

**Draft Variation to the National Environment
protection (Ambient Air Quality) Measure**

Impact Statement

**Prepared for:
National Environment Protection Council**

July 2014

DISCLAIMER

© 2014 Copyright vests in the Commonwealth of Australia and each Australian state and territory

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the National Environment Protection Council (NEPC). Requests and enquiries concerning reproduction and rights should be addressed to Executive Officer, NEPC Service Corporation, Department of the Environment, GPO Box 787 Canberra ACT 2601.

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the National Environment Protection Council.

While reasonable efforts have been made to ensure that the contents of this publication are factually correct, the National Environment Protection Council does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication

CONTENTS

| | |
|---|-----------|
| EXECUTIVE SUMMARY | VII |
| 1 INTRODUCTION | 1 |
| 1.1 Overview | 1 |
| 1.2 Compliance with NEPC requirements | 1 |
| 1.3 Scope and structure of the Impact Statement | 2 |
| 2 CHARACTERISTICS AND MEASUREMENT OF AIRBORNE PARTICULATE MATTER | 4 |
| 2.1 Characteristics | 4 |
| 2.1.1 Overview | 4 |
| 2.1.2 Formation mechanisms and constituents | 4 |
| 2.1.3 Particle size distribution | 5 |
| 2.1.4 Removal mechanisms | 7 |
| 2.2 Methods for measuring PM | 7 |
| 3 EFFECTS AND MONETARY COSTS OF AIRBORNE PARTICULATE MATTER | 9 |
| 3.1 Effects of PM on human health | 9 |
| 3.1.1 Overview | 9 |
| 3.1.2 Evidence for PM _{2.5} | 10 |
| 3.1.3 Evidence for PM ₁₀ | 11 |
| 3.1.4 Evidence for other PM metrics | 11 |
| 3.1.5 Linearity and thresholds | 11 |
| 3.1.6 Relevance to Australia | 11 |
| 3.2 Other effects | 12 |
| 3.2.1 Ecosystems | 12 |
| 3.2.2 PM–climate interactions | 12 |
| 3.2.3 Visibility | 13 |
| 3.2.4 Materials and cultural heritage | 13 |
| 3.3 Costs associated with airborne PM in Australia | 13 |
| 4 POLICY CONTEXT AND LEGISLATION | 16 |
| 4.1 Air quality management in Australia | 16 |
| 4.1.1 Governance | 16 |
| 4.1.2 AAQ NEPM and review | 16 |
| 4.1.3 Use of AAQ NEPM PM standards and goals by jurisdictions | 19 |
| 4.1.4 National Policy Initiatives | 21 |
| 4.1.5 Abatement initiatives | 22 |
| 4.2 International air quality standards and exposure-reduction frameworks | 23 |
| 4.2.1 Air quality guidelines and standards | 23 |
| 4.2.2 Exposure reduction | 29 |
| 5 AIRBORNE PARTICULATE MATTER IN AUSTRALIA | 35 |
| 5.1 Sources | 35 |
| 5.2 Emissions of PM | 36 |
| 5.2.1 Emissions inventories | 36 |
| 5.2.2 Emission projections | 38 |
| 5.3 Ambient PM concentrations | 41 |
| 5.3.1 Overview | 41 |
| 5.3.2 Analysis of monitoring data | 42 |

| | | |
|-------|---|----|
| 5.4 | PM composition and source apportionment | 44 |
| 5.4.1 | Methods | 44 |
| 5.4.2 | Measurements by ANSTO | 44 |
| 5.5 | Other studies | 48 |
| | | |
| 6 | STATEMENT OF THE PROBLEM AND THE CASE FOR GOVERNMENT INTERVENTION | 53 |
| 6.1 | Statement of the problem | 53 |
| 6.2 | Why the AAQ NEPM PM standards need to be updated | 53 |
| 6.3 | Risks of not revising the standards | 54 |
| 6.4 | Rationale and objectives of government intervention | 54 |
| 6.5 | Issues to be addressed in AAQ NEPM variation | 55 |
| 7 | DISCUSSION OF POSSIBLE APPROACHES AND OPTIONS | 57 |
| 7.1 | General air quality management framework | 57 |
| 7.1.1 | Variation of the Ambient Air Quality AAQ NEPM | 57 |
| 7.1.2 | Commonwealth legislation | 57 |
| 7.1.3 | Voluntary guidelines | 58 |
| 7.1.4 | Inter-governmental agreement or memorandum of understanding | 58 |
| 7.1.5 | No change to the current framework | 58 |
| 7.2 | Status of air quality standards | 59 |
| 7.3 | PM metrics and averaging periods | 59 |
| 7.4 | Numerical values of standards | 59 |
| 7.5 | Form of the 24-hour PM standards | 60 |
| 7.5.1 | Background | 60 |
| 7.5.2 | Alternative forms | 61 |
| 7.5.3 | Summary of options for the form of the 24-hour standards | 63 |
| 7.6 | Applicability of standards | 63 |
| 7.7 | Exposure-reduction framework | 63 |
| 8 | IMPACT ANALYSIS | 67 |
| 8.1 | Overview | 67 |
| 8.2 | Analysis of monitoring data and achievability of the standards | 67 |
| 8.2.1 | PM ₁₀ annual mean standard | 67 |
| 8.2.2 | PM ₁₀ 24-hour mean standard | 68 |
| 8.2.3 | PM _{2.5} annual mean standard | 69 |
| 8.2.4 | PM _{2.5} 24-hour mean standard | 70 |
| 8.2.5 | Form of 24-hour standards | 71 |
| 8.2.6 | Comparison between PM ₁₀ and PM _{2.5} standards | 74 |
| 8.3 | HRA project | 77 |
| 8.3.1 | Approach | 77 |
| 8.3.2 | Results | 78 |
| 8.4 | Economic Analysis | 81 |
| 8.4.1 | Approach | 81 |
| 8.4.2 | Results | 82 |
| 8.5 | Summary of information for each sub-option | 85 |
| 8.6 | Other considerations | 87 |
| 8.6.1 | Resourcing implications for jurisdictions | 87 |

| | | |
|-------|---|-----|
| 8.6.2 | Costs to industry and business | 87 |
| 8.6.3 | Social impacts | 87 |
| 9 | PREFERRED OPTIONS | 89 |
| 9.1 | PM metrics for inclusion in the AAQ NEPM | 89 |
| 9.2 | Numerical values for the PM standards | 89 |
| 9.3 | Form of the 24-hour standards | 90 |
| 9.4 | Other PM metrics for possible inclusion in the AAQ NEPM | 90 |
| 9.5 | Form of an exposure-reduction framework | 91 |
| 9.6 | Implementation of an AAQ NEPM variation | 91 |
| 10 | CONSULTATION | 93 |
| 11 | LIST OF TECHNICAL TERMS AND ABBREVIATIONS | 94 |
| 12 | REFERENCES | 97 |
| | APPENDIX A RECOMMENDATIONS FROM THE 2011 AAQ NEPM REVIEW | 103 |
| | APPENDIX B MONITORING METHODS FOR PM ₁₀ AND PM _{2.5} | 108 |
| B.1 | Reference methods | 109 |
| B.2 | Alternative methods | 109 |
| B.2.1 | TEOM | 109 |
| B.2.2 | Filter Dynamic Measurement System (FDMS) | 110 |
| B.2.3 | Beta-Attenuation Monitor (BAM) | 110 |
| B.2.4 | Partisol | 111 |
| B.2.5 | Optical monitors | 111 |
| B.3 | Equivalence and adjustment | 111 |
| B.4 | Implications for Australia | 111 |
| | APPENDIX C ENHEALTH RECOMMENDATIONS | 113 |
| | APPENDIX D PM ₁₀ AND PM _{2.5} MONITORING SITES IN AUSTRALIA | 117 |
| | APPENDIX E ANALYSIS OF PM ₁₀ AND PM _{2.5} MONITORING DATA | 125 |
| E.1 | Data collection | 126 |
| E.2 | Inter-annual trends | 126 |
| E.3 | Seasonal patterns | 133 |
| E.4 | Daily trends | 139 |
| E.5 | Geographical variations | 139 |
| E.6 | Exceedances of air quality standards | 141 |
| | APPENDIX F SUMMARY OF QUESTIONS FOR CONSULTATION | 149 |

EXECUTIVE SUMMARY

Introduction

The National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) establishes national standards and a nationally consistent framework for the monitoring and reporting for six common air pollutants. The pollutants are:

- carbon monoxide (CO)
- lead (Pb)
- nitrogen dioxide (NO₂)
- photochemical oxidants as ozone (O₃)
- sulfur dioxide (SO₂)
- particulate matter (PM) with an aerodynamic diameter of less than 10 micrometres (µm) (known as PM₁₀).

In 2003 the AAQ NEPM was varied to include monitoring and reporting protocols and advisory reporting standards for particles with an aerodynamic diameter of less than 2.5 µm, known as PM_{2.5} (**NEPC 2002**).

An initial review of the AAQ NEPM was completed in 2011 (**NEPC 2011**). In 2012 COAG agreed that the review of the AAQ NEPM particle standards would be prioritised for the following reasons:

- There is strong evidence that exposure to PM has adverse effects on human health, and a lack of evidence for a concentration threshold below which health effects do not occur. This means that there are likely to be adverse health effects at the concentrations currently experienced in Australian cities, even where these are below the current standards and goals (see **Table ES1**).
- PM₁₀ standards are at times exceeded in nearly all regions of Australia (**DSEWPC 2011**); however, such exceedances can occur as a result of uncontrollable natural events.
- The potential health benefits of reducing population exposure to PM – and the associated monetary savings for society – are larger than those for other air pollutants.
- The range of cost-effective abatement policies and actions available for PM is larger than that for other pollutants.

In the decade since the AAQ NEPM was varied there have been significant developments in the understanding of the effects of PM on health and the environment, as well as improvements in monitoring methods.

This Impact Statement has been prepared for the National Environment Protection Council (NEPC) with reference to the requirements of the NEPC Act.

This Impact Statement collates and analyses available information about PM in Australia. It considers the feasibility, costs and benefits of amending the standards and goals relating to PM, as currently defined in the AAQ NEPM. It also considers a framework for reducing population exposure to PM.

The Impact Statement outlines the basis for options being considered by government.

The NEPC acts require that both the draft NEPM and the Impact Statement be made available for public consultation for a period of at least two months. NEPC must have regard to the Impact Statement and submissions received during public consultation in deciding whether or not to vary the AAQ NEPM.

In addition to addressing the requirements of the NEPC Act, impact statements are developed in keeping with the requirements of the Council of Australian Governments.

Key issues considered in this Impact Statement include:

- metrics used to quantify PM in the AAQ NEPM
- numerical values of the PM standards
- form of the PM standards (e.g. allowed exceedances)
- options for an exposure-reduction framework for PM.

Other recommendations concerning specific technical matters (e.g. monitoring methods and protocols, site locations) are being considered through existing processes, and are outside the scope of this Impact Statement.

Preferred options

The preferred options for revising the AAQ NEPM are summarised in **Table ES1**. It is also proposed that the advisory reporting standards for PM_{2.5} could be made performance standards.

Table ES1: Summary of preferred options

| Aspect | Metric | To be included in AAQ NEPM? | Numerical value | Form of standard |
|--|--|-----------------------------|---|--|
| Air quality standards | PM ₁₀ – annual mean | Yes | No standard with consideration of 20 µg/m ³ | – |
| | PM ₁₀ – 24-hour mean | Yes | 40 - 50 µg/m ³ | To be agreed |
| | PM _{2.5} – annual mean | Yes | 8 µg/m ³ | – |
| | PM _{2.5} – 24-hour mean | Yes | 25 µg/m ³ | To be agreed |
| Exposure-reduction framework co-option | Exposure index based on average PM _{2.5} concentration at urban AAQ NEPM monitoring sites within a jurisdiction | Yes | Continual improvement and/or no deterioration. Exposure index used to assess progress in reducing population exposure | To be agreed 3 year rolling average |

The analysis of the PM monitoring data has indicated that the numerical values shown in **Table ES1** would be achievable given the current monitoring networks and trends in concentration. Tighter standards than these are unlikely to be achievable in all jurisdictions. No single preferred option for the 24-hour PM₁₀ standard has been identified. The form of the standards has also been left for consultation.

For exposure reduction, meeting a target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 is unlikely to be achievable in practice. The issues and inconsistencies associated with the measurement of PM_{2.5}, coupled with the need to detect relatively small changes in concentrations, mean that checking progress towards any target would also be very challenging. A more practical approach would involve the development of an exposure index based on monitoring to track population exposure for major urban areas using a three-year rolling average PM_{2.5} concentration, as in Europe). Variations of this approach, such as introducing population weightings for different monitoring sites, could be considered as potential refinements.

Consultation

Input is sought from all stakeholders on the options outlined in the Impact Statement.

- Do you agree with the introduction of an annual PM₁₀ standard, given the apparent adverse health effects of coarse particles and their prevalence in some regions?
- Do you support upgrading the current AAQ NEPM advisory reporting standards for PM_{2.5} to compliance standards?
- Do you support the preferred numerical values for new/revised 24-hour and annual PM_{2.5} and PM₁₀ standards? Which value for the 24-hour PM₁₀ standard do you consider to be the most appropriate, and why?
- What is your preferred option for the form of the 24-hour PM₁₀ and PM_{2.5} standards? Should the options be trialled?
- Do you have any comments regarding the possible inclusion of PM metrics, other than PM₁₀ and PM_{2.5}, in the future?
- Do you agree with the preferred form of the exposure-reduction framework under which an exposure index based on monitoring would be used to track population exposure for major urban areas?

Feedback is also welcomed on the analysis and conclusions, and any other aspect of the Impact Statement. A summary of issues on which feedback is sought is included in Appendix F.

All submissions are public documents unless clearly marked 'confidential' and may be made available to other interested parties, including by being published on the NEPC website. Stakeholders should indicate if their submission is confidential or clearly indicate sections that may contain confidential or sensitive information that is not for publication.

Feedback received during the public comment period will be used to inform the development of the AAQ NEPM variation.

The NEPC Act requires that both the draft AAQ NEPM variation and the Impact Statement be made available for public consultation for a period of at least two months. The consultation period will occur over a ten week period from July to October 2014. The views of stakeholders on these documents are being sought through written and online submissions.

Online submissions are preferred and can be made via < www.nepc.gov.au >

Written submissions may also be made and can be sent to:

**The Executive Officer
National Environment Protection Council
Department of the Environment
GPO Box 787
Canberra ACT 2601**

Email: nepc@environment.gov.au

The closing date for submissions is Friday 10 October 2014.

Following the public consultation period, the NEPC is required to prepare a summary of the issues raised in submissions and responses to them. In deciding whether or not to make the AAQ NEPM variation, the NEPC must take both the Impact Statement and the summary of submissions and responses into account.

The following documents have been released by the NEPC to facilitate public consultation on the NEPM variation:

- Exposure Assessment and Risk Characterisation to Inform Recommendations for Updating Ambient Air Quality Standards for PM_{2.5}, PM₁₀, O₃, NO₂ and SO₂ (referred to in this Impact Statement as the Health Risk Assessment (HRA))
- Summary for Policy Makers of the Health Risk Assessment on Air Pollution in Australia
- Economic Analysis to Inform the National Plan for Clean Air (Particles) (referred to in this Impact Statement as the Economic Analysis)
- Evaluating Options for an Exposure Reduction Framework in Australia
- Methodology for Valuing the Health Impacts of Changes in Particle Emissions

Characteristics and measurement of airborne PM

Airborne PM is a complex mixture of substances that are derived from a range of sources and processes. The contributions of these sources and processes, and the physical and chemical properties of PM vary according to many factors.

PM is often classified as being primary or secondary in origin. Primary particles are emitted directly into the atmosphere. Natural sources of primary particles include wind erosion, bush fires and the production of marine aerosol. Anthropogenic (human-made) sources involve fuel combustion (e.g. power generation, domestic wood heaters, vehicles), mechanical suspension (e.g. entrainment of dust from roads at coal mines), or abrasion/fragmentation (e.g. tyre wear). Industrial activities may involve combustion processes, mechanical processes or chemical processes. Secondary particles are not emitted directly but are formed in the atmosphere through chemical reactions involving inorganic or organic gas-phase components. The main gaseous precursors are oxides of nitrogen (NO_x), ammonia (NH₃), sulfur oxides (SO_x) and volatile organic compounds (VOCs). Studies have shown that secondary particles can contribute significantly to PM concentrations.

Airborne particles are measured using various metrics which relate to particle size, and the two metrics that are used most commonly are PM₁₀ and PM_{2.5}. A variety of instruments and methods are available for measuring PM₁₀ and/or PM_{2.5}. The measurement of PM_{2.5} is inherently more difficult, partly because there is a much smaller mass to measure. The Impact Statement summarises the main PM measurement methods in use in Australia. The AAQ NEPM reference method for monitoring PM₁₀ and PM_{2.5} in Australia is the manual gravimetric method. Some automated and continuous methods can also be used as alternatives to the reference method.

Effects and monetary costs of PM

Health effects

Since the AAQ NEPM variation in 2003 there have been significant advances in the understanding of the health effects of PM. These effects are diverse in scope, severity and duration. They include premature mortality, aggravation of cardiovascular disease and aggravation of respiratory disease. Outdoor air pollution has also recently been classified as carcinogenic to humans, with an emphasis on PM in general and specifically PM in diesel engine exhaust (**IARC 2012, 2013**).

