per cent per 10 µg/m³ increase (95 per cent confidence interval 1–25 per cent) (Beelen et al. 2014). However, the confidence interval around this estimate was much larger, reducing the confidence in the estimate.

6.4 Ambient ozone

Associations between short-term exposure to ground-level ozone have consistently been found to impact respiratory morbidity (for example, increase in asthma incidence and asthma severity, hospital presentations for asthma and reduced lung function) and mortality (WHO 2013; COMEAP 2015). Long-term exposure has been associated with the increased incidence and exacerbation of asthma. However, a comprehensive review by the Committee on the Medical Effects of Air Pollutants (COMEAP 2015) concluded that there was not enough evidence to support an association between long-term effects of ozone exposure and mortality (COMEAP 2015; Atkinson et al. 2016). However, there is emerging evidence of an association with cardiovascular morbidity (WHO 2013; COMEAP 2015).

6.5 Emerging evidence

6.5.1 Non-respiratory and cardiovascular health outcomes associated with air pollution exposure

There is evidence emerging of associations with health outcomes, other than respiratory and cardiovascular outcomes. Several reviews have now found associations between air pollution (mainly PM_{2.5} and ozone) and birth outcomes, such as preterm birth and low birth weight (Shah & Balkhair 2011; Li et al. 2017; Lee et al. 2013; Olsson et al. 2013). Preterm birth and low birth weight are not health effects but they are important predictors of the potential for adverse health impacts in children and adults.

Furthermore, evidence is emerging in relation to diabetes mellitus. Both exposure to air pollution and having diabetes mellitus are risk factors for cardiovascular and respiratory diseases, which in turn make individuals

more susceptible to the effects of pollution. There is, however, some evidence of a (weak) association between air pollution and the actual development of diabetes itself (Janghorbani et al. 2014; Eze et al. 2015) but further research is needed to confirm this.

6.5.2 Exposure response relationship for long-term exposure to particulate matter at very low and very high concentrations

It is well known that short-term exposure to particulate matter shows a linear exposure–response relationship (Pope et al. 2006) and effects have been observed at concentrations as low as those in Australia (Simpson et al. 2005; Barnett et al. 2006; Dennekamp et al. 2010; Straney et al. 2014).

However, at present there is a lack of large cohort studies investigating the health effects of long-term exposure in Australia. The lowest annual average concentration in studies that were used to calculate the exposure response associations for long-term effects (Burnett et al. 2014) are just over 10 $\mu\text{g}/\text{m}^3$. However, annual average concentrations in Melbourne are around 7 $\mu\text{g}/\text{m}^3$. Therefore, evidence is needed to determine the shape of the exposure response curve at these low levels. At present, there are Australian studies underway using large cohorts investigating this with results expected late 2018 to early 2019.

The exposure–response relationship for exposures at long-term high concentrations of particulate matter show a decreasing impact on mortality (Burnett et al. 2014). However, the concentrations where this may occur are concentrations much higher than those seen in Australia, and are closer to concentrations seen in major cities, such as those in China.

6.5.3 Health effects of outdoor smoke episodes

There are an increasing number of studies that have investigated the association between smoke from bushfires and effects on health. A comprehensive review (Reid et al. 2016) concluded that consistent evidence from a large number of studies showed that bushfire smoke exposure was associated with respiratory morbidity. It also concluded that there was growing evidence of an association with all-cause mortality. The authors did suggest that more research is needed to clarify which causes of mortality may be associated with bushfire smoke and that the associations with cardiovascular outcomes need further research (Reid et al. 2016). However, associations with cardiovascular outcomes were found in a local study conducted in Melbourne (Dennekamp et al. 2015) and in a study that included the whole of Victoria (Haikerwal et al. 2015). More recently, a study of the health effects of $\text{PM}_{2.5}$ exposure attributable to bushfire and planned burn smoke in Sydney suggested that this smoke is an important contributor to overall air pollution and the related population health burden. The impact of bushfire and planned burn smoke exposure during 2001–2013 was estimated as being approximately 14 premature deaths per year in Sydney (Horsley et al. 2018).

6.5.4 Particle composition and health effects

Primary particulate matter emissions provide surfaces onto which gases and other particles can adhere, (such as metal oxides, polycyclic aromatic hydrocarbons and volatile organic compounds), thereby facilitating the entry of toxic substances into the body and increasing opportunities to cause adverse health effects (Fuzzi et al. 2015). As discussed in section 2.3, different sources of particulate matter have different characteristics and chemical components.

Once in the lungs, particles come into contact with epithelial cells and provide intimate contact of the adsorbed species with lung tissue (Fuzzi et al. 2015). Rohr & Wyzga (2012) reviewed the short-term health effects of $\text{PM}_{2.5}$ and concluded there were significant findings for components of particulate matter, but not mass alone, suggesting that chemical components are important drivers of effect. Cakmak et al. (2014) indicated that metals associated with $\text{PM}_{2.5}$ increased heart rate, blood pressure and decreased lung function in young adults. Wyzga & Rohr (2015) in their review of the long-term effects of particulate matter also outlined the importance of particulate matter components and the need to further investigate organic compounds to better estimate health effects, and to better focus emission control measures.

6.5.5 Health benefits of reducing air pollution

Most studies have focused on the adverse health effects of exposure to air pollution. There are an increasing number of studies investigating the health benefits of reducing air pollution levels. They can be separated into studies that have used projections to predict health benefits and studies that have measured actual health benefits from an observed reduction in air pollution.

On a global scale, a reduction in air pollution has been predicted to produce large-scale health benefits (and reduced costs) as a result of measures to reduce greenhouse gas emissions in accordance with the Paris agreement (Markandya et al. 2018). Benefits have also been predicted when pollution levels are already low. For example, a recent study from Sydney projected the benefits of reducing PM_{2.5} concentrations by ten per cent over ten years and concluded that this would result in a reduction of 650 (95 per cent confidence interval 430–850) premature deaths, and a reduction of 700 (95 per cent confidence interval 450–930) respiratory and cardiovascular hospital visits (Broome et al. 2015).