The recent advances have been reviewed in a number of key documents (e.g. **USEPA 2009; WHO Regional Office for Europe 2013**), and can be summarised as follows:

- For PM_{2.5}:
 - There is sufficient evidence to conclude that long-term and short-term exposure causes illness and death from cardiovascular conditions, and is likely to cause respiratory conditions.
 - Associations have been observed between exposure and reproductive and developmental effects.
- For PM₁₀:
 - There is extensive evidence that short-term exposure is associated with health effects, and that these effects are independent of the effects of PM_{2.5}.
 - There is evidence of a causal relationship between short-term exposure and cardiovascular and respiratory effects and mortality.
 - There is less evidence that long-term exposure has health effects that are independent of those caused by long-term exposure to PM_{2.5}, nevertheless WHO recommends a long-term air quality standard.
- For other PM metrics:
 - There is increasing, but as yet limited, epidemiological evidence on the association between short-term exposure to ultrafine particles (i.e. particles with an aerodynamic diameter of less than 0.1 µm) and health. This is an area of ongoing research.
 - While there is some evidence that the relationship between PM and health effects depends on chemical composition (e.g. black carbon, secondary organic aerosol (SOA) and secondary inorganic aerosol (SIA)), the evidence is insufficient to conclude that this relationship is causal.

For PM_{2.5} and PM₁₀ the effects observed in Australia and New Zealand are consistent with those reported in the international literature.

Long-term studies have not provided evidence of a threshold for health effects. There is also evidence that exposure to PM at levels experienced in Australian cities is associated with health effects. There would therefore be health benefits from reducing exposure below these levels, and setting standards as low as reasonably achievable.

Other effects

Airborne PM also has adverse impacts on ecosystems, agriculture, visibility, cultural heritage and climate. However, the main focus of public concern is currently on its effects on human health, and these generally account for the majority of the external monetary costs associated with the impacts of air pollution.

Monetary benefits of reducing PM concentrations

Any reduction in exposure to particle pollution will have public health benefits. The health cost of particle air pollution in the NSW Greater Metropolitan is estimated to be around \$4.7 billion per year (NSW DEC 2005; Jalaludin et al. 2011). The greatest proportion (>99%) of the health costs accrue from avoiding premature deaths due to long-term exposure to PM_{2.5}.

Policy context and legislation

AAQ NEPM

AAQ NEPM standards and goals

The AAQ NEPM provides a nationally consistent framework for the monitoring and reporting of ambient air quality in Australia, and establishes air quality standards and goals:

- Air quality standards are expressed as a maximum allowable concentration for a given averaging period.
- Air quality goals are expressed in terms of 'maximum allowable exceedances' to be achieved within 10 years.

The standards and goals of the AAQ NEPM aim to guide policy formulation that allows for the adequate protection of health and wellbeing. Under the current AAQ NEPM, participating jurisdictions (Commonwealth, states and territories) are required to undertake monitoring and public reporting of air pollution and generate data that assist jurisdictions in formulating air quality policies. The AAQ NEPM does not prescribe sanctions for non-compliance with AAQ standards or goals and the AAQ NEPM itself does not compel or direct air pollution control measures.

The specific standards and goals that are set out for short-term (24-hour average) and long-term (annual average) PM₁₀ and PM_{2.5} concentrations in the AAQ NEPM are summarised in **Table ES2**. The standard for PM₁₀ reflects the health-based evidence that was available that informed the making of the AAQ NEPM (NEPC 1998). The advisory standards for PM_{2.5} were also underpinned by the available health evidence, including a risk assessment based on monitoring in four cities over a three-year period (NEPC 2002).

Table ES2: Air quality standards and goals for PM₁₀ and PM_{2.5} in the AAQ NEPM

| Pollutant | Standard | | Goal (maximum allowable exceedances within 10 years) |
|----------------------------------|--------------------|---|---|
| | Averaging period | Maximum concentration | |
| PM ₁₀ | 24 hours | 50 µg/m ³ | 5 days per year |
| PM _{2.5} ^(a) | 24 hours 1 year | 25 µg/m ³ 8 µg/m ³ | Not applicable. Goal is to gather sufficient data nationally to facilitate a review of the advisory reporting standards |

(a) Advisory reporting standards

Use of AAQ NEPM standards by jurisdictions

All states and territories manage emissions and air quality in relation to certain types of sources (e.g. landfills, quarries, crematoria and coal mines). Generally speaking, the jurisdictions have legislation or guidance which includes facility design goals, licence conditions or other ways to protect local communities from the impacts of air pollutants in residential areas outside facility site boundaries. Where this is the case, the AAQ NEPM standards are sometimes used as the criteria for air quality assessments.

The AAQ NEPM standards are currently being used in a variety of locations and contexts, some of which are inconsistent with the original intention of the AAQ NEPM. The AAQ NEPM standards are designed to be applied at locations that are representative of overall air quality in those areas. However, as noted above, they are also sometimes applied at other locations as part of environmental assessment, for example, at the boundary of an industrial facility (i.e. a 'hot spot'). Some jurisdictions are considering alternatives to this approach (e.g. risk-based guidelines for PM in New South Wales (NSW)).

Exposure reduction

In Australia for non-threshold pollutants such as PM, overall health outcomes in a population are driven by large-scale exposure to the prevailing average concentrations, rather than by relatively small-scale exposure to higher concentrations. Where there are no exceedances of air quality standards there may be no impetus to implement measures to further reduce exposure to PM. This has compelled a shift in the approach to air quality management, and in some countries and regions (notably the European Union) this has taken the form of an 'exposure-reduction framework'. The scientific support for the exposure-reduction approach to managing PM has been strengthened by the latest health findings; however, there are currently no targets for exposure reduction in the AAQ NEPM.

International air quality standards and exposure-reduction frameworks

Air quality standards

The Impact Statement reviewed the air quality standards for PM₁₀ and PM_{2.5} that are used internationally. Air quality guidelines have been developed for the most common pollutants by the World Health Organization (WHO). These guidelines are based solely on health considerations, and are used as the basis for development of air quality standards in many countries.

There is currently no annual mean PM₁₀ standard in the AAQ NEPM. Coarse particles are a significant problem in some areas of Australia. Increasing evidence for the adverse effects on health of coarse particles, as distinct from fine particles, suggests that there may be benefits from an annual mean PM₁₀ standard.

The WHO numerical guideline for 24-hour PM₁₀ of 50 µg/m³ has been adopted in Australia and elsewhere (but not in the United States), even though the number of permitted exceedances is greater in Australia than in the WHO guideline. However, fewer exceedances of the standard are provided for in Australia than in most other countries/regions (an exception being New Zealand).

The annual advisory mean standard for PM_{2.5} of 8 µg/m³ in Australia is lower than the current WHO guideline. The current 24-hr PM_{2.5} advisory reporting standard of 25 µg/m³ is identical to the WHO 2005 guideline.

Although the Australian PM standards are numerically lower than, or equivalent to, those in other countries and regions, it is not straightforward to interpret such comparisons and they do not necessarily mean that the Australian standards are more stringent. For example, to a large degree the lower standards in Australia are made possible by relatively low natural background concentrations and the absence of significant anthropogenic transboundary pollution (which is a major issue in Europe, for example). However, as noted earlier, there would still be health benefits in Australia from setting the PM standards as low as reasonably achievable. Also, there are differences in implementation; where they are applied; and there is no sanctions associated with non-compliance with the standards and goals in Australia, whereas there is in other countries and regions.

Exposure-reduction framework

The most prominent example of an exposure-reduction framework is the one that is currently applied in the European Union (EU) through Directive 2008/50/EC. The EU exposure-reduction approach is based on monitoring of PM_{2.5}. Exposure is assessed using an average exposure indicator (AEI) which is calculated as a three-year running annual mean concentration, averaged over all urban background sampling sites in a Member State. The exposure-reduction target applicable to each Member State is a percentage reduction by 2020, with the required reduction being dependent on the baseline concentration in 2010. The Directive also sets an 'Exposure Concentration Obligation', expressed as an AEI of 20 µg/m³, to be met by 2015. This sets a minimum obligation on all Member States.

To understand and quantify population exposure accurately in Australia, information would be required on both (i) the long-term average spatial distribution of air pollution and (ii) the spatial distribution of the population in each urban area. The tools and data to develop an exposure-reduction framework such as the one applied in the EU would include detailed emissions inventories based on a relatively fine grid, comprehensive airshed dispersion models, and high-quality monitoring data. The current AAQ NEPM monitoring networks can provide an indication of the exposure in the area represented by each monitoring site; however, the adoption of an EU-style exposure-reduction framework would require a very significant investment of resources.

Airborne PM in Australia

Emissions inventories and projections

Five jurisdictions in Australia, including the major urban centres of Sydney, Melbourne, Brisbane, Perth and Adelaide have developed emissions inventories; however, there is varying consistency across the jurisdictional inventories and projections in terms of nomenclature, methodology and overall quality.

The most important sectors of activity also differ by jurisdiction. For example, in NSW the largest source of PM₁₀ and PM_{2.5} is coal mining. In metropolitan areas wood heaters, diesel engines and industry are significant sources. Domestic/commercial sources (notably wood heaters) are the most important in Tasmania (TAS). In Victoria (VIC), the largest sources are wood heaters, industry and diesel vehicles. Mobile sources are also important contributors to PM₁₀ and PM_{2.5} in some jurisdictions.

In all jurisdictions emissions of PM₁₀ and PM_{2.5} have been projected to increase between 2011 and 2036, based on, for example, Australian Bureau of Statistics population and industry forecasts. However, the projections vary considerably from jurisdiction to jurisdiction. For example, in NSW, Queensland (QLD) and Western Australia (WA) there is a projected increase in PM₁₀ emissions of around 65%, whereas in VIC and South Australia (SA) it is around 10%. The projected increase in PM_{2.5} emissions ranges from 8% in VIC to around 65% in WA.

Ambient PM concentrations

The air quality environment in Australia is characterised with respect to PM₁₀ and PM_{2.5}, so that the options for the AAQ NEPM variation can be framed in an appropriate context. This work required analysis of the PM₁₀ and PM_{2.5} data from the government-run air pollution monitoring stations in all jurisdictions.

PM concentrations in Australia vary temporally and spatially as a consequence of many different influencing factors. On a day-to-day basis PM concentrations are very variable. Extreme events (notably natural bush fires and dust storms) are often associated with the highest levels of pollution. Various methods are used to measure PM in Australia, and the ability to assess trends can be affected by changes in instrumentation, the relocation of monitoring sites, or a change in the distribution of sites. All of these have occurred in Australia. Notwithstanding, in most jurisdictions there has been a reduction in overall annual mean PM₁₀ and PM_{2.5} concentrations between 2003 and 2012, although in some jurisdictions the concentrations have not decreased significantly. Overall state-average annual mean PM_{2.5} concentrations in 2012 were below the advisory standard of 8 µg/m³; however, it is unclear that the downward trends in annual mean concentrations will continue in the future, especially given that the projections in state inventories show that PM₁₀ and PM_{2.5} emissions are likely to increase under a business-as-usual (BAU) scenario, in spite of controls on emissions from several sectors. Anthropogenic emissions of secondary PM precursors are also predicted to increase in the future.

There continue to be exceedances of the 24-hour PM standards and goals at many monitoring sites. For the 24-hour mean PM₁₀ standard (50 µg/m³), weather, climate and natural events are major factors affecting exceedances. There are no strong underlying trends in the patterns of exceedance. For the advisory 24-hour mean PM_{2.5} standard (25 µg/m³), there have been exceedances at most monitoring sites and in most years.

PM composition

Secondary and natural PM contribute significantly to PM₁₀ and PM_{2.5}. The primary anthropogenic PM_{2.5} component typically represents around 30%–50% of PM_{2.5}. This partial contribution of primary sources complicates air quality management. One of the largest PM_{2.5} components is secondary ammonium sulfate. The relatively slow formation rate of sulfate means that it contributes to PM concentrations on regional scales. Sea salt is an important natural component of PM, even at inland locations, through transport from the coast. There are strong seasonal patterns in PM composition. In inland regional centres of NSW wood smoke is the dominant source of PM_{2.5} during the winter, but is much less important in summer.

Statement of the problem and rationale for government intervention

The need to reduce atmospheric concentrations of PM derives principally from its well-recognised and quantified effects upon human health. The recent historical trend of decreasing ambient concentrations of PM₁₀ and PM_{2.5} is expected to be reversed in the future due to growth in population, economic activity and emissions, with

subsequent increases in population exposure and the incidence of adverse health outcomes, and increases in the monetary costs of air pollution to society.

It is likely to be more difficult to meet the national air quality standards and goals for PM in the future without further intervention. There is an ongoing risk that Australian public health will not be sufficiently protected. Intervention is considered necessary to prompt and accelerate policies and measures to reduce population exposure to particulate air pollution. The extent to which government needs to be involved is informed by environmental and economic data. Updating the AAQ NEPM will reduce these adverse effects by highlighting potential problems and assisting jurisdictions in the formulation of air quality policies to reduce emissions from different sectors.

Government involvement should aim to reduce ambient concentrations of PM₁₀ and PM_{2.5}, especially in populated areas, taking into account the practical limitations on what can be achieved using traditional methods (reducing primary anthropogenic emissions). This needs to be guided by data on PM concentrations and composition. It is known, for example, that a significant proportion of PM is natural and/or secondary in nature. Measures to reduce primary anthropogenic PM emissions should therefore be accompanied by measures to reduce emissions of secondary PM precursors.

Possible approaches and options

General framework

Several alternative types of air quality management framework have the potential to address the problems identified above. The main alternatives are (i) variation of the AAQ NEPM, (ii) Commonwealth legislation, (iii) voluntary guidelines, (iv) an inter-governmental agreement or (v) no change to the current framework. To date the AAQ NEPM framework has allowed for a nationally consistent mechanism for the setting and implementation of air quality standards and goals, and for the monitoring and reporting of air quality against them. The most effective way to ensure future consistency in national air quality management and data collection would be a variation to the existing AAQ NEPM, with states and territories using the AAQ NEPM provisions in their own jurisdiction, as is currently done.

Status of the PM standards

Assuming that an AAQ NEPM variation is the preferred approach, the main choices to be made are whether monitoring and reporting of the PM_{2.5} standards should be of an advisory nature or be adopted as a performance standard, and whether the limits of the existing PM standards should be revised.

PM metrics and averaging periods

The AAQ NEPM currently specifies a 24-hour standard for PM₁₀ concentrations, and advisory reporting standards for 24-hour and annual mean PM_{2.5} concentrations. The addition of an annual mean standard for PM₁₀ is proposed on health grounds. There is currently insufficient data from monitoring networks and health studies in Australia to allow for the consideration of options relating to metrics other than PM₁₀ and PM_{2.5}. Consequently, the options that have been considered here relate solely to the metrics PM₁₀ and PM_{2.5}, and to annual and 24-hour averaging periods in each case.

Numerical values for the PM standards

Potential new air quality standards for both PM₁₀ and PM_{2.5} were considered as options for varying the AAQ NEPM. The options – shown in **Table ES3** – were based on international guidance (e.g. WHO and the United States Environmental Protection Agency (USEPA)), but were also informed by Australian conditions.

One aspect for consideration is whether single-year or multi-year averages are used for the monitoring data when comparing measurements with the standards; for example, a three-year averaging period is used in the US. This is not explicitly addressed in the Impact Statement however.

Table ES3: Options and sub-options – air quality standards

| Action | Options | Sub-option ^(a) | Standard ^(b) |
|----------------------|-----------------------------------|---------------------------|-----------------------------|
| Particle standards | PM ₁₀ annual mean | A20PM ₁₀ | 20 µg/m ³ |
| | | A16PM ₁₀ | 16 µg/m ³ |
| | | A12PM ₁₀ | 12 µg/m ³ |
| | PM ₁₀ 24-hour mean | D50PM ₁₀ | 50 µg/m ³ |
| | | D40PM ₁₀ | 40 µg/m ³ |
| | | D30PM ₁₀ | 30 µg/m ³ |
| | PM _{2.5} annual mean | A10PM _{2.5} | 10 µg/m ³ |
| | | A08PM _{2.5} | 8 µg/m ³ |
| | | A06PM _{2.5} | 6 µg/m ³ |
| | PM _{2.5} 24-hour mean | D25PM _{2.5} | 25 µg/m ³ |
| D20PM _{2.5} | | 20 µg/m ³ | |
| D15PM _{2.5} | | 15 µg/m ³ | |

- (a) A = annual mean; D=daily mean
(b) Current standards are shown in bold

Form of 24-hour standards

The 'form' of a standard refers to the way in which the standard is interpreted and applied. The form of the standard prescribes the approach used to compare actual air quality measurements with the numerical value of the standard. For the annual mean concentration this is relatively straightforward, as only one value is obtained from the measurements. For the 24-hour standard it is more complicated, as there is a need to decide which of the daily measurements in a year should be compared with the standard. For example, in the US, the form of the standard relates to the use of descriptive statistics, and in the case of the 24-hour standard for PM_{2.5} the 98th percentile (averaged over three years) is used. A percentile is a value below which a given percentage of observations in a sample fall. The 98th percentile for the 24-hour PM_{2.5} standard excludes the highest 2% of measured concentrations from comparison with the standard. The 98th percentile was selected as it represents a balance between limiting peak (extreme event) pollutant concentrations and providing a stable regulatory target (**USEPA 2011**). In the US and Europe there is also the possibility for jurisdictions to remove the data for natural or exceptional events (such as bush fires and dust storms) prior to comparing measurements with the standard.

Four options for the form of the 24-hour standards are to be considered for the AAQ NEPM:

- Business as usual option. A rule that allows a fixed number of exceedances of a PM standard in a given year (as is currently the case for PM₁₀), but with no exclusion of data for activity specific exceptional events. The fixed number of allowable exceedance days (e.g. five days per year) would be based on an estimated number of exceptional events. For reporting purposes the occurrence of exceptional events will be recorded, and various statistics will be presented (including percentiles), but these will not be used when comparing measured concentrations with the standard.
- A rule that allows a fixed number of exceedances of a PM standard in a given year, based on the exclusion of data for activity specific exceptional events. This is similar to the approach used in the EU.
- A rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with no specific exclusion of data for exceptional events. For reporting purposes the occurrence of exceptional events will be recorded and various statistics will be presented (including percentiles), but these will not be used when comparing measured concentrations with the standard.
- A rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with the exclusion of data for exceptional events. This is similar to the approach used for PM_{2.5} in the US.