There is also increasing evidence from reviews and recent studies of measurable health benefits from actions to reduce air pollution from specific sources (Henschel et al. 2012; WHO 2013; Rich 2017; Health Effects Institute 2018). The reduction in air pollution in these studies were a result of regulatory actions such as changes in heating fuel (for example, coal ban and wood burning regulations) and traffic-related initiatives (Rich 2017). The health benefits measured in these studies were mainly related to respiratory and cardiovascular health and mortality (Henschel et al. 2012; WHO 2013; Rich 2017; Health Effects Institute 2018). Other studies found health benefits from interventions aimed at short-term improvements in air quality during sporting events (such as the Olympic games) (WHO 2013; Rich 2017).

A very recent (April 2018) comprehensive study found that regulations targeting power plants and vehicles in the Atlanta region in the US were effective in reducing pollutant emissions. The study found fewer associated emergency department visits for asthma and other lung outcomes compared with what would normally have been expected without the regulations (Health Effects Institute 2018). The authors suggested that the health benefits increased over time as the air pollution control measures were fully implemented and emissions decreased.

On a more local scale, a study from Tasmania showed that efforts to reduce pollution from wood smoke were associated with a reduction in annual mortality in males. The reduced emissions were also associated with a reduction in cardiovascular and respiratory mortality during winter months (Johnston et al. 2013).

6.6 The relationship between indoor and outdoor air quality

While this report does not address indoor air quality, it is acknowledged that people spend a significant proportion of their lives indoors. In some cases, this has been predicted to be up to 90 per cent of the time (Australian Bureau of Statistics 2004). Outdoor air pollutants can migrate into homes. There are also significant sources of pollutants and irritants associated with common indoor activities (Table 4). These are listed as there does need to be greater understanding of exposure in the indoor environment. The concentrations of criteria pollutants in outdoor air are much higher and the assessment of indoor air quality is more complex due to the nature and variability of sources of indoor pollutants.

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Table 4: Sources and health effects of various indoor pollutants and irritants (Department of Environment and Energy n.d.)

Pollutant	Major source(s)	Health effects
Nitrogen dioxide (NO₂)	Gas combustion	Chronic respiratory disease
Carbon monoxide (CO)	Kerosene, gas and solid fuel combustion, cars idling in enclosed garage, cigarette smoke	Aggravation of cardiovascular disease, poor foetal development
Formaldehyde	Pressed wood products, consumer products, hobby, crafts	Eye, nose and throat irritation
Volatile organic compounds (VOCs)	New building products, cleaning products, office equipment, consumer products	Eye, nose and throat irritation, headache, lethargy
Passive smoke	Tobacco smoking	Eye, nose and throat irritation, aggravation of asthma, chronic respiratory disease, lung cancer
House dust mite allergens	Dust mites in bedding, carpets, furniture	Aggravation of asthma, nasal inflammation, eczema
Mould spores	Bathrooms, damp rooms, window sills, indoor plants, poorly ventilated areas	Aggravation of asthma, nasal irritation and inflammation
Lead in indoor dust	Pre-1970s paint, hobbies and renovations	Poor childhood intellectual development
Pet dander	Cats and dogs	Aggravation of asthma and hay fever

6.7 Other impacts of air pollution

Air pollution can also have significant impacts beyond human health. Smoke from bushfires and planned burns is a concern for the viticulture sector. It was estimated that in addition to the tragic loss of life and property, the 2009 Black Saturday bushfires resulted in approximately \$299 million in losses for the wine industry (Brodison 2013).

Beyond the direct damage to plants from bushfires, the impact of smoke on grapes prior to harvest can also cause significant problems. Smoke-tainted grapes can produce wine which can have objectional characteristics, such as a smoky, ashy or medicinal taste (Krstic 2015). The Victorian Department of Economic Development, Jobs, Transport and Resources and Latrobe University are investigating the impacts of smoke taint as well as determining the mechanism under which it occurs.

There is limited research in Australia on the effects of air pollutants on vegetation or wildlife and no dedicated research effort in place to address the potential for impacts.

7 Factors influencing air quality in Victoria now and in the future

7.1 Weather patterns over the last 10 years

In 2013, EPA released the *Future Air Quality in Victoria* report, which was prepared in partnership with the CSIRO (EPA Victoria 2013). The report identified future trends for air pollutants and their drivers. Vehicle technology and population growth were identified as key factors that could impact future air quality to 2030. The report also predicted an increase in large-scale dust events associated with wind-blown dust, along with a slight decrease in moderate scale dust. EPA is currently in the process of updating its emissions inventory which is a key input into updating the work done during the future air study.

7.2 Influence of population on air pollution

Population size is linked with air pollution: a greater population size generally results in the production of more air pollutants. Additionally, a bigger population signifies more people being exposed to air pollution. In Victoria, the Australian Bureau of Statistics (2017) estimated that as of 30 June 2017, Victoria's residential population had increased by 144,400 people since 2012. This corresponds with an increase of 2.3 per cent. Melbourne grew by 125,400 or 2.7 per cent over the same period. By comparison, the ABS estimated that the Australian population would grow to 24.6 million over the same period of time (Table 5).

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Table 5: Population Growth (Australia 2011–2017) for Victorian Statistical Areas (Australian Bureau of Statistics, 2018)

Statistical Area (Level 4)	Population (2011)	Population (2016)	Population (2017)	Average Population Density (people/km ²)
Ballarat	148,143	159,785	162,140	182
Bendigo	142,406	154,885	157,151	248
Geelong	255,686	285,371	292,943	436
Hume	161,287	171,651	173,680	33
Latrobe - Gippsland	259,384	274,627	278,188	46
Melbourne - Inner	534,255	635,933	659,515	5,322
Melbourne - Inner East	356,378	380,210	386,167	2,800
Melbourne - Inner South	395,465	426,081	432,740	2,889
Melbourne - North East	453,488	520,295	534,201	1,564
Melbourne - North West	332,431	382,072	394,083	1,438
Melbourne - Outer East	494,744	520,754	526,496	1,328
Melbourne - South East	684,230	793,612	819,657	1,727
Melbourne - West	638,901	765,986	794,022	1,895
Mornington Peninsula	279,211	300,373	303,859	824
North West	149,495	151,591	151,751	75
Shepparton	146,799	131,776	132,523	66
Warrnambool and South West	122,223	124,247	124,490	69
Grand Total	5,534,526	6,179,249	6,323,606	

Figure 24 shows that most of this population growth has occurred in the south east, west and inner parts of Melbourne. The only region in Victoria to record a decrease since 2011 was Shepparton, which decreased from 146,799 to 131,776 people in 2016, with an increase in the following year to 132,523 people. This information can be used to inform monitoring programs in the future to address traffic, population and infrastructure changes that may lead to air quality problems.

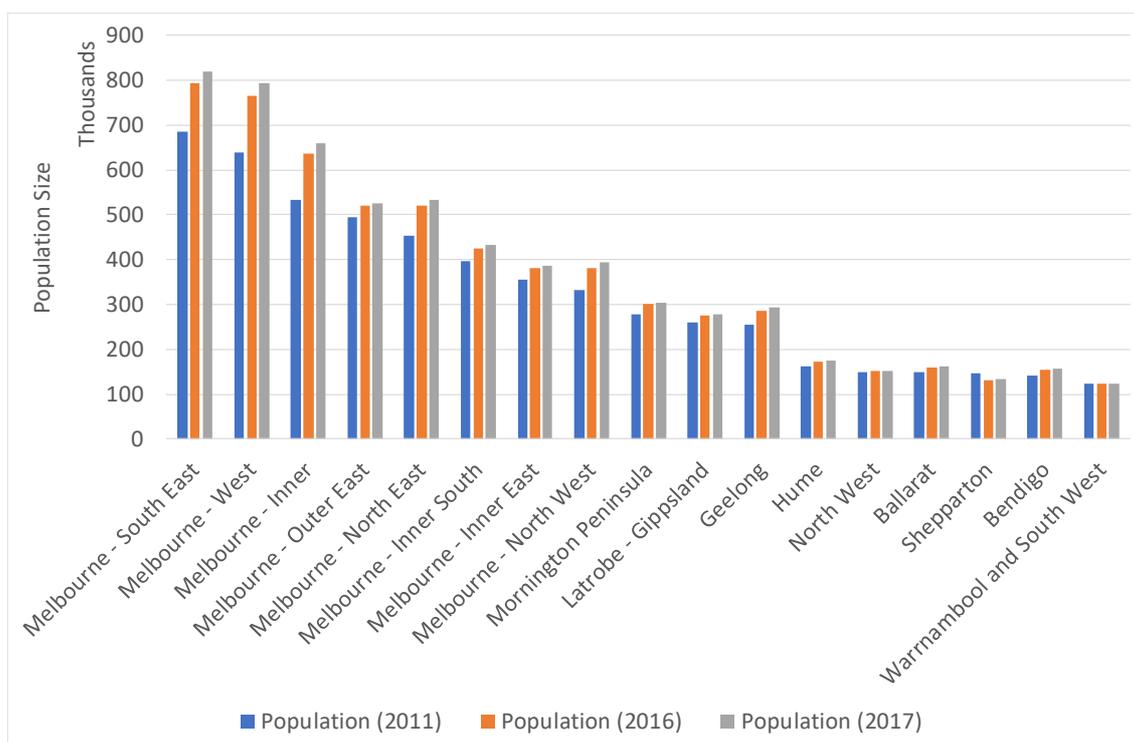


Figure 24: Population Change in Victoria

7.3 Predictions of future air quality

EPA's *Future Air Quality in Victoria* report (EPA Victoria 2013) identified that ozone concentrations in Melbourne were generally lower than the expected non-urban background of 25–30 ppb. This is due to ozone reacting with nitric oxide in urban environments which results in lower concentrations compared with non-urban settings. Nitric oxide is emitted, along with nitrogen dioxide, from combustion processes such as those from car engines. It is expected that as car exhaust emissions decrease with increasing engine efficiency, there will be an increase in the formation of tropospheric ozone (EPA Victoria 2013).

The data used for this prediction was based on inventory data collected in 2006 aligned with the census data collected by the ABS. EPA is currently in the process of updating this inventory to align with the 2016 census data.

7.4 The emergence of new technologies

EPA is responsible for monitoring, assessing and reporting on air quality in Victoria. Much of EPA's ambient air monitoring network is operated according to the appropriate Australian Standards and accredited by National Association of Testing Authorities (NATA). Due to the cost of installation and maintenance of these types of networks, they are not always appropriate. Low cost sensors are being trialled by EPA and external partners to evaluate their performance and ability to provide greater spatial resolution of air quality. These trials have demonstrated that while these sensors cannot compete with Australian Standard methods, they can provide useful data and insights about impacts (Fisher et al. 2017b).

To improve the understanding of the performance of low cost sensors, EPA established a smoke chamber with Victoria University in Werribee to trial 21 different particle instruments with smoke from different fuels. These instruments ranged from Australian Standard methods to low cost light scattering sensors. The trial showed that many of the low-cost sensors had greater uncertainty and different sensitivities to different types of smoke from different fuel sources. However, it was possible to correlate the data from low cost sensors with Australian Standard methods. This indicates that it is possible to use these types of sensors in parallel with existing monitoring networks to increase both temporal and spatial coverage (Fisher et al. 2017a).

8 Next steps

This report highlights the need for good and appropriately targeted monitoring to better understand and map air pollution to inform decision making. Further, it highlights that even though air quality is good in Melbourne, we still have localised problems with the potential for increases in the future due to population and climate pressures.

Traditional monitoring and modelling have focused on determining pollutant concentrations over time and space with a focus on population health impacts. This allows for comparison with air quality standards to determine where and when pollution may pose a risk of health impacts to the community. A limitation of this approach is that it focuses on the presence of pollutants in the atmosphere, rather than trying to determine where air pollutants could be coming from or understanding the benefits and effectiveness of management and different interventions. In addition, the monitoring undertaken to date has focussed on major population centres. With increasing population and environmental changes, efforts to understand regional airsheds, and population and ecosystem impacts will be necessary.

Techniques such as source apportionment studies could be used in the future to assist in determining the contribution of different sources to air quality and enable more targeted approaches for more significant pollution sources. Source apportionment data could be used to determine where the most effective reductions to air pollution could be made. It would also enable a better understanding of the baseline concentrations of air pollutants from natural sources, such as sea salts, but also provide a database of sources and their composition – an increasingly important issue when considering health impacts.