The form of the 24-hour standards should also result in an appropriate balance between the annual mean and 24-hour standards. For example, where these two metrics are applied together there may be a tendency at a given monitoring site for one of them to be exceeded more frequently than the other. From a health and economic perspective – and hence in terms of policy – it is advisable to place more emphasis on the annual mean standard than on the 24-hour standard. As long as separate annual and 24-hour standards are in place, this should not present a practical problem. However, if the numerical value and form of the 24-hour standard are defined so that it is exceeded more frequently than the annual mean standard, this would lead the 24-hour standard to be the controlling standard, with greater potential for action to be focused on short-term concentrations.

Applicability of the AAQ NEPM standards

The approach whereby the AAQ NEPM standards for PM are based on measurements at sites that reflect the general exposure of populations in large metropolitan areas is planned to be maintained. Under this general exposure approach the standards and goals are applicable to urban sites away from sources of pollution, such as busy roads and industrial stacks. Individual jurisdictions can employ complementary methods to inform development applications for proposed infrastructure and industrial proposals in a variety of locations and contexts.

Feasibility of an exposure-reduction framework

The introduction of an exposure-reduction framework into the AAQ NEPM has been considered as a 'co-option'. It is assumed that progress towards reducing exposure would be framed in terms of the monitored PM_{2.5} concentration in major urban areas (as in the AEI approach used in the EU), or an equivalent modelling approach. Two options have been considered, as shown in **Table ES4**. Option ER1 includes the target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 assessed in the Economic Analysis project. Option ER2 would involve a similar approach, without a specific numerical target but with an explicit aim of continual improvement and/or no deterioration of air quality.

Table ES4: Options and sub-options – exposure-reduction

| Option | Sub-option | Description ^(a) | Target |
|--|------------|---|---|
| Exposure-reduction framework co-option | ER1 | 'Exposure index' based on average PM _{2.5} concentration at metropolitan AAQ NEPM monitoring sites | 10% reduction in the annual mean PM _{2.5} concentration between 2015 and 2025 |
| | ER2 | 'Exposure index' based on average PM _{2.5} concentration at metropolitan AAQ NEPM monitoring sites | Continual improvement and/or no deterioration of air quality. Exposure index is used to assess progress in terms of reducing exposure |

(a) The 'exposure index' could either be specified as a single year average or a multi-year average (for example, a three-year average is used in the EU). It is likely that the exposure index would apply only to agglomerations with a population above a certain threshold.

A complete understanding of population exposure in Australia would involve significant investment. However, undertaking first steps towards characterising exposure based on the existing monitoring network would require little or no investment on the part of the jurisdictions. The robustness of the exposure index in a given jurisdiction will increase as jurisdictions monitor PM_{2.5} at more sites.

Impact analysis

Analysis of monitoring data

Numerical values of standards

It is important to consider the achievability of the various options for varying the AAQ NEPM. The impact analysis explores the achievability of the different options and sub-options across Australia with respect to the historical data (for 2003–2012) and trends. Achievability was judged in terms of the likelihood that concentrations will meet a given standard/goal within a reasonable time period, based on the historical trends. This work was complementary to the assessment that was conducted for future concentrations in the Economic Analysis project.

In the Economic Analysis some options were found to be unfeasible in most jurisdictions because the standard was very close to, or below, the regional background concentration. Such conclusions were based on broad generalisations about PM composition which were made to ensure a consistent approach across jurisdictions. The distinction between different PM components was not explicitly considered in the impact analysis, as insufficient local data on PM composition were available in all jurisdictions. However, the different PM components were implicitly included in the measurements.

The literature on health suggests that it would be advisable to include an annual mean standard for PM₁₀ in the AAQ NEPM. The monitoring data and the future projections from the Economic Analysis indicate that a value for the standard of 20 µg/m³ could be achievable and economically beneficial.

The PM₁₀ monitoring data (and the Economic Analysis) indicate that a tightening of the 24-hour standard for PM₁₀ (currently 50 µg/m³) could encourage future improvements in air quality.

For annual mean PM_{2.5} the monitoring data (and the Economic Analysis) indicate that a value for the standard of 8 µg/m³ would be achievable and economically beneficial. Most jurisdictions are already complying with this on an average basis. A move to a standard of 6 µg/m³ however, would appear unrealistic given the background levels of air pollution, and the projected growth in population and emissions.

The PM_{2.5} monitoring data indicate that of the options for a 24-hour standard, the most realistically achievable approach would be to retain the 25 µg/m³ standard.

Form of 24-hour standards

There is no single analysis that can be done to confirm whether any one form of a 24-hour standard is systematically 'better' than any other form of the standard. The most suitable form depends on the objective of the monitoring and the required level of stringency. It is likely that the jurisdictions will want to identify local issues that affect the form of the standards, and therefore this issue has been left for the consultation phase.

The current approach used in the AAQ NEPM – a fixed number of allowed exceedances per year – is straightforward in terms of definition and application, but is arbitrary in nature. It is also difficult to compare results across jurisdictions. For example, the geographical size of Australia means that there are very different climatic influences on PM concentrations in different jurisdictions, and the scale of human activity is vastly different in say, Sydney and Darwin. There can be more than the permitted number of exceedances in one year due to natural events alone. A percentile rule is simple to apply, and the Australian jurisdictions are already calculating percentile values in their AAQ NEPM submissions. Percentiles provide stable and practical reference points for tracking trends in air quality, although they do not aid the understanding of the causes of high-pollution events. A natural or exceptional events rule can overcome some of the confusion concerning the concept of allowable exceedances (either in terms of a fixed number of days or through a percentile) by identifying the real-world causes of pollution events.

The Impact Statement examined specific combinations of standard and allowed exceedance days. This indicated which forms of the standards would be likely to be achievable, but provided no information on the division between those exceedances resulting from human activity and those resulting from natural events. Whilst the jurisdictions already provide basic information on the reasons for exceedances, the formal inclusion of a natural/exceptional events rule in the air quality standards would require the development of a consistent and more advanced approach. A trial could be conducted to test such an approach.

HRA project

The HRA project addressed the period 2006–2010, and can therefore be said to have characterised current exposure to PM, and the effects of the air quality standard options in relation to this current exposure.

The key elements of the HRA were as follows:

- Hazard assessment which involved a review of the literature on the health effects of air pollution.
- Exposure assessment. Baseline (current) exposures and exposures for each air quality standard sub-option were calculated from measured PM concentrations. Calculations were done with and without the influence of extreme pollution events such as bush fires. The HRA estimated exposure in 32 Australian conurbations, including the major metropolitan areas. It should be noted that the results of the HRA do not actually reflect the real-world impacts of setting standards. Rather, they reflect the impact of different exposure scenarios in which the ambient concentrations are set at the values of the options for the standards. However, the HRA assessment does provide a useful indication of what might happen in the future should projected increases in emissions lead to an increase in the PM_{2.5} concentration.
- Risk characterisation. Population data, mortality data and hospitalisation data for the 32 conurbations were combined with exposure data to estimate city-specific deaths and hospitalisations attributable to the exposures for the baseline and the sub-options. Natural background concentrations were subtracted from the exposure data in order to determine the health effects attributable to human activity.

It was found that decreasing short-term exposure to PM₁₀ would reduce attributable hospital admissions for childhood respiratory disease and pneumonia/bronchitis in people aged 65 and above. For the short term (daily) sub-options 50PM₁₀, 40PM₁₀ and 30PM₁₀ these health outcomes would be reduced by around 30%, 50% and 65% respectively over the four cities of Sydney, Melbourne, Brisbane and Perth **Morgan et al. (2013)**.

Morgan et al. (2013) commented that for long-term exposure to PM_{2.5} the HRA results are generally consistent with previous Australian and US estimates. Annual mortality attributable to baseline long-term exposure to PM_{2.5} is estimated to be equivalent to approximately 1590 deaths, or 2.2%, in the four cities. Only the sub-option 6PM_{2.5} would produce meaningful reductions in long-term mortality relating to PM_{2.5} compared with baseline exposures (equivalent to a reduction of approximately 530 deaths or 34%).

The long-term (annual) sub-option 8PM_{2.5} (and also 10PM_{2.5}) would equate to an increase in exposure based on current PM_{2.5} concentrations. This is because annual mean PM_{2.5} concentrations at most monitoring sites are currently lower than 8 µg/m³.

Decreasing short-term (daily) exposure to PM_{2.5} – as per the sub-options 25PM_{2.5}, 20PM_{2.5} and 15PM_{2.5} – would reduce attributable cardiovascular hospital admissions and attributable childhood asthma hospital emergency department attendance by around 30%, 45% and 60% respectively over the four cities (**Morgan et al. 2013**).

It was also noted in the HRA Summary for Policy Makers that the health effects of short-term exposure to PM_{2.5} are driven primarily by the numerous mid-range values within the concentration distribution, and not by the peak exposure days. Therefore, control strategies that focus primarily on reducing extreme days are less likely to achieve reductions in PM_{2.5} exposures that most contribute to health effects, compared with an approach that focuses on reducing the middle range of the PM_{2.5} exposure distribution.

Economic Analysis

The Economic Analysis project addressed the period 2011–2036, and therefore characterised potential future exposure. The project examined the costs and benefits of introducing a package of potentially feasible national abatement measures over the 25-year period relative to a BAU scenario. The actual air quality standard sub-options in **Table ES2** were incidental to this process in the sense that there was no requirement for ambient concentrations to be the same as the standards, as in the HRA project. Rather, the project assessed the likely achievability of the sub-options by 2036 given the trends in emissions and the implementation of the abatement measures. The exposure-reduction target (option ER1) was assessed in a similar way, except for the period 2015–2025.

Not all possible national and state-based abatement measures were considered in the Economic Analysis. The potential benefits would be greater if all possible abatement measures could be assessed. In other words, the benefits identified in the Economic Analysis are likely to be representative but are probably conservative.

Under the BAU scenario it was estimated that there would be overall increases in the population-weighted PM concentrations over the period 2011–2036 due to increases in emissions. For PM₁₀ the increase would be between 0.2 µg/m³ and 2.4 µg/m³, depending on the jurisdiction. PM_{2.5} would increase by up to 1.5 µg/m³, depending on the jurisdiction; the exception was Victoria, where there would be a slight reduction in the PM_{2.5} concentration. As emissions increased slightly during the period 2011–2036, this reduction must be due to a change in the spatial distribution of the population (i.e. people moving away from areas with higher concentrations to areas with lower concentrations).

The increases in concentration under the BAU scenario would be offset in some jurisdictions by the introduction of any national abatement measures to reduce primary anthropogenic PM emissions. The scale of the concentration reductions was modest, but the monetised health benefits in the airsheds considered in the analysis were substantial. The scale of concentration reductions was limited by the contribution of natural and secondary particles to PM_{2.5}. However, reductions in primary anthropogenic PM emissions are also likely to be associated with reductions in the emissions of secondary PM precursors, whereas in the Economic Analysis it was assumed (because of the absence of a suitable model) that the secondary PM contribution would be constant with time. This means that the benefits calculated in the Economic Analysis represent a conservative estimate.

By 2036 the health benefit of meeting each standard was estimated at around \$20.7 billion to \$21.7 billion, and the net benefit after the costs of abatement measures were included was around \$6.4 billion to \$7 billion). It should be noted that the health benefits for the individual standards are not additive.

Meeting the target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 (option ER1) would require very significant additional abatement measures in most jurisdictions. It is concluded that the proposed exposure-reduction target is currently unlikely to be feasible in practice. Nevertheless, it is important to emphasise the likely benefits of an exposure-reduction framework. Even where an AAQ NEPM standard is not exceeded there is a health benefit associated with reducing concentrations, and an exposure-reduction framework provides an appropriate mechanism for this. Therefore, the incorporation of option ER2 into the AAQ NEPM should be considered. This would involve the development of an exposure index for PM_{2.5} for assessing progress against an implicit aim of continual improvement and/or no deterioration of air quality. Option ER2 could be adopted at little or no additional cost to the jurisdictions.

Summary of information for each sub-option

The information obtained for each of the options for the PM₁₀ and PM_{2.5} standards is summarised in **Table ES5**. The main aspects to note are as follows:

- The latest health findings indicate that it would be advisable to include an annual mean standard for PM₁₀ in the AAQ NEPM. This is supported by enHealth. The historical PM₁₀ monitoring data and the future projections from the Economic Analysis indicate that a value for the standard of 20 µg/m³ would be practicable and appropriate.
- The PM₁₀ monitoring data and Economic Analysis indicate that a tightening of the 24-hour standard for PM₁₀ (currently 50 µg/m³) could encourage future improvements in air quality. A change to a standard of 40 µg/m³ would be possible, particularly in most urban areas. However, it would be advisable to retain the 50 µg/m³ standard as an option to be considered during consultation. As moving to the lower value could present some difficulties in certain jurisdictions, an alternative would be to consider an intermediate option of 45 µg/m³. Additionally a move to a lower standard could mean that the 24-hour standard is exceeded more frequently than the annual mean standard, and therefore becomes the controlling standard.
- For annual mean PM_{2.5} the monitoring data and the Economic Analysis indicate that a value for the standard of 8 µg/m³ would be appropriate. Most jurisdictions are already complying with this on an average basis. A move to a standard of 6 µg/m³ would be unrealistic given background levels of air pollution and the projected increases in population and emissions.

-
- The PM_{2.5} monitoring data indicate that the options for a 24-hour standard of 20 µg/m³ and 25 µg/m³ would be feasible. However, if the zero-exceedance rule is retained it would be more realistic to retain the 25 µg/m³ standard. In the Economic Analysis it was concluded that meeting a standard of 20 µg/m³ would be unlikely to be feasible given the large reductions in primary emissions that would be required in several jurisdictions.

The findings for the exposure-reduction options are also summarised in **Table ES5**. Option ER1 is unlikely to be feasible in practice, and option ER2 should be considered.

Other considerations

Resourcing implications for jurisdictions

The resourcing obligations imposed on the jurisdictions by varying the AAQ NEPM PM standards predominantly relate to monitoring and reporting requirements (as currently exist). Monitoring and reporting costs are currently being incurred by jurisdictions and would not be expected to change simply by changing the numerical value of the standards, except perhaps if an annual average PM₁₀ standard is introduced. As PM₁₀ is already being measured under the AAQ NEPM, any such increase should be small. An expansion of the PM_{2.5} monitoring network, commensurate with adoption of formal standards should these be introduced, would be expected over time. Costs associated with the phase-in of PM_{2.5} instrumentation, where it currently don't exist, would be managed over time with planned instrument upgrades and monitoring site refurbishment.

The establishment and management of an exposure-reduction framework according to the options defined in **Table ES4** would entail little or no extra cost. If the jurisdictions choose to assess population exposure in detail through an EU-style exposure-reduction framework, then the costs associated with setting up emissions inventories, regional dispersion models and additional monitoring stations would become more significant.

Costs to industry and business

Options for tighter AAQ NEPM monitoring and reporting standards for ambient particle emissions are presented. The AAQ NEPM itself does not compel or direct pollution control measures. The application of AAQ NEPM standards is at the discretion of individual jurisdictions, and subject to jurisdiction's review processes.

Direct costs associated with the AAQ NEPM standards relate to monitoring and reporting levels of air pollution.

Meeting proposed monitoring and reporting standards for particles would result in significantly improved net economic benefits compared to current standards in terms of improved health outcomes. The proposals include a number of options. If the tightest annual PM₁₀ option were supported in the consultation process, this could have implications for the way jurisdictions choose to manage future licence conditions for some industries.

Social impacts

The AAQ NEPM aims to guide policy formulation for the adequate protection of human health and wellbeing. The AAQ NEPM itself does not compel or direct pollution control measures and accordingly, there are no direct social impacts associated with the variation.

The application of AAQ NEPM standards is at the discretion of individual jurisdictions, and subject to jurisdiction's review processes. Meeting proposed monitoring and reporting standards for particles would result in significantly improved net economic benefits compared to current standards in terms of improved health outcomes.

Table ES5: Summary of information for each sub-option

| Action | Option | Sub-option | Standard ^(a) | Achievability based on analysis of ambient PM data ^(b) | Conclusions from HRA (change in current exposure) | Conclusions from Economic Analysis (2036) | | | Net benefit (\$, 2011 prices) |
|------------------------------|--------------------------------|----------------------|---|---|---|---|--|--|-------------------------------|
| | | | | | | Feasible in principle? ^(b) | Further emission reduction required (by state)? ^(c) | Emission reductions likely to be achievable? | |
| Air quality standards | PM ₁₀ annual mean | A20PM ₁₀ | 20 µg/m ³ | Likely | N/A | Yes | WA | Yes | \$6.4 billion |
| | | A16PM ₁₀ | 16 µg/m ³ | Unlikely | N/A | Yes | NSW, VIC, QLD, WA, NT | No | – |
| | | A12PM ₁₀ | 12 µg/m ³ | Very unlikely | N/A | No | – | – | – |
| | PM ₁₀ 24-hour mean | D50PM ₁₀ | 50 µg/m ³ | Likely | Decrease | Yes | None | No reduction required | – |
| | | D40PM ₁₀ | 40 µg/m ³ | Likely | Decrease | Yes | TAS | Yes | \$6.6 billion |
| | | D30PM ₁₀ | 30 µg/m ³ | Unlikely | Decrease | No | – | – | – |
| | PM _{2.5} annual mean | A10PM _{2.5} | 10 µg/m ³ | Likely | Increase ^(d) | Yes | None | No reduction required | – |
| | | A08PM _{2.5} | 8 µg/m ³ | Likely | Increase ^(d) | Yes | TAS | Yes | \$6.5 billion |
| | | A06PM _{2.5} | 6 µg/m ³ | Unlikely | Decrease | Yes | NSW, QLD, SA, WA, TAS, NT, ACT | No | – |
| | PM _{2.5} 24-hour mean | D25PM _{2.5} | 25 µg/m ³ | Likely | Decrease | Yes | TAS, ACT | Possible | \$6.9 billion |
| D20PM _{2.5} | | 20 µg/m ³ | Likely | Decrease | Yes | TAS, ACT | No | – | |
| D15PM _{2.5} | | 15 µg/m ³ | Unlikely | Decrease | No | – | – | – | |
| Exposure-reduction framework | Co-option | ER1 | 10% reduction in exposure to PM _{2.5} between 2015 and 2025, based on monitoring | N/A | N/A | No | All except NT | No | N/A |
| | | ER2 | Continual improvement and/or no deterioration. Exposure index, based on monitoring | N/A | N/A | Yes | N/A | N/A | N/A |

(a) Current standards are shown in bold.