The increasing community awareness of air quality issues and the growing availability of low-cost air quality sensors is leading to larger amounts of data being collected and shared. Using this additional data is a challenge for environmental regulators due to the increased uncertainty around the measurement techniques used by low-cost sensors. However, making better use of this data will help increase spatial awareness of air pollutant trends, in addition to its potential for better identification of air pollution hot spots. Now, and into the future, EPA needs to be able to assess the suitability of these low-cost sensors and other remote sensing products such as satellites and drones to determine how they compare and perform against reference methods and equivalent-grade equipment that it currently uses. This will allow for the most effective and targeted use of the sensors, to ensure they complement the existing ambient air monitoring network.

In the future, further attention will need be given to ultrafine particles for a number of reasons. Firstly, ultrafine particles are difficult to measure. Due to the very low mass of the individual particles, the current methods for monitoring PM_{2.5} and PM₁₀ are not appropriate for ultrafine particles and techniques based on particle count are more suitable. Ultrafine particles are also postulated to be more important from a health perspective than larger particulate matter size fractions. There is also debate about whether source and composition are more important than size. While there have been some limited studies of ultrafine particles and their impacts on mortality and morbidity, there is still insufficient research and data to reach clear conclusions about their impacts. Consequently, there is a need for robust monitoring and management. The ability to discern the source of ultrafine particles remains a challenge and supports the need for further work on this topic, including the chemical characterisation of particles and health studies related to both particle composition and size.

Ozone monitoring must continue and work to address the implications of a warmer climate on predicted concentrations. Understanding emissions of precursor pollutants needs to be further developed to understand whether the trends of increasing averages is likely to continue.

Current air quality predictions are based on human interpretation of data and meteorological conditions. But as the amount of available data increases in the future, there will be the opportunity to leverage machine learning to predict and undertake air quality assessments. Another area of potential future work with machine learning is the assessment of multiple air pollution constituents in ambient air. Current regulatory standards are written around individual air pollutants, which are sometimes adjusted for other air pollutants and confounding factors. However, it is unlikely these standards are representative of human health exposure responses in real situations. Machine learning is potentially a way of analysing for these

synergistic and additive effects of individual air pollutants in ambient air to better quantify the real impacts of air pollution and therefore inform improved standards and management responses.

There are many benefits to reducing air pollutants from entering the atmosphere. However, there are also interventions which may protect populations and vulnerable groups from the effects of air pollution when they do occur. EPA needs to develop approaches and interventions to reduce the impacts of pollutants in airsheds and it needs systems to be able to assess their effectiveness. We need to be able to better understand both the impacts of air pollutants at the local level, and improvements in health associated with improved air quality over time. We also need to provide advice on interventions to reduce harm from specific sources and events such as bushfires and emergency incidents.

In order to meet the future air quality challenges highlighted in this report, we need to be innovative in how we address knowledge gaps. We must strengthen our science by using modern research methods and technologies and leveraging ever-increasing sources of data to enhance traditional monitoring and evaluation methods. This will lead to more comprehensive, fit-for-purpose information that will increase our understanding of air pollution and its health impacts, and help ensure a prosperous and liveable Victoria, now and always.

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Appendix 1 – additional tables

Table 6: AQI value ranges and categories

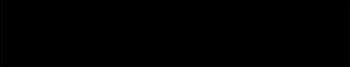
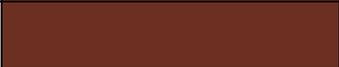
AQI Category	Lower range of AQI	Upper range of AQI	Colour
Very good	0	33	
Good	34	66	
Fair	67	99	
Poor	100	149	
Very poor	150	>150	

Table 7: Fine particles in smoke concentration ranges and health categories

PM _{2.5} health category	Lower range of 24hr PM _{2.5} (µg/m ³)	Upper range of 24hr PM _{2.5} (µg/m ³)	Colour
Low	0	8.9	
Moderate	9	25.9	
Unhealthy - sensitive	26	39.9	
Unhealthy – all	40	106.9	
Very unhealthy - all	107	177.9	
Hazardous (high)	178	249.9	
Hazardous (extreme)	250	>250	

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Table 8: Number of days with Air quality index values in Melbourne & Geelong 2016

No. of days (2016)	Alphington	Altona North	Box Hill	Brighton	Brooklyn	Dandenong	Footscray	Geelong South	Macleod	Melton	Mooroolbark	Point Cook
Very good	116	305	278	269	112	266	128	124	291	299	196	254
Good	187	34	52	75	133	69	171	152	41	35	111	98
Fair	43	6	10	14	57	21	33	54	2	14	33	9
Poor	15	1	5	6	42	7	24	17	5	2	15	2
Very poor	5	3	3	2	21	3	7	19	2	1	11	3
Total days	366*	349	348	366*	365	366*	363	366*	341	351	366*	366*
% Days good to very good	83%	97%	95%	94%	67%	92%	82%	75%	97%	95%	84%	96%

* 2016 was a leap year

Table 9: Number of days with air quality index values in Melbourne & Geelong 2017

No. of days (2017)	Alphington	Altona North	Box Hill	Brighton	Brooklyn	Dandenong	Footscray	Geelong South	Macleod	Melbourne CBD	Mooroolbark	Point Cook
Very good	66	267	242	283	92	189	106	97	270	86	128	244
Good	205	51	32	43	120	123	185	189	44	115	158	87
Fair	55	19	11	18	76	44	49	48	8	16	38	19
Poor	31	11	4	5	51	4	17	16	7	13	24	9
Very poor	8	2	0	0	26	5	8	15	1	4	17	1
Total days	365	350	289	349	365	365	365	365	330	234	365	360
% Days good to very good	74%	91%	95%	93%	58%	85%	80%	78%	95%	86%	78%	92%

Air pollution in Victoria – a summary of the state of knowledge

Table 10: Number of days with air quality index values in Latrobe Valley and Wangaratta 2016

No. of days (2016)	Churchill	Moe	Morwell East	Morwell South	Traralgon	Wangaratta
Very good	221	134	148	171	68	36
Good	112	194	162	131	217	3
Fair	23	27	32	23	52	0
Poor	8	6	10	23	25	0
Very poor	0	0	2	18	4	1
Total days	364	361	354	366	366	40
% Days good to very good	91%	91%	88%	83%	78%	98%*