(b) On average for Australia (does not apply to individual sites).

(c) In addition to the reductions that could be achieved by implementation of a package of all feasible of national measures.

(d) Equates to an increase in exposure based on current PM_{2.5} concentrations because annual mean PM_{2.5} concentrations at most monitoring sites are currently lower than 8 µg/m³.

1 INTRODUCTION

1.1 Overview

In 1998 the *National Environment Protection (Ambient Air Quality) Measure* (AAQ NEPM) established national standards for six common air pollutants known as 'criteria pollutants', and provided a consistent framework for the monitoring and reporting of ambient air quality^{1,2}. The criteria pollutants are:

- carbon monoxide (CO)
- nitrogen dioxide (NO₂)
- sulfur dioxide (SO₂)
- lead (Pb)
- photochemical oxidants as ozone (O₃)
- particulate matter (PM) with an aerodynamic diameter of less than 10 micrometres (µm) (known as PM₁₀).

The AAQ NEPM was varied³ in 2003 to include monitoring and reporting protocols and advisory reporting standards for particles with an aerodynamic diameter of less than 2.5 µm, known as PM_{2.5}. The rationale for including PM_{2.5} in the AAQ NEPM is described in the associated impact statement (**NEPC 2002**).

An initial review of the AAQ NEPM was completed in 2011 (**NEPC 2011a**). In 2012 COAG agreed to prioritise work on particles for the following reasons:

- There is strong evidence that exposure to PM has adverse effects on human health, and a lack of evidence for a concentration threshold below which health effects do not occur. This means that there are likely to be adverse health effects at the concentrations currently experienced in Australian cities, even where these are below the current standards and goals (see **Section 4.1.2.3**).
- PM₁₀ concentrations frequently exceed the current national 24-hour standard and goal in nearly all regions of Australia (**DSEWPC 2011**). However, such exceedances can occur as a result of uncontrollable natural events.
- The potential health benefits of reducing population exposure to PM – and the associated monetary savings for society – are larger than those for other air pollutants.
- The range of cost-effective abatement policies and actions available for PM is larger than that for other pollutants.

In the decade since the AAQ NEPM was varied, there have been significant developments in the understanding of the effects of PM on health and the environment, as well as improvements in monitoring methods.

This Impact Statement collates and analyses available information about PM in Australia. It considers the feasibility, costs and benefits of amending the standards and goals relating to PM, as currently defined in the AAQ NEPM, and the prospect of introducing a framework for reducing population exposure to PM.

This Impact Statement has been prepared for the National Environment Protection Council (NEPC) with reference to the requirements of the NEPC Act. It outlines the basis for options being considered by government.

1.2 Compliance with NEPC requirements

The Impact Statement has been compiled in accordance with NEPC requirements, as follows:

¹ <http://www.comlaw.gov.au/Details/C2004H03935/Download>

² 'Criteria pollutants' is a term used internationally to describe common air pollutants that have been regulated and are used as indicators of air quality. The standards for these pollutants are based on criteria that relate to well- documented health and/or environmental effects. The criteria air pollutants tend to be common to most geographical areas.

³ National Environment Protection (Ambient Air Quality) Measure variation (2003), Gazette 2003, no. S190.

-
- *National Environment Protection Council Act 1994* – under the NEPC Act the NEPC may introduce, vary or revoke any AAQ NEPM, and section 17 requires the Council to prepare the following for the proposed measure (in this case a change to the standards for PM):
 - (a) a draft of the proposed measure
 - (b) an impact statement relating to the proposed measure that includes:
 - (i) the desired environmental outcomes
 - (ii) the reasons for the proposed measure, and the environmental impact of not making the measure
 - (iii) a statement of the alternative methods of achieving the desired environmental outcomes, and the reasons why those alternatives have not been adopted
 - (iv) an identification and assessment of the economic and social impact on the community (including industry) of making the proposed measure
 - (v) a statement of the manner in which any regional environmental differences in Australia have been addressed in the development of the proposed measure
 - (vi) the intended date for making the proposed measure
 - (vii) the timetable (if any) for the implementation of the proposed measure
 - (viii) the transitional arrangements (if any) in relation to the proposed measure.
 - *COAG Best Practice Regulation: A Guide for Ministerial Councils and National Standard Setting Bodies (COAG 2007)*.

The following documents are foundation references of the Impact Statement:

- the AAQ NEPM Review (**NEPC 2011a**)
- the *Methodology for Setting Air Quality Standards in Australia (NEPC 2011b)*, which provides a clearly defined (but not prescriptive) framework and establishes approaches to assessment
- work supporting the review of PM standards:
 - an assessment of the options for an exposure-reduction framework for PM in Australia (referred to hereafter as the ‘Exposure Reduction project’) (**Bawden et al. 2012**)
 - a methodology for valuing the health impacts of changes in PM emissions (referred to hereafter as the ‘PM Valuation project’) (**Aust et al. 2013**)
 - a health risk assessment of PM, O₃, NO₂ and SO₂ (referred to hereafter as the ‘HRA project’) (**Frangos & DiMarco 2013**). A *Summary for Policy Makers of the Health Risk Assessment on Air Pollution in Australia* has also been produced to assist in the communication of the technical content of the HRA project for the purpose of policy development (referred to hereafter as the ‘Summary for Policy Makers’) (**Morgan et al. 2013**)
 - an economic analysis of a range of potential air quality standards for PM_{2.5} and PM₁₀, with consideration of an exposure-reduction framework and PM-abatement measures (referred to hereafter as the ‘Economic Analysis project’) (**Boulter & Kulkarni 2013**).

A wide range of additional material was also considered, including work undertaken to support air quality management policy, both in Australia and overseas, and the peer-reviewed scientific literature.

1.3 Scope and structure of the Impact Statement

When developing air quality standards a ‘weight-of-evidence’ approach is typically used. Health studies play a central role, but the NEPC Act also requires an analysis of environmental, economic and social factors (**NEPC 2011b**). The Impact Statement therefore presents the available information on each of these aspects in relation to specific options for varying the AAQ NEPM standards for PM.

The analysis takes into account some, but not all, of the recommendations of the AAQ NEPM review. The scope of the Impact Statement is defined in terms of the AAQ NEPM review recommendations in **Appendix A**, which summarises how each recommendation has been considered in the Impact Statement.

Key issues addressed by this Impact Statement include:

- the metrics used to quantify PM in the AAQ NEPM
- the numerical values of the PM standards
- the form of the PM standards (e.g. allowed exceedances)
- the options for an exposure-reduction framework for PM.

Other recommendations concerning specific technical matters (e.g. monitoring methods and protocols, site locations) are being considered through existing processes, and are outside the scope of this Impact Statement.

The remaining chapters of the Impact Statement address the following aspects:

- the characteristics and measurement of airborne PM (**Chapter 2**). This chapter summarises the current understanding of the nature of PM, and raises some important issues
- the effects and monetary costs of airborne PM (**Chapter 3**). This chapter focuses mainly on the health effects of particles, and includes some general cost information based on Australian studies
- the policy context and legislation, both in Australia and internationally (**Chapter 4**)
- airborne PM in Australia (**Chapter 5**). This chapter summarises the emissions inventories and projections in each Australian jurisdiction, and includes an analysis of PM₁₀ and PM_{2.5} data from air pollution monitoring sites across the country
- a statement of the problem and the case for government intervention (**Chapter 6**)
- a discussion of the possible approaches and options (**Chapter 7**). This includes the alternative standards for PM₁₀ and PM_{2.5} that are being considered.
- an impact analysis of the options (**Chapter 8**)
- a summary of the preferred options for further consideration (**Chapter 9**). The identification of the preferred options is based on the available evidence
- recommendations for consultation (**Chapter 10**).

A summary of the key points, and potential questions for the public consultation phase, are provided at the end of each chapter. The consultation questions are also listed in **Appendix F**.

2 CHARACTERISTICS AND MEASUREMENT OF AIRBORNE PARTICULATE MATTER

2.1 Characteristics

2.1.1 Overview

Airborne PM is a complex mixture of substances that are derived from a range of sources and processes. The contributions of these sources and processes, and hence the physical and chemical properties of PM, vary according to many factors including location, season, time of day, and both local and regional weather conditions.

The phrase 'airborne particulate matter' is subject to interpretation on a number of different levels. Various historical designations such as 'dust', 'smoke' and 'soot' now compete with stricter scientific descriptions, definitions and metrics that relate to the chemical and physical properties of particles. For example, particles are termed either 'primary' or 'secondary' depending on how they are formed, and either 'natural' or 'anthropogenic' (human-made) with respect to their original source. One of the most important considerations is particle size, with research, legislation and policy often focusing on specific size metrics. These distinctions are described below. Readers seeking a more comprehensive treatment are directed to, for example, the reports of **AQEG (2005, 2012)** and **USEPA (2009)**.

2.1.2 Formation mechanisms and constituents

2.1.2.1 Primary particles

Primary particles are emitted directly into the atmosphere. Natural sources of primary particles include wind erosion, some bush fires, and the production of marine aerosol. Anthropogenic sources involve fuel combustion (e.g. power generation, domestic wood heaters, vehicles), mechanical suspension (e.g. entrainment of dust from roads at coal mines), or abrasion/fragmentation (e.g. tyre wear). Industrial activities may involve combustion processes, mechanical processes or chemical processes. The main constituents of primary particles are elemental carbon, organic compounds, and crustal elements such as silicon (Si), aluminium (Al), calcium (Ca) and iron (Fe).

The amount (in tonnes per year) of primary particles emitted from each source in a given area is quantified in an 'emissions inventory'. In Australia the major anthropogenic sources of PM include mining, transport, industry, domestic solid fuel combustion (wood heaters) and planned (hazard-reduction) burning. More information on emissions in Australia is provided in **Chapter 5**.

2.1.2.2 Secondary particles

Secondary particles are not emitted directly but are formed in the atmosphere through chemical reactions involving inorganic or organic gas-phase components. The process by which secondary particles are formed is termed 'nucleation', whereby molecules of low volatility condense to form solid or liquid matter. There are two distinct types of process. Most secondary particles form by 'heterogeneous' nucleation in which newly formed substances condense onto existing particles, thereby causing them to grow. The second process is called 'homogeneous' nucleation. Some newly-formed molecules have extremely low vapour pressure and, in the absence of an abundance of pre-existing particles (which would favour heterogeneous nucleation), will condense to form wholly new particles (**AQEG 2005**).

The formation of secondary inorganic aerosol (SIA) is comparatively well understood, although some mechanistic details still remain to be determined (**USEPA 2009**). SIA is composed mainly of ammonium sulfate ((NH₄)₂SO₄) and ammonium nitrate (NH₄NO₃), with some sodium nitrate. These compounds originate from the conversion of precursor sulfur oxides (SO_x) and nitrogen oxides (NO_x) in the atmosphere to sulfuric and nitric acids, which are then neutralised by atmospheric ammonium (NH₄⁺). The precursor to atmospheric ammonium is ammonia (NH₃). SO_x and NO_x typically arise from combustion sources. NH₃ emissions are dominated by agricultural sources, such as the decomposition of urea and uric acid in livestock waste (**AQEG 2005**).

Secondary organic aerosol (SOA) is linked to the formation and continuing transformation of low-volatility organic compounds in the atmosphere. The formation of these compounds is governed by a complex series of reactions involving a large number of organic species (**Kroll & Seinfeld 2008**). As a result of this complexity a great deal of uncertainty exists around the process of SOA formation, and source identification presents a substantial challenge (**USEPA 2009**).

The formation of secondary particles happens slowly; the overall oxidation rates of SO₂ and NO₂ are around 1% per hour and 5% per hour respectively. The slowness of these processes – and the fact that the resulting particles are small and therefore have a relatively long atmospheric lifetime – means that secondary particles are usually observed many kilometres downwind of the source of the precursors. Sources of SO₂ typically contribute to secondary sulfate hundreds to thousands of kilometres downwind, whereas NO_x emission sources typically contribute to secondary nitrate tens to hundreds of kilometres downwind. Consequently, there is a reasonably even distribution of secondary PM on a regional scale, with smaller differences between urban and rural areas than for primary particles (**Laxen et al. 2010**). Various studies have shown that secondary particles can contribute significantly to PM concentrations, especially at background sites (see, for example, the extensive review by the United States Environmental Protection Agency (USEPA) (**USEPA 2009**)).

2.1.2.3 Water

Water is a normal component of PM, but the amount present is very variable, and the amount detected depends on the measurement method (e.g. whether an instrument inlet is heated or unheated). Water binds to hydrophilic components of PM such as sulfate, ammonium, nitrate and sea salt. Therefore, reducing emissions of SO₂, NO_x and NH₃ should not only lower the concentrations of their secondary PM components, it should also reduce the mass of particle-bound water (**Matthijsen & ten Brink 2007**).

2.1.3 Particle size distribution

Airborne particles range in diameter from less than 0.01 µm to around 100 µm (a micrometre (µm) is one millionth of a metre). Particles larger than 100 µm, which tend to fall out of the atmosphere within minutes, are commonly termed 'dustfall'. **Figure 2.1** shows a typical atmospheric PM size distribution by mass, as well as formation pathways, elimination (removal) mechanisms and constituents.

It is common to see particles described in terms of three modes relating to sources and size: the nucleation mode, the accumulation mode, and the coarse particle mode. The nucleation mode consists of particles emitted directly from combustion sources, such as road vehicle exhaust, waste incineration and domestic burning. These particles typically have a diameter of less than around 0.05 µm, so even though they may be present in large numbers, each particle is so small that this mode forms only a small proportion of the total aerosol mass. Nucleation mode particles are transformed by coagulation and condensation into larger accumulation mode particles. Accumulation mode particles range between around 0.05 µm and 1 µm in diameter, and usually form a significant fraction of the total aerosol mass. They are also efficient light scatterers, and often dominate optical effects such as visibility. As well as being formed via the coagulation of nucleation mode particles, accumulation mode particles originate from primary emission sources and gas-to-particle transformations in the atmosphere. Particles larger than around 1 µm form the coarse particle mode, and typically include wind-blown crustal matter and material released during mechanical abrasion processes. These coarse particles can also contribute substantially to total aerosol mass.

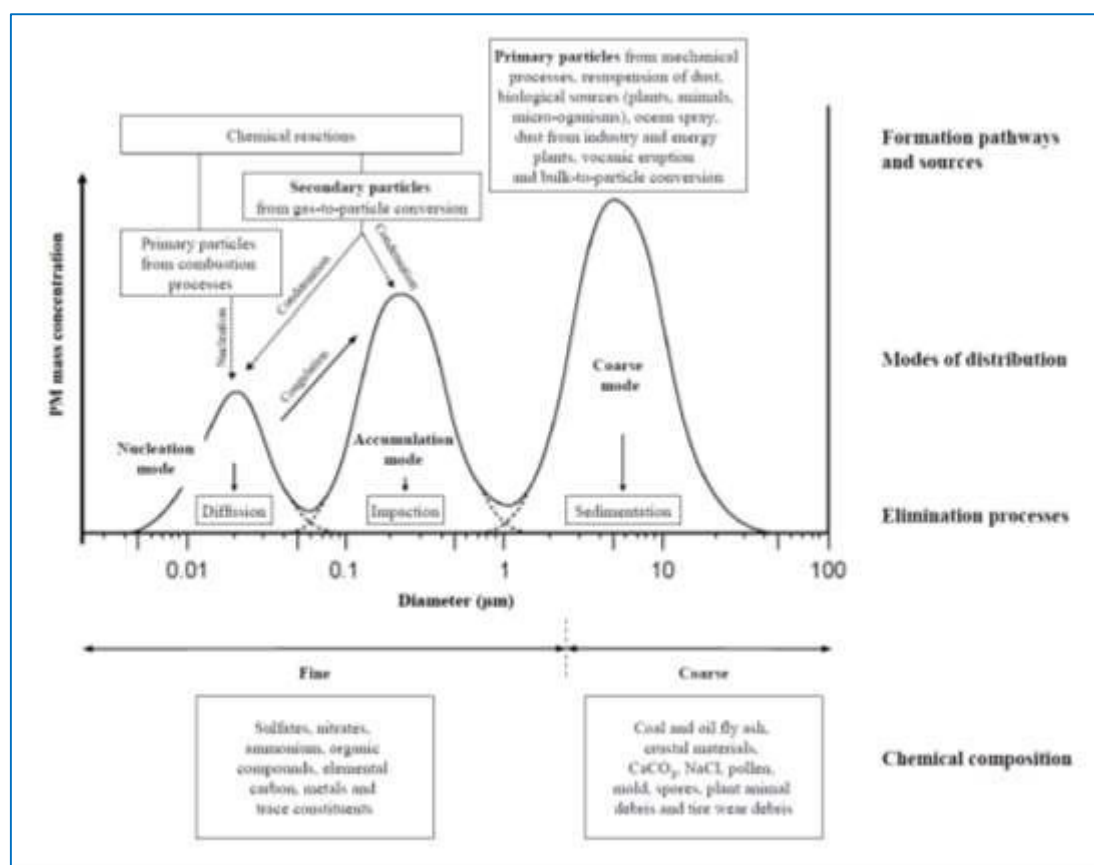


Figure 2.1: Particle classification, size distribution, formation and elimination processes, modes of distribution and composition (Cambrá-López et al. 2010).