*Limited sample size of 40 days in the year due to time station was established

Table 11: Daily station air quality index values Latrobe Valley and Wangaratta 2017

No. of days (2017)	Churchill	Moe	Morwell East	Morwell South	Traralgon	Wangaratta
Very good	175	145	130	144	75	142
Good	130	177	157	166	198	46
Fair	32	31	62	31	55	41
Poor	9	7	12	14	28	52
Very poor	3	2	4	10	7	47
Total days	349	362	365	365	363	328
% Days good to very good	87%	89%	79%	85%	75%	57%

Appendix 2 – additional emissions inventory outputs

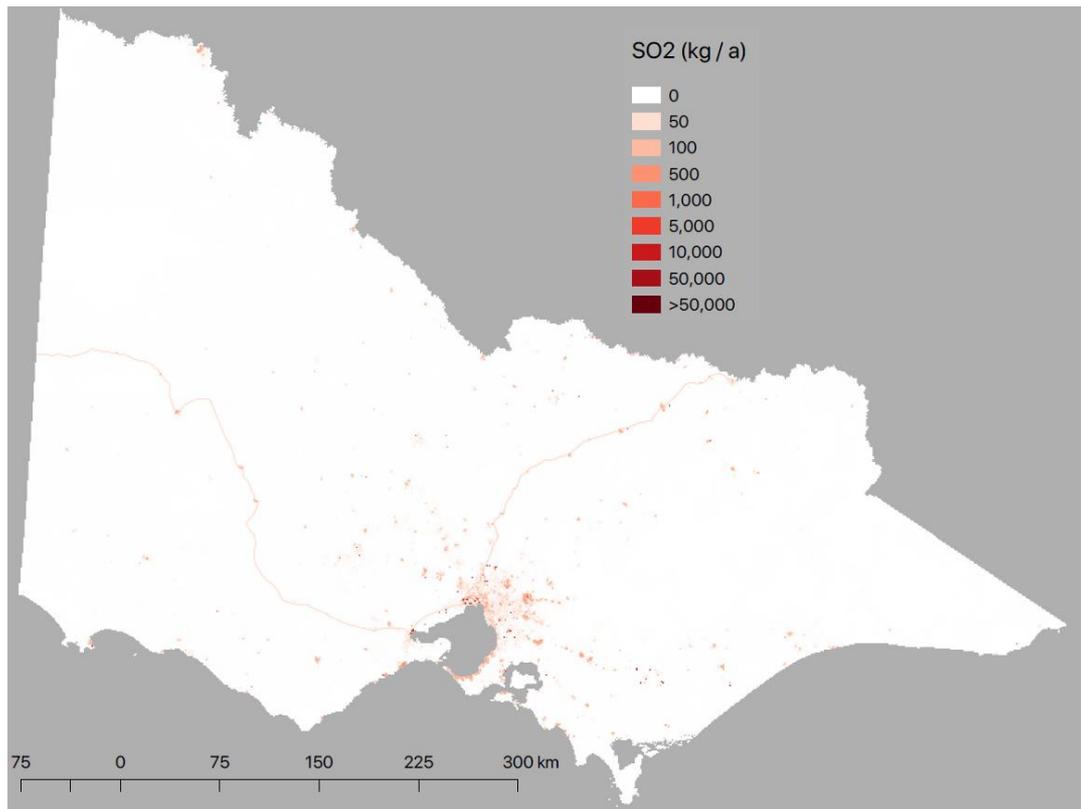


Figure 25: 2016 emissions inventory SO₂ kg/annum

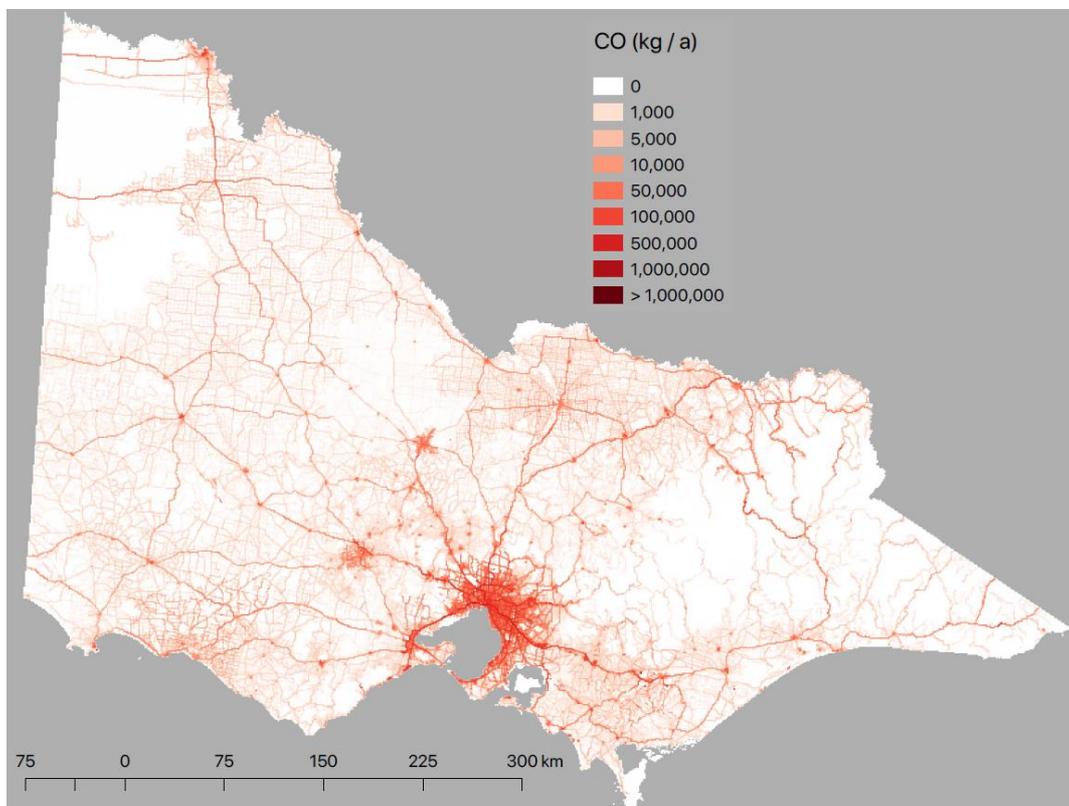


Figure 26: 2016 emissions inventory CO kg/annum

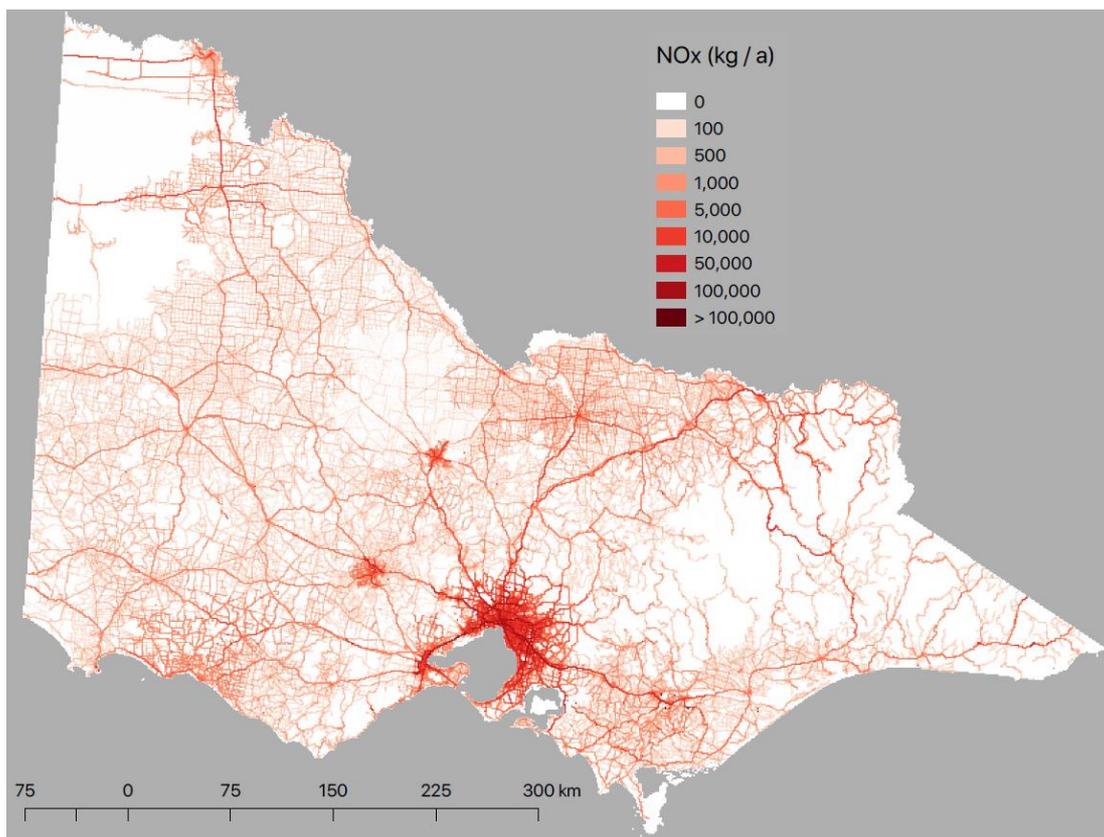


Figure 27: 2016 emissions inventory NOx kg/annum

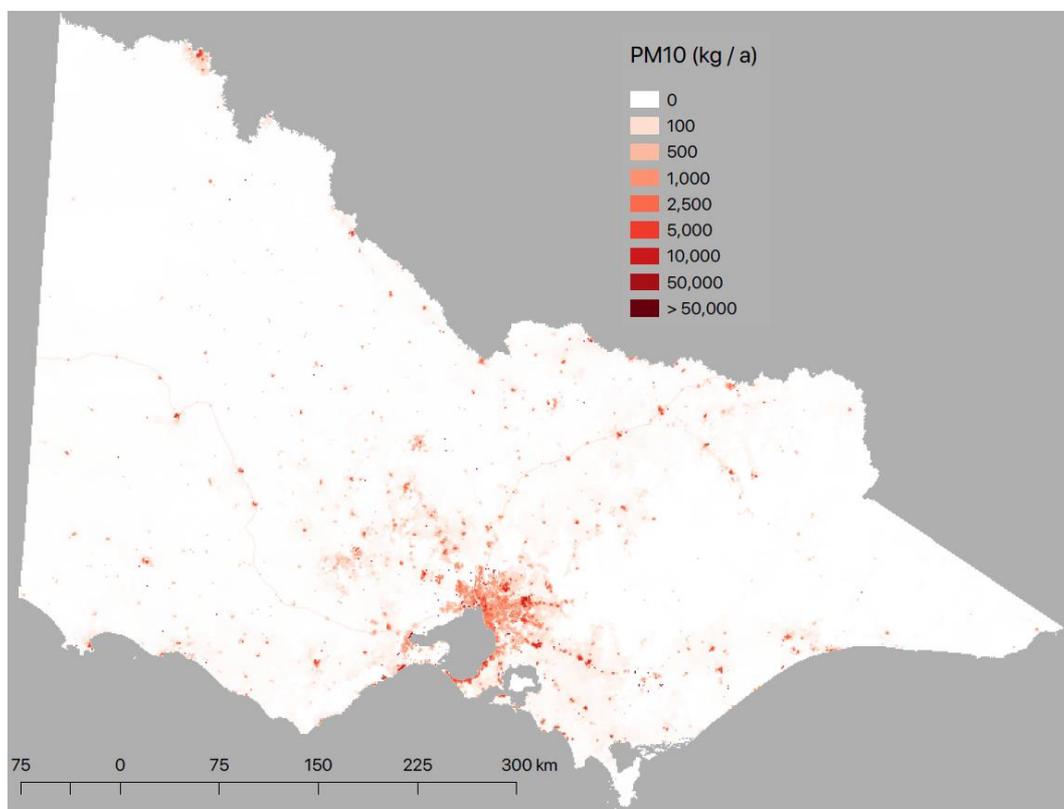


Figure 28: 2016 emissions inventory PM₁₀ kg/m²/annum

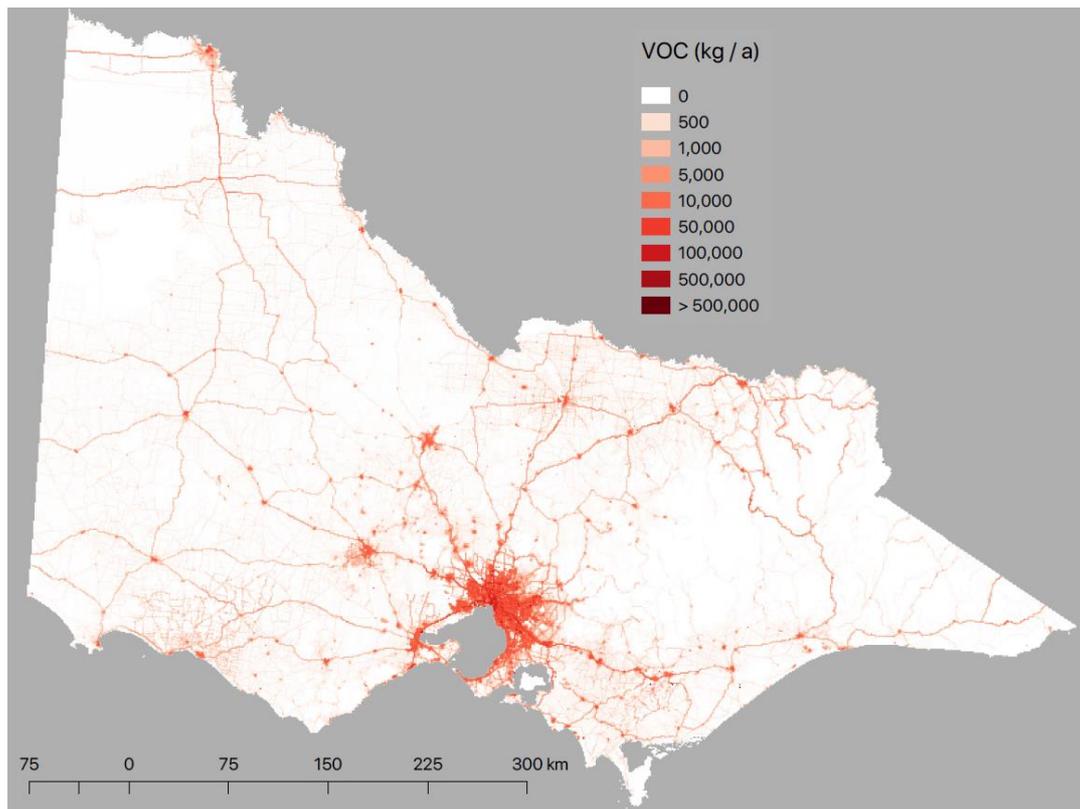


Figure 29: 2016 emissions inventory VOC kg/m²/annum

Appendix 3 – lead monitoring results

Monitoring for lead in TSP and PM₁₀ was conducted from 1995 to 2004. With the introduction of unleaded petrol and the phase out of leaded petrol, concentrations of lead in the Melbourne airshed decreased significantly. The peak station for lead in Collingwood was closed in