Mass concentration is not the only parameter that is used to describe PM; other parameters include the number of particles and their surface area. The form of the size distribution is highly dependent upon how it is expressed. For example, it takes one billion particles of diameter 0.01 µm to equal the volume and mass of one particle of diameter 10 µm. Thus, the number-weighted size distribution gives great emphasis to the nucleation mode; in a typical sample of airborne particles it is usual for 70–80% of the number count of particles to be in the so-called ‘ultrafine’ size range (<0.1 µm) (AQEG 2005).

Airborne particles are measured using various metrics which relate to particle size, and some of the terms and metrics in common use are explained in **Table 2.1**. The two metrics most widely applied at present are PM₁₀ and PM_{2.5}. It can be seen from **Figure 2.1** that PM₁₀ contains the nucleation mode, the accumulation mode and most of the coarse mode. PM_{2.5} is a sub-set of PM₁₀; it also contains the nucleation mode and the accumulation mode, but only a small part of the coarse mode.

AQEG (2012) pointed out that PM₁₀ and PM_{2.5} (and similar) are unusual among air quality metrics in that they are effectively defined by the measurement method rather than as some unambiguous chemical or physical component of the air (such as a gaseous compound). To a large extent this is the consequence of the metrics featuring in legislation before a good scientific understanding of airborne particles was available. As a better understanding has emerged, it has proved difficult to modify the definitions because of the implications for the legislation.

Table 2.1: Metrics used to describe airborne particulate matter

| Term | Definition |
|--|---|
| TSP | Total suspended particulate (matter). |
| PM ₁₀ | Mass concentration of particles passing through a size-selective inlet with a 50% efficiency at 10 µm. This means that almost all the particles in a sample have an aerodynamic diameter of 10 µm or less. These particles are sometimes referred to as 'inhalable', in that they are small enough to be breathed in by humans. |
| PM _{2.5} | As for PM ₁₀ , but with an aerodynamic diameter of 2.5 µm or less. These particles are sometimes referred to as 'fine' or 'respirable', and can penetrate deeper into the lungs than the larger particles in the PM ₁₀ size fraction. |
| PM _{2.5-10} Or PM _{COARSE} | Mass concentration of 'coarse' particles, determined as the difference between PM ₁₀ and PM _{2.5} . This is not altogether consistent with the definition of the coarse particle mode in the size distribution (see Figure 2.1). |
| PM ₁ | As for PM ₁₀ , but with an aerodynamic diameter of 1 µm or less. |
| PM _{0.1} | As for PM ₁₀ , but with an aerodynamic diameter 0.1 µm or less. These are referred to as 'ultrafine' particles. |

2.1.4 Removal mechanisms

Particles are removed from the atmosphere by both dry deposition and wet deposition processes. Dry deposition is caused by gravitational sedimentation, interception/impaction, diffusion or turbulence, although other processes can occur. In wet deposition, atmospheric water (raindrops, snow, etc.) scavenges airborne particles, with subsequent deposition on the earth's surface. As noted earlier, nucleation mode particles also coagulate and condense into larger particles.

The efficiency of the above processes depends on particle size, and hence particles in the different modes have different atmospheric lifetimes. Deposition and coagulation are effective for very small particles due to diffusion. Deposition through settling or impaction is effective for large particles. The removal mechanisms are the least effective for particles in the intermediate size range. Consequently, nucleation mode particles reside in the atmosphere for a few hours, whereas accumulation mode particles have atmospheric residence times of several weeks, and can be transported for hundreds to thousands of kilometres, potentially crossing regional borders. The dispersion of particles in the PM_{2.5} fraction can therefore effectively be treated like that of a gas. This highlights the need to quantify PM_{2.5} at a regional scale, as much of the urban concentration is driven by the regional background (**AQEG 2012**). Coarse mode particles tend to remain in the air for minutes to days, typically travelling a distance of less than 10 km.

2.2 Methods for measuring PM

Measurements of PM in ambient air are usually made to assess compliance with air quality standards or to understand the chemical and physical processes that affect PM composition and concentrations (and hence to develop better models).

A variety of instruments and methods are available, and most of these measure PM₁₀ and/or PM_{2.5}. However, the measurement of PM_{2.5} is inherently more difficult, partly because there is a much smaller mass to measure. As noted above, the method of measurement has a substantial impact on what is measured. In Australia and elsewhere, reference methods have been developed to provide standardisation in the measurement of PM and to improve the comparability of data from different sites. The reference methods for PM₁₀ and PM_{2.5} in Australia involve a manual gravimetric approach, in which a filter is weighed before and after sampling to determine the PM mass. For a variety of practical reasons, the reference methods have not been widely adopted in Australia and other countries (e.g. the UK). A number of non-reference instruments are in widespread use, including the Tapered Element Oscillating Microbalance (TEOM), the Filter Dynamic Measurement System (FDMS), the Beta-Attenuation Monitor (BAM) and optical systems. Not all these methods are equivalent to the reference methods for AAQ NEPM purposes.

Appendix B summarises the Australian reference methods and the main alternatives used in Australia. It is beyond the scope of this Impact Statement to describe the operational characteristics and advantages/disadvantages of these in detail, or to address the future direction of PM monitoring in Australia. Such issues are being addressed by technical working groups.

Key points from Chapter 2

Characteristics of airborne PM

- PM is a complex mixture of substances that are derived from a range of sources and processes. The contributions of these sources and processes, and hence the physical and chemical properties of PM, vary according to many factors.
- The components of PM are often classified as primary or secondary. Both primary and secondary PM can have natural and anthropogenic sources.
- It is common to see particles described in terms of three modes relating to sources and size: the nucleation mode, the accumulation mode, and the coarse particle mode. Particles in the three modes have different properties.

Measurement of airborne PM

- Airborne particles are measured using various metrics which relate to particle size, and the two metrics that are used most commonly are PM₁₀ and PM_{2.5}. PM₁₀ and PM_{2.5} are somewhat ambiguous, being effectively defined by the measurement method.
- A variety of instruments and methods are available for measuring PM₁₀ and/or PM_{2.5}. The measurement of PM_{2.5} is inherently more difficult, partly because there is a much smaller mass to measure.
- The reference method for monitoring PM₁₀ and PM_{2.5} in Australia is the manual gravimetric method.
- Some automated and continuous methods (TEOM, FDMS, BAM, optical monitors) can be used as alternatives to the reference methods, but not all these methods are equivalent to the reference method for NEPM purposes.

Proposed questions for consultation: Characteristics and measurement of airborne PM

- The characteristics of airborne PM are described in some detail. Would any further information on airborne PM characteristics assist in informing action to reduce airborne PM? If so, please provide details.
- Please provide any additional Australia-specific aspects of PM measurement that you believe are important to the actions to reduce airborne PM being considered in this Impact Statement.

3 EFFECTS AND MONETARY COSTS OF AIRBORNE PARTICULATE MATTER

This chapter of the Impact Statement summarises the effects of airborne PM and the monetary costs of these effects where they have been quantified in Australia. Airborne PM has adverse impacts on human health, ecosystems, visibility, cultural heritage and climate (**USEPA 2009; AQEG 2012**). The main focus of public concern is currently on its direct effects on human health, which account for the majority of the external costs associated with the impacts of air pollution⁴. Most of the chapter is therefore devoted to this aspect; however, a brief synopsis of each of the other impacts has also been included to demonstrate the importance of reducing levels of PM and the linkages between different impact areas.

3.1 Effects of PM on human health

3.1.1 Overview

Since the establishment of the AAQ NEPM in 1998 and the variation in 2003, there have been several significant advances in the understanding of the health impacts of ambient PM. In recent years evidence has accumulated indicating that airborne particles have a range of adverse effects on health. These effects – which are diverse in scope, severity and duration – include the following:

- premature mortality
- aggravation of cardiovascular disease such as atherosclerosis
- aggravation of respiratory disease such as asthma
- changes to lung tissue, structure and function
- cancer⁵
- reproductive and developmental effects
- changes in the function of the nervous system.

Importantly, the International Agency for Research on Cancer has recently classified outdoor air pollution as carcinogenic to humans, with a specific emphasis on PM and diesel engine exhaust (**IARC 2012, 2013**).

The biological effects of inhaled particles are determined by their physical and chemical properties, by the sites of deposition, and by their mechanisms of action. The potential of particles for causing health effects is directly linked to their size (**Harrison et al. 2010**). With normal nasal breathing larger particles with an aerodynamic diameter between 10 µm and 100 µm are deposited in the extrathoracic part (nose, mouth and throat) of the respiratory tract. These are then usually easily eliminated by the body through expiration or by ingestion. Most of the particles in the 5–10 µm range are deposited in the proximity of the larynx and enter the thoracic region. However, particles with a diameter of less than 2.5 µm can penetrate deep into the human respiratory system. PM_{2.5} and PM₁₀ have been shown in numerous epidemiological studies to be associated with mortality and hospitalisation from cardiovascular and respiratory causes. A growing body of research has pointed towards the PM_{2.5} fraction as being the most significant in relation to health outcomes.

⁴ Excluding any climate-related effects of greenhouse gas emissions.

⁵ Particles may contain carcinogenic substances such as polycyclic aromatic hydrocarbons (PAHs) or heavy metals.

A number of different types of study have been used to investigate the health effects of PM. Broadly, these are:

- population-based epidemiological studies
- clinical studies in humans
- toxicological studies in animals and in vitro.

Epidemiological studies show that real-world exposure to ambient levels of PM is associated with health effects. Because of this, air quality standards are generally based on the results on these studies. Clinical and toxicological studies support the findings of epidemiological studies by showing, for example, that there are biologically plausible mechanisms by which an air pollutant might cause a health effect. An association observed in a well-designed epidemiological study is more likely to be causal if:

- the association is consistent with the results of other epidemiological studies conducted in different places and by different investigators
- the evidence drawn from different lines of enquiry (for example, clinical and toxicological studies) is coherent with that drawn from epidemiological studies
- there are biologically plausible mechanisms for the hypothesised health effect.

The recent advances in the understanding of the health impacts of air pollution, and specifically the impacts of PM, have been extensively reviewed and summarised in a number of key documents, including:

- *Air quality guidelines – global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide (WHO Regional Office for Europe 2006)*
- *Integrated Science Assessment for Particulate Matter (USEPA 2009)*
- *Long-term exposure to air pollution: effect on mortality (COMEAP 2009)*
- *The mortality effects of long-term exposure to particulate air pollution in the United Kingdom (COMEAP 2010)*
- *Review of evidence on health aspects of air pollution (REVIHAAP) project (WHO Regional Office for Europe 2013)⁶.*

The following sections consider the health evidence for PM₁₀, PM_{2.5} and other PM metrics.

3.1.2 Evidence for PM_{2.5}

There is sufficient evidence to conclude that long-term and short-term exposure to PM_{2.5} causes illness and death from cardiovascular conditions, and is likely to cause respiratory conditions (USEPA 2009; WHO Regional Office for Europe 2013). The effects observed in relation to PM_{2.5} from a large study conducted in Australia and New Zealand (EPHC 2010) are consistent with the effects reported in the international literature.

Associations have also been observed between exposure to PM_{2.5}, reproductive and developmental effects, and cancer. In 2009, the USEPA concluded the evidence was suggestive of a causal relationship (USEPA 2009).

⁶ The report from the REVIHAAP project is presented in terms of answers to 24 questions that were relevant to the ongoing review of European Union (EU) policies on air pollution, and to the health aspects of these policies. The project reviewed the scientific literature for PM, ground-level ozone, NO₂, SO₂, individual metals and PAHs published after the 2005 global update of the WHO air quality guidelines.

3.1.3 Evidence for PM₁₀

There is extensive evidence that short-term exposure to PM₁₀ is associated with health effects, and that these effects are independent of the effects of PM_{2.5}.

In 2009 the USEPA concluded that there was suggestive evidence of a causal relationship between short-term exposure to coarse particles (PM_{2.5-10}) and cardiovascular and respiratory effects and mortality (**USEPA 2009**). Since that time, evidence of these short-term effects has increased significantly, and the WHO has stated that 'sufficient evidence exists for proposing a short-term standard for PM₁₀, to protect against the short-term health effects of coarse particles, in addition to fine particles' (**WHO Regional Office for Europe 2013**).

There is substantially less evidence that long-term exposure to PM₁₀ has health effects that are independent of those caused by long-term exposure to PM_{2.5}. However, in regard to management of long-term exposure, the WHO has stated that 'a limit to protect against long-term exposure should be maintained as new evidence is published on health effects of long-term exposure to PM₁₀ from Europe, and as long as there remains uncertainty about if these health effects would be eliminated by reduction of long-term exposure to PM_{2.5} alone' (**WHO Regional Office for Europe 2013**).

As with PM_{2.5}, the effects observed in the Australian and New Zealand NEPC multi-city study (**EPHC 2010**) in relation to PM₁₀ exposure are consistent with those observed internationally.

3.1.4 Evidence for other PM metrics

There is increasing, but as yet limited, epidemiological evidence on the association between short-term exposure to ultrafine particles and cardiovascular and respiratory health (**WHO Regional Office for Europe 2013**). This is an area of ongoing research.

Studies have also investigated the relationship between measures of specific PM components (for example, black carbon, SOA and SIA) and health effects (**WHO Regional Office for Europe 2013**). In the future, the use of these metrics may provide a better indication of exposure to PM from particular sources, such as vehicle exhaust, and may improve the understanding of the associated health risks. While there is some evidence that the relationship between particles and their health effects depends on their chemical composition, the evidence is insufficient to conclude this relationship is causal (**Bell 2012**).

3.1.5 Linearity and thresholds

The linearity of the relationship between exposure to PM_{2.5} and health response – and correspondingly the existence or otherwise of a threshold for health effects – has been the subject of several studies since the WHO 2005 air quality guidelines global update. For studies of short-term exposure to PM_{2.5} there is substantial evidence of associations down to very low levels. Studies of long-term exposure face greater methodological challenges to fully assess thresholds and linearity, and fewer long-term studies have examined the shape of the concentration–response functions. **WHO Regional Office for Europe (2013)** commented that long-term studies have not detected significant deviations from linearity (i.e. no evidence of a threshold for effects) for the ambient levels of PM_{2.5} observed in Europe. Similarly, researchers in the United States have consistently found no evidence of a threshold concentration below which adverse health effects are not observed (**Pope and Dockery 2006; Brook et al. 2010; USEPA 2009**). In Canada, **Crouse et al. (2012)** investigated the long-term exposure to ambient PM_{2.5} in non-immigrant adults, and observed associations with cardiovascular mortality at concentrations as low as only a few micrograms per cubic meter. This last study is particularly relevant, because it investigated the effects of PM_{2.5} at levels commonly experienced in Australia.

3.1.6 Relevance to Australia

At the time the AAQ NEPM was introduced there were few Australian epidemiology studies linking adverse health effects with exposure to air pollution. Consequently, the AAQ NEPM standards were based on evidence from overseas, particularly from the United States. The review of the AAQ NEPM noted that subsequent epidemiology studies in Australia have shown similar effects to those in some other countries; the effects appear to be similar to those in Canada, but greater than those in the United States and Europe. These studies provide evidence of adverse health effects at pollution levels that are currently experienced in Australian cities (**NEPC 2011a**).

Australia currently has a short-term (24-hour) ambient standard for PM₁₀, and advisory short-term and long-term (annual) standards for PM_{2.5} (see **Section 4.1.2.3**). The Australian Environmental Health Standing Committee (enHealth)⁷ has provided advice⁸ to support the revision of the PM standards in the AAQ NEPM. This advice is provided in **Appendix C**. The main enHealth recommendations are as follows:

- Given the clear evidence that long-term and short-term exposure to PM_{2.5} causes adverse health effects, enHealth strongly supports the proposal to introduce formal national standards for annual average and 24-hour average PM_{2.5} concentrations.
- In light of the increasing evidence that short-term exposure to PM₁₀ is independently associated with health effects, enHealth supports a formal 24-hour standard for PM₁₀.
- While there is less certainty around the health effects of long-term exposure to PM₁₀, enHealth considers that the introduction of a long-term PM₁₀ standard would be prudent, given (a) the increasing evidence in this area, (b) the uncertainty that all health effects would be eliminated by controlling PM_{2.5} only, and (c) the currently sparse nature of PM_{2.5} monitoring in Australia.

The AAQ NEPM review noted that there are no routine monitoring data in Australia that could be used for epidemiological studies of ultrafine particles, or to set standards for such particles (**NEPC 2011a**). Similarly, there are no Australian health studies for the coarse PM size fraction (PM_{2.5-10}), and very few monitoring data to support the setting of standards for individual PM components.

3.2 Other effects

3.2.1 Ecosystems

AQEG (2012) observed that PM may have both direct and indirect effects on ecosystems. There appear to be few direct effects of dry particles on vegetation except where leaf surfaces are covered by dust (e.g. from industrial or agricultural activity), but hygroscopic particles deposited on leaf surfaces enable the efficient bi-directional transport of water and solutes between the leaf interior and the leaf surface. Large accumulations of particles on leaves may affect the drought tolerance of trees, potentially leading to regional tree dieback. However, the largest effects of human-made aerosols on ecosystems are likely to be indirect. Secondary PM_{2.5} makes an important contribution to sulfur and nitrogen deposition, leading to the acidification and eutrophication of natural ecosystems.