December 2004 as levels were demonstrated to be consistently low compared to the air quality objectives.

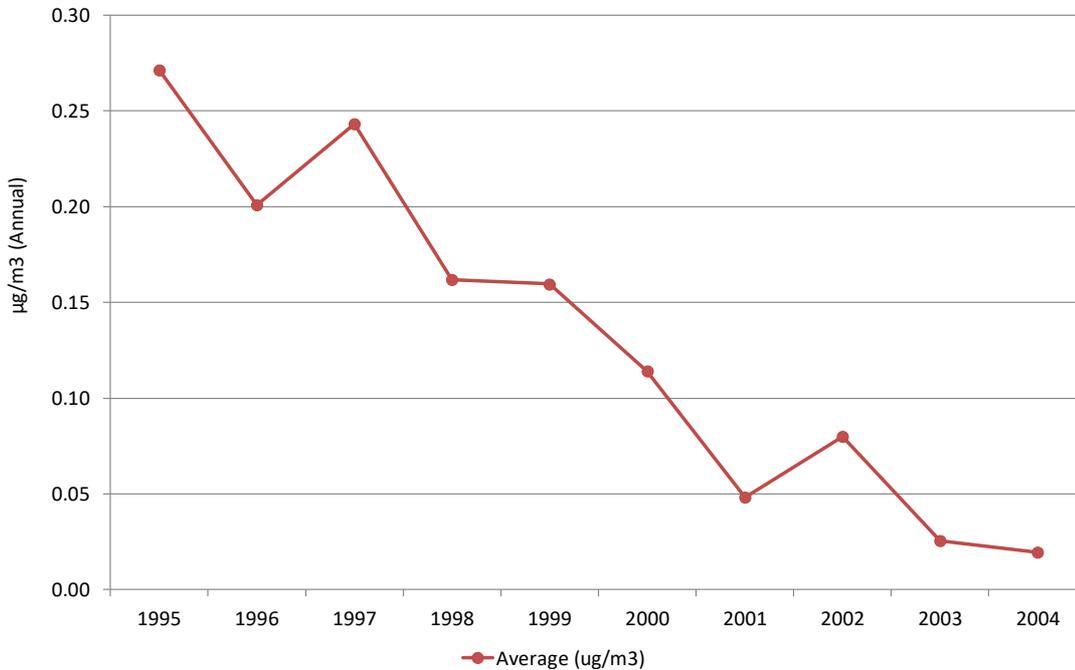


Figure 30: Historical annual averages for lead (Collingwood 1995-2004)

Appendix 4 – air monitoring equipment that produces data for EPA’s website

For monitoring small particles – PM₁₀

TEOM – a tapered element oscillating microbalance monitor – continually measures the concentration of airborne particles. It does this by collecting and weighing the particles using a very sensitive balance. TEOMs are standard across EPA’s network and meet the Australian National Standard (AS 3580.9.8–2008).