3.2.2 PM–climate interactions

The different components of PM have different effects on climate. On the one hand, secondary aerosols are reflective, and the scattering of solar radiation has a cooling effect on climate. The cooling effects of sulfate aerosol may have partly masked the warming effects of greenhouse gases. Black carbon, on the other hand, absorbs solar radiation and thus exerts a warming effect on climate. Aerosols also act as cloud condensation nuclei, increasing droplet numbers and decreasing the average droplet size. This process affects the ability of the clouds to scatter radiation. The precipitation efficiency from the clouds is also reduced, so that their lifetime is increased. Overall, aerosols have a net cooling effect but its magnitude is highly uncertain (**AQEG 2012**). The effects of PM on ecosystems described earlier may also indirectly affect concentrations of the greenhouse gases carbon dioxide and methane.

AQEG (2012) notes that it is difficult to predict the effects of climate change on regional air quality. Hot summers are likely to become more 'typical' in the future, leading to a higher frequency of summer pollution episodes. Emissions of volatile organic compounds (VOCs), which are implicated in secondary PM formation, will also increase at higher temperatures.

⁷ enHealth is a standing committee that falls under the auspices of Australian Health Protection Principal Committee (AHPPC). It includes representatives from Commonwealth, state and territory health departments, the New Zealand Ministry of Health, and the National Health and Medical Research Council. enHealth provides environmental health policy advice, implements the National Environmental Health Strategy, consults with key stakeholders, and develops and coordinates research, information and practical resources on environmental health matters at a national level.

⁸ Stated in a letter from enHealth to Mr Barry Buffier of the Air Thematic Oversight Group on 4 October 2013.

3.2.3 Visibility

The presence of particles and gases in the atmosphere is associated with reduced visibility (often referred to as 'haze'). This not only reduces amenity but can also pose a safety hazard. The public often considers visibility to be an indicator of overall air quality, which could negatively impact on quality of life. The phenomenon is due to the light scattering or light absorption properties of particles and gas molecules, and fine particles are known to be amongst the most effective agents.

3.2.4 Materials and cultural heritage

The effects of air pollution on materials are related to both aesthetic appeal (mainly due to soiling) and physical damage. Deposited particles cause the soiling of building materials and culturally important items such as statues and works of art. The soiling of buildings constitutes a visual nuisance that leads to the loss of architectural value. It requires remediation by cleaning, washing or repainting, and an increased frequency of treatment of the exposed surface may reduce the usefulness of the soiled material. **USEPA (2009)** concluded that there is sufficient evidence of a causal relationship between PM and effects on materials. Physical damage from dry deposition of PM can also accelerate natural weathering processes. For example, the natural process of metal corrosion is enhanced by exposure to PM; the formation of hygroscopic salts increases the duration of surface wetness and enhances corrosion. Particles, especially carbon, may help catalyse chemical reactions that result in the deterioration of materials.

3.3 Costs associated with airborne PM in Australia

The economic burden associated with exposure to air pollution can be linked to direct costs to the health system for hospital admissions and visits to the doctor, medication costs, costs to businesses for reduced productivity and absenteeism, and costs to individuals experiencing mild or severe health effects (**BDA Group 2013**).

The health costs of air pollution in Australia are estimated to be in the order of \$11.1 billion to \$24.3 billion annually, solely as a result of mortality (**Begg et al. 2007; Access Economics 2008**). For Sydney alone it has been estimated that reducing exposure to PM₁₀ could save \$4.7 billion per year (**NSW DEC 2005b**). More recently, **Jalaludin et al. (2011)** found that if the PM₁₀ concentration in the NSW Greater Metropolitan Region (GMR) could be reduced to 10 µg/m³ then approximately 490 respiratory disease hospitalisations would be avoided each year. If the PM_{2.5} concentration could be reduced to 5 µg/m³ then, on average, approximately 860 deaths and 510 cardiovascular disease hospitalisations would be avoided annually. The health benefit for the NSW GMR as a consequence of reducing ambient PM_{2.5} and PM₁₀ to these levels was estimated to be \$5.7 billion. Road transport is an important source of PM; the health costs of PM₁₀ emissions from road transport in Australia have been estimated to be \$2.7 billion per year (**BTRE 2005**).

Premature death is the most significant health endpoint from a cost perspective. For the NSW GMR **Jalaludin et al. (2011)** noted that the greatest proportion (>99%) of the health benefits were accrued from avoiding premature deaths due to long-term exposure to PM_{2.5}. Premature death is the major driver of health benefits because of the high monetary value allocated to a human life. For example, **Jalaludin et al. (2011)** used a value of a statistical life (VSL) of \$6.5 million, compared with around \$5000 for the cost of a respiratory disease hospital admission and around \$9000 for the cost of a cardiovascular disease hospital admission.

Health benefits from lower particle emissions will vary between Australian airsheds⁹ due to climate, meteorology, demographics and population exposure. More recent estimates of the monetary benefits of reducing PM₁₀ and PM_{2.5} concentrations were obtained in the economic analysis undertaken (**Boulter & Kulkarni 2013**), and these are described in more detail later in the Impact Statement.

⁹ The concept of the 'airshed' is used frequently in the context of air quality management in Australia. An airshed is the body of air that lies above a particular geographic area and behaves in a broadly coherent way with respect to the dispersion of air pollutants. Airsheds are typically bounded by meteorology and topography, often leading to the containment of air pollutants. However, pollutants having a long atmospheric lifetime can be transported between different airsheds.

Key points from Chapter 3

Health effects of airborne PM

- Airborne PM has a range of adverse effects on health, including premature mortality and aggravation of cardiovascular/respiratory disease. Outdoor air pollution has been classified as carcinogenic to humans, with an emphasis on PM in general and specifically PM in diesel engine exhaust.
- For PM_{2.5}:
 - There is sufficient evidence to conclude that long-term and short-term exposure causes illness and death from cardiovascular conditions, and is likely to cause respiratory conditions.
 - Associations have been observed between exposure and reproductive and developmental effects.
- For PM₁₀:
 - There is extensive evidence that short-term exposure is associated with health effects, and that these effects are independent of the effects of PM_{2.5}.
 - There is evidence of a causal relationship between short-term exposure and cardiovascular and respiratory effects and mortality.
 - There is less evidence that long-term exposure has health effects that are independent of those caused by long-term exposure to PM_{2.5}, although WHO recommends a long-term air quality standard for PM₁₀.
- For other PM metrics:
 - There is increasing, but as yet limited, epidemiological evidence on the association between short-term exposure to ultrafine particles and health.
 - While there is some evidence that the relationship between PM and health effects depends on chemical composition (e.g. black carbon, SOA and SIA), the evidence is insufficient to conclude that this relationship is causal.
- For PM_{2.5} and PM₁₀ the effects observed in Australia and New Zealand are consistent with those reported in the international literature.
- There is evidence that exposure to PM at levels experienced in Australian cities is associated with health effects. There would therefore be health benefits from reducing exposure below these levels, and setting standards as low as reasonably achievable.

Monetary costs of airborne PM

- Reducing exposure to PM₁₀ and PM_{2.5} in Sydney alone could save around \$5 billion per year.
- The greatest proportion (>99%) of the health benefits are accrued from avoiding premature deaths due to long-term exposure to PM_{2.5}.

Proposed question for consultation: Health effects and monetary costs of airborne PM

- Is there any any additional Australia-specific information on the health effects or monetary costs of PM that should be included? If so, please provide details.

4 POLICY CONTEXT AND LEGISLATION

4.1 Air quality management in Australia

4.1.1 Governance

4.1.1.1 National Environment Protection Council (NEPC)

The National Environment Protection Council is a statutory body with law-making powers. It was established under the National Environment Protection Council Act 1994 (Commonwealth)(the NEPC Act), and corresponding legislation in other Australian jurisdictions. The members of the NEPC are ministers from the participating jurisdictions. The NEPC's primary functions are to make National Environment Protection Measures (NEPMs), and to assess and report on the implementation and effectiveness of NEPMs in participating jurisdictions.

A NEPM is a legislative instrument that is designed to protect particular aspects of the environment in a consistent way across state, territory and Commonwealth jurisdictions. It may have one or more goals, standards and protocols, and may also contain guidelines. As defined by the NEPC Act, a NEPM standard consists of quantifiable characteristics of the environment against which environmental quality can be assessed. The implementation of NEPMs is outside the NEPC's jurisdiction, and is achieved through state and territory legislation and associated regulations. Each jurisdiction is required to allocate sufficient resources to enforce the NEPM and report annually on its implementation.

4.1.2 AAQ NEPM and review

4.1.2.1 Overview

As noted in **Section 1.1**, in 1998 the AAQ NEPM established national standards for six criteria pollutants, including PM₁₀, and provided a consistent framework for the monitoring and reporting of ambient air quality. The AAQ NEPM was varied in 2003 to include advisory reporting standards for PM_{2.5}. The AAQ NEPM was supported by a peer review committee (PRC) which produced a set of advisory technical papers, and provided guidance and advice on monitoring and reporting.

A strategic and technical review of the AAQ NEPM was published in 2011 (**NEPC 2011a**). This review assessed whether the AAQ NEPM was achieving its desired environmental outcome, and provided an opportunity for feedback from interested parties regarding the efficacy of the current framework. In 2012 NEPC agreed that the review's recommendations would be prioritised (described in **Section 4.1.4**). The recommendations of the 2011 review are listed in **Appendix A**, which also describes how each one has been considered in this Impact Statement.

4.1.2.2 AAQ NEPM goal

The overall goal of the AAQ NEPM is to attain 'ambient air quality that allows for the adequate protection of human health and wellbeing'.

4.1.2.3 PM standards and goals

The AAQ NEPM establishes air quality standards and goals:

- Air quality standards are expressed as a maximum concentration for a given averaging period.
- Air quality goals are expressed in terms of 'maximum allowable exceedances' to be achieved within 10 years.

The specific standards and goals that are set out for short-term (24-hour average) and long-term (annual average) PM₁₀ and PM_{2.5} concentrations in the AAQ NEPM are summarised in **Table 4.1**. There is currently no annual mean standard for PM₁₀.

Table 4.1: Air quality standards and goals for PM₁₀ and PM_{2.5} in AAQ NEPM

| Pollutant | Standard | | Goal (maximum allowable exceedances within 10 years) |
|----------------------------------|--------------------|---|--|
| | Averaging period | Maximum concentration | |
| PM ₁₀ | 24 hours | 50 µg/m ³ | 5 days per year |
| PM _{2.5} ^(a) | 24 hours 1 year | 25 µg/m ³ 8 µg/m ³ | Not applicable. Goal is to gather sufficient data nationally to facilitate a review of the advisory reporting standards. |

(a) Advisory reporting standards.

The standard for PM₁₀ corresponds to the health-based evidence that was available in the mid-to-late 1990s to inform the making of the AAQ NEPM (**NEPC 1998**). The advisory standards for PM_{2.5} were also underpinned by the available health evidence, including a risk assessment based on monitoring in four cities over a three-year period (**NEPC 2002**).

The standards and goals of the AAQ NEPM are not enforceable but aim to guide policy formulation that allows for the adequate protection of health and wellbeing. Under the current AAQ NEPM, participating jurisdictions (Commonwealth, states and territories) are required to undertake reporting and monitoring activities to provide data that assist jurisdictions in formulating air quality policies. The AAQ NEPM itself does not compel or direct pollution control measures.

4.1.2.4 Exposure reduction

For non-threshold pollutants such as PM, it has become clear that the overall health outcomes in a population are driven by large-scale exposure to the prevailing background concentration, rather than by relatively small-scale exposure to higher concentrations at localised 'hot spots'. This has compelled a shift in the approach to air quality management, and in some countries and regions (notably the EU) this has taken the form of an 'exposure-reduction framework'. Exposure-reduction is discussed in more detail in **Section 4.2.2**. There are currently no targets for exposure reduction in the AAQ NEPM.

4.1.2.5 Performance monitoring stations

The states and territories are currently required to monitor and report on air quality to determine whether the AAQ NEPM standards are being met within populated areas. Two approaches are available for evaluating performance against the standards:

- Pollutant concentrations can be measured at 'performance monitoring stations'.
- Pollutant concentrations can be assessed by other means that provide information that is equivalent to measurements. These methods could include, for example, the use of emissions inventories, dispersion modelling, and comparisons with other regions.

Clauses 13(1) and 13(2) of the AAQ NEPM provide guidance on the location of performance monitoring stations¹⁰. The air quality standards are designed for locations that are generally representative of the level of exposure of the broad population, rather than for 'hot spots' near major point sources or roads. The AAQ NEPM monitoring protocol (**PRC 2001a**) states that some monitoring stations should be located in populated areas which are expected to experience relatively high concentrations, providing a basis for reliable statements about air pollution within the region or sub-region as a whole. These stations are called 'generally representative upper bound (GRUB) for community exposure' sites. A performance monitoring station should be operated in the same location for at least five years.

The number of performance monitoring stations for a region with a population of 25,000 people or more is the next whole number above the value calculated in accordance with the formula $(1.5 \times P) + 0.5$, where **P** is the

¹⁰ Performance monitoring stations should be sited, to the extent practicable, in accordance with the requirements of Australian Standard AS2922–1987(Ambient Air – Guide for Siting of Sampling Units).

population of the region (in millions). Additional (or fewer) performance monitoring stations can be implemented depending on local and regional conditions, or existing pollutant levels.

Under the current monitoring protocol in the AAQ NEPM, the exposure of people who live near major sources of pollution – such as busy roads – is not assessed through air quality monitoring. Such people are likely to be exposed to higher levels of air pollution than those measured at performance monitoring stations (**NEPC 2011a**).

4.1.2.6 Trend monitoring stations

Some performance monitoring stations in each state or territory must be nominated as 'trend' stations. The number of trend stations must be sufficient to enable the assessment of long-term changes in ambient air quality in different parts of the jurisdiction. A trend station must be operated in the same location for at least ten years.

4.1.2.7 Monitoring methods – PM₁₀

Clause 16 of the AAQ NEPM requires Australian Standard monitoring methods to be used for each specific pollutant (see **Section B.1** in **Appendix B**). Where an Australian Standard Method has not yet been developed for a monitoring method, appropriate internationally recognised methods or standards may be used that provide equivalent information for assessment purposes. **PRC (2001c)** provides guidance on the handling of TEOM PM₁₀ data.

4.1.2.8 Monitoring methods – PM_{2.5}

The measurement and assessment of PM_{2.5} is to be undertaken at existing or planned performance monitoring stations for PM₁₀. Each participating jurisdiction must establish at least one monitoring location for PM_{2.5}. The USEPA reference (or equivalent) methods for monitoring PM_{2.5} should be used. Continuous methods (e.g. TEOM) may also be employed in addition to the reference method.

Schedule 5 of the AAQ NEPM establishes a program to assess whether the TEOM could be considered to generate data that are equivalent to the PM_{2.5} reference method. The Schedule describes the requirement for each jurisdiction to undertake a program of monitoring using co-located instruments for the purpose of determining equivalence.

4.1.2.9 Evaluation of performance against standards and goal

Clause 17 of the AAQ NEPM sets out the criteria for evaluating performance against the standards and goals. Jurisdictions are required to assess their annual performance against the AAQ NEPM standards and goals at each monitoring station. Performance is assessed as 'met', 'not met', or 'not demonstrated'¹¹.

4.1.2.10 Reporting

Each year, jurisdictions must submit an annual report to the NEPC on the implementation and effectiveness of the AAQ NEPM. Clause 18 of the AAQ NEPM establishes the reporting requirements for annual performance reports, including the performance assessment described above, an analysis of the extent to which the standards are met, a statement of the progress made towards achieving the goal, and a description of the circumstances that led to any exceedances of the standards, including the influence of natural events and fire management.

4.1.2.11 Accountability

Under the NEPC Act, accountability for meeting the standards lies in the public reporting; that is, there are no penalties associated with non-compliance. Jurisdictions are only required to evaluate their performance at each monitoring station against the AAQ NEPM standards and goals, and to report the results to the NEPC each year.

¹¹ Not demonstrated relates to whether there were sufficient data available for a pollutant at the monitoring station to enable an assessment.

4.1.3 Use of AAQ NEPM PM standards and goals by jurisdictions

4.1.3.1 Overview

The AAQ NEPM standards were established in relation to broad air quality within airsheds, and are applicable at urban locations away from hot spots. The original intent of the AAQ NEPM was to avoid monitoring near localised point sources of pollution and at peak sites, as these would not represent general population exposure¹² (**NEPC 2011a**). Generally speaking, the Australian states and territories manage emissions and air quality in relation to certain types of source (e.g. landfills, quarries, crematoria and coal mines). The jurisdictions have legislation or guidance which includes design goals, licence conditions or other instruments for protecting local communities from ground-level impacts of pollutants in residential areas outside site boundaries. Where this is the case, the AAQ NEPM standards are often used as the criteria for air quality assessments. For example, environmental licences may contain conditions requiring compliance with the AAQ NEPM standards at a site boundary or at the nearest sensitive receptor. Environmental licences often also contain requirements to implement costly monitoring of ambient air quality. If a company is shown not to comply with licence conditions, in many cases legal action can be taken.

The following paragraphs summarise how the AAQ NEPM standards for PM are implemented in this context by the separate jurisdictions.

4.1.3.2 NSW

In NSW the statutory methods that are used for assessing air pollution from stationary sources are listed in the document *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (**NSW DEC 2005a**). The NSW approved methods do not contain specific information on the assessment of, for example, transport schemes and land-use changes. Air quality must be assessed in relation to criteria and averaging periods for specific pollutants (including PM₁₀) that are taken from several sources, notably the AAQ NEPM. There is no requirement to evaluate PM_{2.5} in the NSW approved methods. The modelling of industrial emissions is required for licensing applications. The approved methods document sets the AAQ NEPM standard for PM₁₀ as an assessment criterion at the nearest sensitive receptor, but it is often applied at the boundary.

New 'Risk Based Particulate Matter Guidelines' are being developed, and these are intended to inform revised processes for scheduled industrial development in NSW. These guidelines are being developed in a form that could potentially be more broadly adopted by other jurisdictions. For example, with regard to industrial point source emissions, in practice ambient standards are not a relevant mechanism to manage such emissions; point sources are better managed by tighter point source regulation.

4.1.3.3 Victoria

The *Victorian State Environment Protection Policy (SEPP) for Ambient Air Quality* (SEPP (AAQ)) sets air quality objectives and goals for the state (**EPA Victoria 2013**). The SEPP adopts the specifications of the AAQ NEPM, and also includes a separate objective for visibility-reducing particles.

Victoria's *State Environment Protection Policy for Air Quality Management* (SEPP (AQM)) establishes the framework for managing emissions into the air environment in Victoria from all sources (**EPA Victoria 2013**). The aims of the SEPP (AQM) are to:

- meet the air quality objectives outlined in the SEPP (AAQ)
- drive continuous improvement
- achieve the cleanest air possible.

The management framework and attainment program for the protection of air quality contained in the SEPP (AQM) address not only ambient (or regional) air quality, but also the management of particular sources (for

¹² The NEPM review did note that areas impacted by industrial emissions could be included as part of a population exposure monitoring regime, as the general population also includes these sub-populations.

example, industry, motor vehicles and open burning) and local air quality impacts, including air toxics, odorous pollutants, greenhouse gases and ozone-depleting substances.

For high-risk industrial activities ('scheduled premises'), EPA Victoria regulates compliance against the SEPP (AQM) through works approvals and licensing. The key requirements include meeting ground-level concentration criteria for many air quality indicators (in addition to the ambient criteria pollutants), best practice management, and continuous improvement.

4.1.3.4 Queensland

In Queensland the potential environmental impacts of developments and activities, especially those defined as environmentally relevant activities, are currently managed on a site-specific basis through assessment and conditioning under the *Environmental Protection Act 1994 (Qld)*.

As part of the assessment process, potential air quality impacts are evaluated against the *Environmental Protection (Air) Policy 2008 (Air EPP)* made under the Environmental Protection Act (**Queensland Government 2012**). The Air EPP is the principal policy guidance for managing air quality. The Air EPP identifies environmental values to be enhanced or protected, states indicators and air quality objectives for enhancing or protecting the environmental values, and provides a framework for making consistent, equitable and informed decisions about the air environment. The Air EPP presents air quality objectives for 31 indicators (air pollutants). Objectives for both PM₁₀ and PM_{2.5} are included, and are the same as those in the AAQ NEPM. The detailed regulatory requirements for assessing and managing environmental issues are contained in the Environmental Protection Regulation 2008 (Qld), also made under the Environmental Protection Act.

The *Integrated Development Assessment System* is the process for assessing and deciding development applications at the property level. Development applications are assessed under the Sustainable Planning Act 2009 (Qld). This process includes assessment against local planning instruments and for any impacts the proposed development may have on the surrounding environment.

The *State Planning Policy 5/10 Air, Noise and Hazardous Materials (2010)* complements the existing assessment and management framework by providing a more strategic focus on the location of industrial land uses (particularly in relation to sensitive land uses such as housing) that can impact on community and human health, wellbeing, amenity and safety, from issues such as air pollutants (**Queensland Department of Environment and Resource Management 2010**).

The most direct and common use of the PM standards in the AAQ NEPM in Queensland is in the government's air quality monitoring program. This program was developed in accordance with the AAQ NEPM's monitoring and reporting protocols. Data collected through the program are reported against the AAQ NEPM standards to show compliance or exceedance.

4.1.3.5 South Australia

South Australia references the PM standards for a range of purposes, which include requirements relating to ground-level concentrations for development applications and licence conditions. For example there is an expectation that submissions for new developments include high quality modelling reports from experienced practitioners, which provide conservative estimates for ground-level impacts of emissions from industrial activities meeting the PM₁₀ standards and, under some circumstances, the PM_{2.5} advisory reporting standards.

Conditions to meet the PM standard(s) may be applied within licences under the *Environment Protection Act 1993 (SA)* and/or within development approvals under the *Development Act 1993 (SA)*. Other orders or authorisations, or environment improvement plans under the Environment Protection Act may also potentially embody the standards.

Where appropriate, licensees can be required to undertake stack emission testing or monitoring to maintain emission levels to meet design ground-level concentrations. In some instances licensees are also required to undertake ambient monitoring for PM₁₀ and/or PM_{2.5} to confirm that they are meeting the long-term and short-term standards. Non-licensed activities can also be required to control emissions to meet these standards.

4.1.3.6 Western Australia

In Western Australia proponents are required to conduct assessments of the air quality impacts of existing or proposed sources of air pollutants under Part IV, or in relation to works approvals and licences under Part V, of the *Environmental Protection Act 1986* (WA). There is an expectation that the ambient air quality criteria (e.g. AAQ NEPM) will be achieved at all existing or likely future off-site sensitive receptors. For the purposes of air quality assessment, a 'sensitive receptor' means a location where people are likely to reside or congregate; this may include a dwelling, school, hospital, nursing home, child care facility or public recreation area or land zoned residential that is either developed or undeveloped. Locations of cultural or environmental significance, including 'environmentally sensitive areas' declared under the Act, may also be recognised as sensitive receptors and determined on a case-by-case basis. In exceptional circumstances, the Department of Environment Regulation or the Department of Health may recommend an alternative ambient air quality guideline be applied in ambient air quality assessments that are not consistent with the AAQ NEPM.

4.1.3.7 Other jurisdictions (Tasmania, Northern Territory and Australian Capital Territory (ACT))

In Tasmania, state and local governments control emissions from industrial activities through permits and environment protection notices. Currently, emissions from industries are regulated under the general provisions of the *Environmental Management and Pollution Control Act 1994* (Tas) and the *Land Use Planning and Approvals Act 1993* (Tas). Conditions are applied during the development assessment process, and compliance is then regulated by either the local council for smaller activities or by the EPA for larger activities. The *Environment Protection Policy (Air Quality) 2004* (EPP) also provides a framework for the management and regulation of both point and diffuse sources. The EPP sets particle limits to apply at the boundary of an activity, which can be incorporated into the premise's conditions. These limits are not necessarily those specified in the AAQ NEPM; however, the AAQ NEPM standards are applied during the setting of permit conditions by reference to the standards being met at the nearest sensitive receptor, which may or may not be at the boundary.

In the Northern Territory the AAQ NEPM criteria are typically applied, although there is no formal recognition of the AAQ NEPM standards in Northern Territory regulatory instruments.

The ACT does not formally reference the AAQ NEPM standards. However, it does use them in the planning approval and formal Environmental Impact Assessment processes to ensure that they will be achieved. In the absence of specific guidelines for the ACT, either the NSW approved methods are employed or the emission limits in the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 are applied.

4.1.3.8 Summary

The AAQ NEPM standards are often used in a variety of locations and contexts, some of which are inconsistent with the intention of the AAQ NEPM. The AAQ NEPM standards are designed for use at locations representative of overall air quality in those areas; however, they are also sometimes applied at other locations as part of environmental assessment (for example, at the boundary of an industrial facility, i.e. a 'hot spot'). Some jurisdictions are considering alternatives to this approach (e.g. risk-based guidelines for PM in NSW).

4.1.4 National Policy Initiatives

In 2010 the then Environment Protection and Heritage Council (EPHC) recommended a strategic approach to air quality management in Australia. In 2011 a number of further steps were taken towards improving the regulation of air pollution, including the AAQ NEPM review (**NEPC 2011a**), the publication of a methodology for the setting of standards (**NEPC 2011b**), and the identification of air quality as a 'Priority Issue of National Significance' (**COAG 2012**). In 2012 COAG agreed that the review of the AAQ NEPM particle standards be prioritised and staged for the following reasons:

There is strong evidence that exposure to PM has adverse effects on human health, and a lack of evidence for a concentration threshold below which health effects do not occur. This means that there are likely to be adverse health effects at the concentrations currently experienced in Australian cities, even where these are below the current standards and goals (see **Table ES1**).

PM₁₀ standards are exceeded in nearly all regions of Australia (**DSEWPC 2011**); however, such exceedances can occur as a result of uncontrollable natural events.

The potential health benefits of reducing population exposure to PM – and the associated monetary savings for society – are larger than those for other air pollutants.

The range of cost-effective abatement policies and actions available for PM is larger than that for other pollutants.

Actions under the first stage include:

- a health risk assessment (HRA) for PM, ozone, NO₂ and SO₂
- development of potential air quality standards for PM
- consideration of an exposure-reduction framework
- identification of possible PM-abatement options, including options for implementing national product standards to control emissions from a range of products and equipment
- a cost-benefit analysis (CBA) of potential air quality standards, an exposure-reduction framework and abatement measures for PM (including PM_{2.5}).

This first stage of the review focused on PM due to the current levels of PM in the atmosphere, the current population exposure, the size of the health benefits to be gained, and the range of available cost-effective actions for reducing PM emissions and concentrations.

The work completed to support the first stage review has included the following:

- Exposure Reduction project (**Bawden et al. 2012**)
- PM Valuation project (**Aust et al. 2013**)
- HRA project (**Frangos & DiMarco 2013**) and an associated summary for policy makers (**Morgan et al. 2013**)
- Economic Analysis project (**Boulter & Kulkarni 2013**).

4.1.5 Abatement initiatives

Meeting hypothetical new air quality standards for PM₁₀ and PM_{2.5} typically requires the introduction of new abatement measures. Abatement measures are available for each sector, and they act by either reducing emissions (the main approach), by reducing ambient concentrations, or by reducing exposure.

Various potentially feasible national measures to reduce PM pollution are being considered. These measures were summarised in the Economic Analysis project (**Boulter & Kulkarni 2013**), and are as follows:

- *Existing measures currently being assessed.* These are 'existing' abatement measures that are being considered through NEPC:
 - Non-road diesel engines – Introduction of national emission standards
 - Wood heaters – Introduction of national measures to reduce emissions through wood heater design, or performance standards to promote compliance of retail models with these standards and to influence in-service operational performance
 - Non-road spark ignition engines and equipment – Introduction of national emission standards.
- *Additional potential measures.* These are potential additional PM-abatement measures based on a review of Australian studies and successful programs. These measures related to the following emission sources:
 - Diesel trains – Introduction of emission standards, accelerated replacement of old locomotives, and driver assistance software to reduce fuel use
 - In-service diesel equipment – Extension (to other jurisdictions) of the NSW framework for retrofitting high-polluting diesel engine equipment with diesel particulate filters (DPFs)

- Shipping – Use of low-sulfur fuel at berth, and a memorandum of understanding (MOU) to reduce vessel speed as ships approach and depart ports
 - Coal dust – Application of best practice controls for PM at coal mines
 - Light commercial vehicles – Behaviour change program ('eco-driving' to reduce engine idling), and a targeted inspection and maintenance program using a remote-sensing device to identify high-emitting vehicles.
- *Other potential measures.* In addition to the above measures, several other potential abatement measures are available from the literature. These measures are:
- penalties and incentives to reduce emissions from gross-polluting heavy-duty diesel vehicles
 - use of licence conditions at mine sites to reduce emissions from in-service non-road diesel engines
 - measures to reduce emissions from in-service wood heaters
 - use of vegetation to reduce atmospheric concentrations of PM.

4.2 International air quality standards and exposure-reduction frameworks

4.2.1 Air quality guidelines and standards

The following paragraphs summarise the main air quality standards for PM₁₀ and PM_{2.5} that are used internationally. The numerical values of the different standards, and the associated criteria, are summarised at the end of the section.

4.2.1.1 WHO 2005 global update

Air quality guidelines have been developed for the most common pollutants by the World Health Organization (WHO). These guidelines are based solely on health considerations, and are used as the basis for development of air quality standards and legislative frameworks in many countries. WHO recommends that social and economic issues for each country or region should be considered when setting local standards (**NEPC 2011b**).

The guidelines were initially published by the WHO in 1987, and were revised in 1997 and 2000. The guidelines were most recently subject to a global update in 2005 (**Who Regional Office for Europe 2006**). For each update WHO assesses both the epidemiological and toxicological data, although in recent years the emphasis has been on the use of population-based epidemiological studies. The results of controlled human exposure studies and of toxicological studies add to the weight of evidence for an adverse effect linked to exposure to the pollutant under consideration, and also provide evidence for the biological plausibility of the effects observed in the epidemiological studies. Strict criteria have been developed to guide the selection and evaluation of studies as part of systematic reviews of the literature. To assess the achievability of the guideline values, WHO conducts a qualitative assessment of the health data and reviews air quality data from various parts of the world.

WHO Regional Office for Europe (2006) established air quality guidelines for both short-term (24-hour) and long-term (annual) exposure to PM_{2.5} and PM₁₀ (**Table 4.2**). These guidelines were the lowest levels (at the time) at which total, cardiopulmonary and lung cancer mortality had been shown to increase in response to long-term exposure to PM_{2.5}. The guidelines are based on studies that use PM_{2.5} as an indicator. The PM_{2.5} guideline values are converted to the corresponding PM₁₀ guideline values by application of a PM_{2.5}/PM₁₀ ratio of 0.5. When setting local standards, and assuming the relevant data are available, a different value for this ratio (i.e. one that better reflects local conditions) may be employed. The 24-hour mean guidelines are specified as the 99th percentile¹³.

¹³ A percentile is a value below which a given percentage of observations in a sample fall. For example, the 90th percentile is the value below which 90% of the observations may be found. The 50th percentile is the same as the median. In terms of 24-hour PM concentrations, the sample for a given year consists of 365 values (or 366 in a leap year). Given that 98% of the 24-hour values fall below the 98th percentile value, in a standard year this means that 357.7 (i.e. 0.98 x 365) values fall below the 98th percentile value. If an air quality standard is set as the 98th percentile of the 24-hour values, this means that 357.7 values must be below that value. In other words, 7.3 exceedance days are permitted. It is not practical to consider fractions of a day in this context, however and therefore this would be rounded down to 7 days.

Table 4.2: WHO guidelines for PM_{2.5} and PM₁₀

| PM metric | Annual mean guideline (µg/m ³) | 24-hour mean guideline (µg/m ³) ^(a) |
|-------------------|--|--|
| PM _{2.5} | 10 | 25 |
| PM ₁₀ | 20 | 50 |

(a) 99th percentile

Whether the 24-hour or the annual average guideline is the more restrictive tends to vary between countries, this being largely dependent on the specific pollutant sources and their locations. When evaluating the guidelines it is generally recommended that the annual average take precedence over the 24-hour average since, at low levels, there is less concern about episodic excursions. Meeting the guideline values for the 24-hour mean will, however, protect against peaks of pollution that would otherwise lead to substantial excess morbidity or mortality. It is recommended that countries with areas not meeting the 24-hour guideline values undertake immediate action to achieve these levels in the shortest possible time.

4.2.1.2 WHO REVIHAAP

The current state of scientific knowledge, as summarised in the 2013 REVIHAPP report, shows a wide range of adverse effects on health associated with exposure to PM_{2.5} and PM₁₀. The data strongly suggest that these effects have no threshold within the ambient concentration ranges, exhibit a mostly linear concentration–response function, and are likely to occur at fairly low concentrations. Studies have shown associations with adverse health outcomes at pollutant levels lower than those in the studies on which the 2005 global update were based. The scientific basis for the WHO guidelines for PM_{2.5} and PM₁₀ is therefore now even stronger than in the 2005 global update. As the evidence base for the association between PM and short-term and long-term health effects becomes much larger and broader, it will be important to update the guidelines. This is particularly important as recent long-term studies show associations between PM and mortality at levels well below the current WHO guideline level for PM_{2.5} of 10 µg/m³ (**WHO Regional Office for Europe 2013**).

Recommendations for PM_{2.5}

The REVIHAAP report suggests that the following points need to be considered in legislative decisions concerning PM_{2.5}:

- Although short-term effects may contribute to long-term health problems, those affected by short-term exposures are not necessarily the same as those suffering from the consequences of long-term exposures.
- Not all biological mechanisms relevant to short-term effects are necessarily relevant to the long-term effects, and vice versa.
- Areas that have relatively moderate long-term average concentrations of PM_{2.5} may still have short-term episodes of high concentrations.

Many countries and cities around the world issue pollution warnings when daily PM levels are considered to be hazardous. This can motivate episode-specific control strategies, as well as inform the public, so that mitigation actions (such as reducing driving, staying inside, reducing exercise, and taking appropriate medication) can be taken. The establishment of a 24-hour limit guarantees the adoption of monitoring strategies that provide daily information.

In light of the above, it was concluded in the REVIHAAP report that there is a need to regulate both 24-hour average and annual average PM_{2.5} concentrations.

Recommendations for PM₁₀

The REVIHAAP project considered whether the health evidence supported separate limit values for PM₁₀ in parallel to those for PM_{2.5}. A clear picture emerged that coarse particles have an independent effect on health, and therefore that PM₁₀ is not just a proxy measure of PM_{2.5}. Coarse and fine particles deposit at different locations in the respiratory tract, have different sources and composition, act through partly different biological mechanisms, and result in different health outcomes. Recent studies have strengthened the evidence for an association between short-term and long-term exposure to PM₁₀ and health. It was therefore concluded that:

-
- Sufficient evidence exists for a short-term standard for PM₁₀ to protect against the short-term health effects of coarse particles in addition to those of fine particles. Alternatively, a short-term exposure limit value for coarse particles may be considered, provided that an effective PM_{2.5} short-term exposure limit is also enacted.
 - A limit to protect against long-term PM₁₀ exposure should be maintained as long as there remains uncertainty about whether the health effects of coarse particles would be eliminated by reducing long-term exposure to PM_{2.5} alone. This concern exists especially for respiratory and pregnancy outcomes, while cardiovascular disease and other diseases related to systemic inflammatory responses are more likely to be linked to long-term exposures to fine particles.