For monitoring small particles – PM_{2.5}

EPA has a number of different air monitoring monitors that can be used to measure PM_{2.5} levels. Some of these, such as the BAM and indicative monitors (nephelometers and portable air monitors), produce data that goes on our website. Other monitors (such as Partisols and HiVols) are used as a reference method to ensure the accuracy of EPA’s data. Some types of portable monitors are used to respond to major pollution events.

The data collected by PM_{2.5} air monitoring equipment falls into three data categories: data measured by the reference method; data from monitors with equivalence to the reference method; and data from monitors that are categorised as being ‘near reference’. The uncertainty associated with near reference monitors, such as the portable and sensor monitors, are reduced by applying an adjustment factor based on correlations to BAM measurements where possible.

The main types of monitors are as follows:

BAM – a standard beta attenuation monitor automatically measures and records airborne particles. This monitor works by collecting particles on a filter tape and measuring the reduction in beta rays travelling through the particles. From this, the concentration of airborne particles is calculated. BAMs meet the Australian National Standard (AS 3580.9.12–2013) and have equivalence to the reference method. 24-hour rolling average data collected by BAMs is used to automatically trigger cautionary health advice on EPA AirWatch. BAMs are currently used to measure PM_{2.5} at the following stations: Alphington; Footscray; Geelong South; Morwell South; Morwell East; Traralgon; Moe; and Churchill.

Portable air monitors – these use sensitive, light-scattering sensors to detect particles. These monitors produce indicative PM_{2.5} data that is usually less accurate than data collected by other types of particle monitors. The portable air monitors provide the community with a more flexible air monitoring network, which allows EPA to monitor air quality at more locations. Portable air monitors are currently used to measure PM_{2.5} at the following sites: Box Hill; Brighton; Dandenong; Altona North; Melton; Macleod; and Wangaratta.

Nephelometer – these monitors measure the amount of particles in the air using very sensitive, light-scattering sensors (in a similar way to portable air monitors). Indicative PM_{2.5} data is calculated from the nephelometer’s visibility reduction reading, which is of a comparable accuracy to the data produced by portable air monitors. Nephelometers are currently used to measure indicative PM_{2.5} at the following sites: Mooroolbark; Brooklyn; and Point Cook.

Appendix 5 – relationship between visibility as Airborne Particle Index and PM_{2.5} (Alphington air monitoring station 2017)

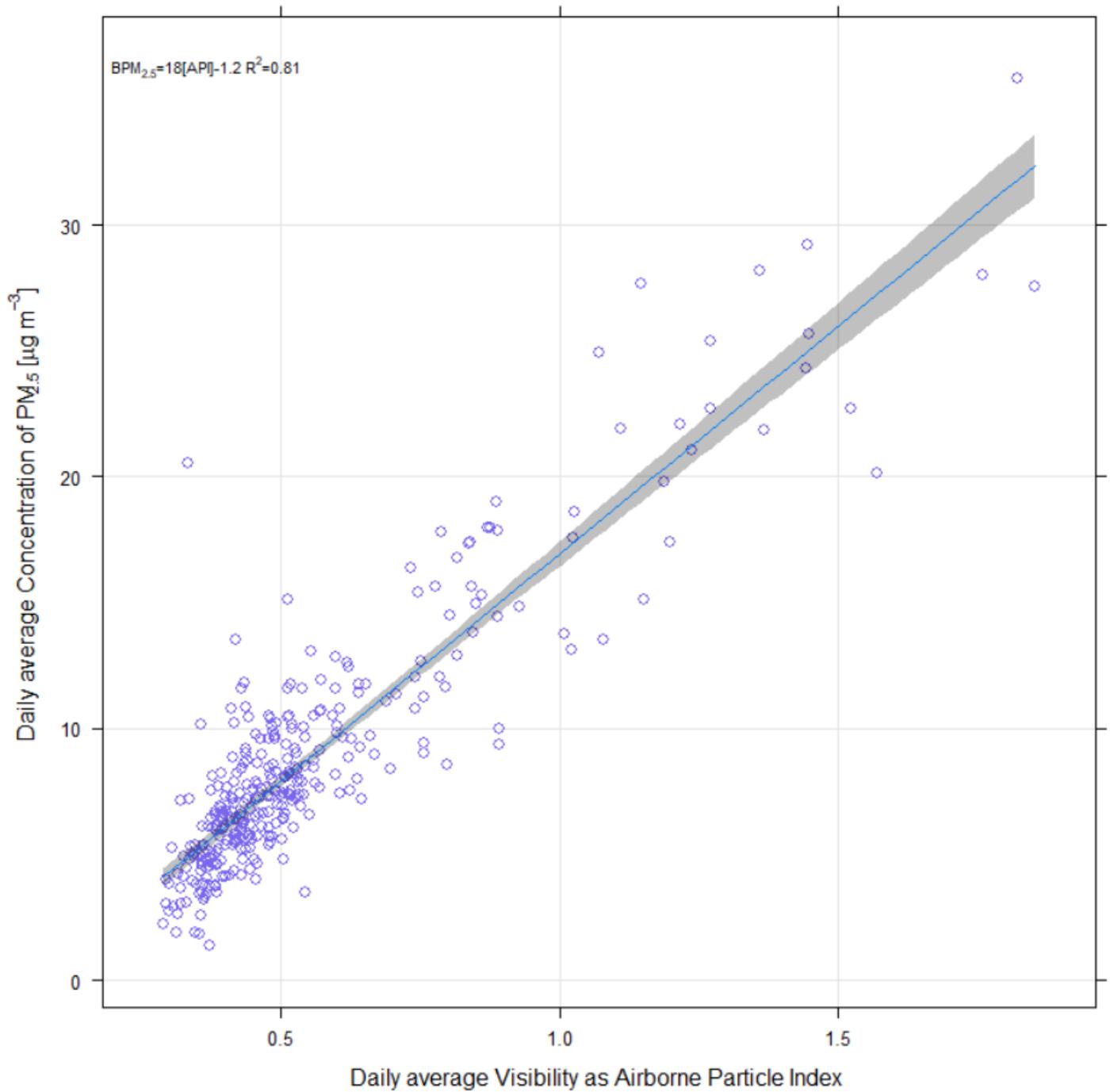


Figure 31: Relationship between visibility as Airborne Particle Index and PM_{2.5} (Alphington air monitoring station 2017)

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