Other recommendations

The REVIHAAP report states that it would be advantageous to develop an additional air quality guideline to capture the effects of road vehicle PM emissions that are not well captured by PM_{2.5} alone, building on the work on black carbon and/or elemental carbon and evidence for other pollutants in vehicle exhaust emissions (**WHO Regional Office for Europe 2006**). Besides the public health and/or air quality concerns, black carbon is also an important short-lived climate forcer which contributes to the warming of the earth's atmosphere. Reducing black carbon emissions from sources with a high black carbon/organic carbon ratio helps to mitigate short-term climate change.

Another appropriate goal proposed by the REVIHAAP report is to reduce non-tailpipe emissions from road traffic, given the increasing relative contribution of these emissions as vehicle exhaust emissions decrease.

The REVIHAAP report notes that although there is considerable evidence that ultrafine particles can contribute to the health effects of PM, the data (measured as particle number) on concentration–effect functions are too scarce to recommend an air quality guideline for ultrafine particles. The same evaluation applies for organic carbon. Current efforts to reduce the numbers of ultrafine particles in engine emissions should continue, and their effectiveness be assessed, given the potential health effects.

The health effects of coarse particles reviewed in the REVIHAAP report mean that maintaining independent short-term and long-term limit values for both PM₁₀ and PM_{2.5} – to protect against the health effects of both fine and coarse particles – is well supported.

4.2.1.3 United States

The United States Environmental Protection Agency (USEPA) establishes National Ambient Air Quality Standards (NAAQS) for criteria pollutants. The NAAQS are legally binding on states, which must develop state implementation plans to ensure compliance. States can impose their own standards as long as the national standards are maintained. For example, California has tighter standards for some air pollutants compared with the NAAQS.

The NAAQS are based solely on the consideration of health effects, including sensitive populations; economic considerations are not explicitly taken into account. However, there is a requirement for economic analyses for information purposes, and these analyses have generated a substantial amount of useful information. NAAQS for criteria air pollutants are developed using quantitative risk assessments and city-specific data (for a number of cities across the country). Secondary limits¹⁴ are set for non-health effects (e.g. visibility, animals, crops, buildings).

It is worth noting that recent reviews have led to the tightening of the annual mean standard for PM_{2.5} from 15 µg/m³ to 12 µg/m³ (**USEPA 2009, 2010, 2013**). The aim of this was to provide increased protection against the health effects associated with both long-term and short-term exposure.

In assessing and reporting compliance, the USEPA has 'exceptional event' and 'natural event' policies that enable the removal of unusual events from the dataset when determining compliance. The natural events rule applies to severe occurrences such as volcanic or seismic activity, bush fires and dust storms. The exceptional events rule also includes occurrences such as high winds, sandblasting, structural fires, chemical spills and industrial accidents, high pollen counts, construction and demolition, highway construction, agricultural tilling,

¹⁴ These secondary standards are not to be confused with secondary PM.

unusual traffic congestion, prescribed burning, clean-up activities after a major disaster, plus several others. There are strict guidelines for the identification, flagging and reporting of the data, and the rules only apply in the assessment of whether an area is in violation of the air quality standards.

4.2.1.4 European Union

The European Union *Directive on Ambient Air Quality and Cleaner Air for Europe (2008/50/EC)* is one of the key legislative instruments under the European Commission's Thematic Strategy on Air Pollution. The Directive encompasses and supersedes a number of previous Directives, and defines the air quality standards and objectives which establish the minimum requirements for Member States¹⁵. It was the first EU directive to include limits on ambient concentrations of PM_{2.5}. The Directive obliges Member States to adhere to the PM_{2.5} limit value of 25 µg/m³. This value must be achieved by 2015 and, where possible, by 2010. To achieve these objectives there are a number of other legislative instruments which aim to reduce air pollution by controlling emissions.

As well as requiring the monitoring of PM_{2.5} concentrations, Directive 2008/50/EC calls for measurement of the chemical composition of PM_{2.5} at rural background sites. Compositional analysis allows the assessment of sources (see below) and is also a check on the mass measurement (i.e. the sum of the mass of the chemical compounds should be equal to the directly measured mass).

Before Member States compare ambient air pollutant concentrations with relevant legally binding limit values, they may subtract the contribution of natural sources. European Commission Staff Working Paper 6771/11 (**EC 2011**) provides guidance on which sources can be regarded as 'natural', and on methods to quantify and subtract the contribution of these sources. Commission Decision 2004/461/EC established a questionnaire on air quality assessment as a tool for annual reporting under the Directive. In completing the questionnaire, Member States must cite the methods used to assess the natural contribution to exceedances, documenting any models used. So-called 'reason codes' for individual exceedances have to be used. The questionnaires submitted by Member States containing 2008 and 2009 data indicate that natural contributions to exceedances were only reported for PM₁₀ (**EEA 2012**).

The Working Paper sets out six key principles that the Commission applies when evaluating Member State claims that an exceedance is due to natural contributions:

- The contributions must not be caused by direct or indirect human activities.
- The quantification of the natural contribution must be sufficiently precise.
- The quantification of the natural contribution must be consistent with the averaging period of the limit value.
- The quantification of the natural sources must be spatially attributed.
- The contributions must be demonstrated based on a systematic assessment process.
- The quantification of the natural sources must be demonstrated for each pollutant separately.

Special attention should be paid to the first principle. This can hamper attempts to justify air pollution resulting from events that can occur with or without human intervention, such as wild fires. For such fires to be classified as natural sources they must have been initiated by natural causes (e.g. lightning). Human-related causes such as littering of forests should not be reported as natural events (**EEA 2012**).

The Working Paper provides a non-exhaustive list of sources whose contributions may be subtracted from national air pollution figures:

- wind-blown desert dust particles
- sea-spray aerosols
- volcanic dust particles
- wild fire particles.

¹⁵ European air quality policy is currently undergoing a thorough review to assess its effectiveness and future direction (see http://ec.europa.eu/environment/air/review_air_policy.htm).

Methodologies for identifying and quantifying the contribution of these sources are described and discussed in the Working Paper and, as noted above, include the chemical analysis of PM sampled at regional background measurement sites.

A second non-exhaustive list in the Working Paper sets out sources that the European Commission does not consider to be eligible for subtraction when PM limit values are exceeded:

- primary biological aerosols, including, for example, spores or pollen
- secondary organic biogenic aerosols
- resuspension of dust particles, such as from roads and pavements in cities.

Eleven Member States reported exceedances of PM₁₀ limit values in 2008 and/or 2009. The highest numbers of exceedances were reported by Mediterranean countries (Cyprus, France, Greece, Italy and Spain). The highest number of stations reporting natural contributions was located in Spain. The main natural source contributing to exceedances was 'transport of natural particles from dry regions outside the Member State' (Saharan dust), followed by sea spray and wild fires (**EEA 2012**).

4.2.1.5 United Kingdom

UK legislation to control exposure to PM was first developed during the 1990s. The focus was initially on controlling exposure to short-lived peak concentrations, as the epidemiological evidence at the time indicated that health effects were primarily associated with these peaks. A 24-hour standard for PM₁₀ of 50 µg/m³ was therefore introduced. The use of such air quality standards has meant that control strategies have primarily been aimed at reducing pollutant concentrations at hot spots, where monitoring has shown the standard can be exceeded. These hot spots have most commonly been identified alongside busy roads. The re-orientation of attention towards PM_{2.5}, coupled with the evidence that long-term concentrations were more significant in health terms than short-term peaks, has led to changes in legislation. The UK introduced the idea of a PM_{2.5} standard in its Air Quality Strategy update (**Defra 2007**). EU Directive 2008/50/EC is now transposed into UK law through the Air Quality Standards Regulations 2010 (**Laxen et al. 2010**).

4.2.1.6 Canada

Environment Canada and Health Canada have recently established new national air quality standards for PM_{2.5} and ground-level ozone. The new air quality standards were established by the federal government under the Canadian *Environmental Protection Act 1999*, on 25 May 2013. The provinces and territories will undertake actions to achieve the standards. For the first time in Canada, the standards include a long-term (annual) target for PM_{2.5}. These standards are more stringent and more comprehensive than the previous Canada-wide standards for PM_{2.5} and ozone. The national standards do not cover PM₁₀, but some Canadian provinces, such as British Columbia, do have PM₁₀ standards.

4.2.1.7 New Zealand

In New Zealand the National Environmental Standards for Air Quality are regulations made under the Resource Management Act 1991. The standards were first introduced in 2004, and include a 24-hour limit for PM₁₀. Regional councils and unitary authorities are responsible for managing air quality under the Act, and are required to identify areas where air quality is likely, or known, to exceed the standards. Guidelines also exist for annual mean PM₁₀ and 24-hour PM_{2.5}.

4.2.1.8 Summary

The WHO guidelines and the adopted standards for PM₁₀ and PM_{2.5} in Australia and the countries reviewed above, as well as some additional countries and regions, are listed in **Table 4.3**.

There is currently no annual mean PM₁₀ standard in the AAQ NEPM. It is worth noting that coarse particles are a significant problem in some areas of Australia (e.g. dust and sea salt contribute significantly to PM₁₀), and the REVIHAAP report concluded that there is increasing evidence for the adverse effects on health of coarse particles (**WHO Regional Office for Europe 2013**). This suggests that an annual mean PM₁₀ standard should be introduced in Australia.

The WHO numerical guideline for 24-hour PM₁₀ of 50 µg/m³ has been adopted in Australia and elsewhere (but not in the United States), although the number of permitted exceedances is greater in Australia than in the WHO guideline. However, fewer exceedances of the standard are allowed in Australia than in most other countries/regions (an exception being New Zealand). The REVIHAAP report recommended a re-evaluation of the PM₁₀ limit values in Europe.

Table 4.3: Summary of international air quality standards for PM₁₀ and PM_{2.5}

| Organisation/ Country/Region | PM ₁₀ | | PM _{2.5} | |
|---------------------------------|--|---|---|---|
| | Annual mean standard (µg/m ³) | 24-hour standard (µg/m ³) ^(a) | Annual mean standard (µg/m ³) | 24-hour standard (µg/m ³) ^(a) |
| WHO | 20 | 50 ^(b) | 10 | 25 ^(b) |
| Australia | – | 50 (5) | 8^(c) | 25 (0)^(c) |
| Canada | – ^(d) | 120 ^(d,e) | 10/8.8 ^(f) | 28/27 ^(f) |
| China | 70 | 150 | 35 | 75 |
| European Union | 40 | 50 (35) | 25 ^(g) | – |
| New Zealand | 20 ^(h) | 50 (1) | – | 25 ^(h) |
| Singapore | 20 | 50 | 12 ⁽ⁱ⁾ | 37.5 ⁽ⁱ⁾ |
| UK (all) | 40 | 50 (35) | 25 | – |
| UK (Scotland) | 18 | 50 (7) | 12 | – |
| United States (all) | – | 150 (1) ^(j) | 12 ^(j) | 35 ^(j,k) |
| United States (California) | 20 | 50 | 12 | – |

- (a) Number in brackets shows allowed exceedances per year
 (b) Stated as 99th percentile
 (c) Advisory standard
 (d) Some provinces have standards for PM₁₀
 (e) Objective
 (f) By 2015/2020

- (g) The 25 µg/m³ value is initially a target, but will become a limit in 2015. There is also an indicative 'Stage 2' limit of 20 µg/m³ for 2020.
 (h) Guideline
 (i) By 2020
 (j) Averaged over three years
 (k) Stated as 98th percentile

The annual advisory mean standard for PM_{2.5} in Australia is lower than the current WHO guideline, and is numerically the lowest of the countries included in the review. At the moment, for annual average PM_{2.5} there is a considerable gap between the WHO guideline of 10 µg/m³ and the United States standard of 12 µg/m³. The EU limit values are much higher, and one of the recommendations of the REVIHAAP report was that these should be lowered. The report also concluded that there is a need for an additional PM_{2.5} short-term (24-hour) limit value in Europe. It will be important to update the current WHO guidelines, as recent long-term studies show associations between PM and mortality at levels well below the current annual WHO air quality guideline for PM_{2.5} of 10 µg/m³.

The WHO 2005 global update recommended a 24-hour guideline for PM_{2.5} of 25 µg/m³. This has been adopted as the advisory reporting standard in the AAQ NEPM.

Although the Australian PM standards are numerically lower than, or equivalent to, those in other countries and regions, it is not straightforward to interpret such comparisons and they do not necessarily mean that the Australian standards are more stringent. For example, to a large degree the lower standards in Australia are made possible by relatively low natural background concentrations and the absence of significant anthropogenic transboundary pollution (which is a major issue in Europe, for example). However, as noted earlier, there would still be health benefits in Australia from setting the PM standards as low as reasonably achievable. There are also differences in implementation; there is no legal requirement for compliance with the standards and goals in Australia, whereas there is in other countries and regions.

Options for the numerical values and form of the standard in the AAQ NEPM are discussed in **Chapter 7** and **Chapter 8**. Given that the existing Australian standards are generally lower than, or equivalent to the WHO

guidelines and the standards in other countries, it is important to focus on the achievability of the various options for varying the AAQ NEPM. This analysis is presented in **Chapter 5**.

4.2.2 Exposure reduction

4.2.2.1 Rationale and general approaches

As noted above, most monitoring and assessment to date has largely been directed towards evaluating air quality against standards and goals at specific locations. However, over the typical range of ambient PM concentrations the relationship between the concentration and the health response is, broadly speaking, linear. This means that sensitive individuals – such as asthmatics and people with respiratory or cardiovascular disease – may be affected even where an AAQ NEPM standard is not exceeded¹⁶. There is therefore still a health benefit (and cost saving) to be gained from any reduction in overall population exposure¹⁷.

Overall health outcomes are driven by large-scale population exposure to the prevailing background PM concentration. By way of example, the health benefits associated with reducing the average PM concentration by 1 $\mu\text{g}/\text{m}^3$ across a population of 100,000 people are ten times greater than those from reducing the average PM concentration by 10 $\mu\text{g}/\text{m}^3$ across a population of 1000 people. These benefits are not affected by the absolute concentration. Thus, for a given population, reducing the average PM concentration from 28 $\mu\text{g}/\text{m}^3$ to 27 $\mu\text{g}/\text{m}^3$ is expected to deliver the same health benefits as reducing the average concentration from 8 $\mu\text{g}/\text{m}^3$ to 7 $\mu\text{g}/\text{m}^3$ (**Bawden et al. 2012**).

Whilst air quality standards have an important role to play in driving down PM concentrations where exceedances are measured or predicted, localised remedial actions are unlikely to lead to large-scale reductions in population exposure. In addition, in areas of higher population density where there are no exceedances of the standards, there is currently no driver to implement measures to reduce exposure to PM (**Bawden et al. 2012**). One approach that is being implemented internationally to address this issue is to add an exposure-reduction overlay for non-threshold pollutants to air quality standards. The scientific support for the exposure-reduction approach to managing PM air quality has been strengthened by the REVIHAAP findings (**WHO Regional Office for Europe 2013**).

Bawden et al. (2012) emphasised the importance of drawing a distinction between approaches which maximise equity (whereby individuals most at risk of exposure to the highest concentrations are protected to a uniform, minimum standard), and those which maximise efficiency (which relates to the ability to maximise health benefits across the population, e.g. life-years saved). AAQ NEPM standards for PM have an important role to play in maximising equity, but can be usefully complemented by an exposure-reduction approach which seeks to maximise efficiency. To ensure equity the exposure-reduction approach should be combined with a traditional air quality standard to provide a minimum degree of health protection everywhere.

The AAQ NEPM review suggested that the EU approach (see below) provides an appropriate model as a basis for an exposure-reduction framework for inclusion in the AAQ NEPM (**NEPC 2011a**). However, it is not the only one. **Bawden et al. (2012)** identified the following main approaches to an exposure-reduction framework:

- emission-reduction approaches
- exposure-reduction approaches
- air pollution indices
- damage cost approaches.

Some examples of these approaches are summarised below.

¹⁶ PM₁₀ concentrations in Australian cities are below the standards for most of the time; high observed PM concentrations are typically a result of bush fires and dust storms (**DSEWPC 2011**).

¹⁷ Population exposure refers to the exposure of the population as a whole to ambient air pollution, rather than the personal exposure of individuals. Population exposure is especially important for non-threshold pollutants such as PM₁₀ and PM_{2.5}.

4.2.2.2 Emission-reduction approaches

The 1979 *Geneva Convention on Long Range Transboundary Air Pollution* (CLRTAP) (**UNECE 1979**) was the first internationally-binding instrument to tackle the problems of air pollution on a broad, regional basis. It has been extended by eight specific protocols. The 1999 Protocol to Abate Acidification, Eutrophication, and Ground-level Ozone (**UNECE 2005**), more commonly referred to as the - Gothenburg Protocol - sets emissions ceilings, which were to be attained by 2010, for four pollutants: SO_x, NO_x, VOCs and NH₃. The Protocol has been recently extended to include emissions ceilings for PM_{2.5} and measures to prioritise the reduction of short-lived climate pollutants (e.g. elemental carbon).

The National Emissions Ceiling Directive (NEC Directive) (2001/81/EC), which came into force in 2001, sets upper limits for each EU Member State for total emissions in 2010 and thereafter. In the NEC Directive the key controls in relation to PM have been on emissions of SIA precursors: NO_x, SO_x and NH₃. Emissions of VOCs are also covered, but as precursors of ozone rather than as precursors of SOA. The emission ceilings set within the Directive are complementary to, or more stringent than, those established within the Gothenburg Protocol. It is expected that a revised NEC Directive will set new emissions ceilings to be met by 2020, and possibly beyond, and will be extended to include emissions of primary PM_{2.5}.

4.2.2.3 Exposure-reduction approaches

The exposure-reduction approach is currently applied in the European Union. Directive 2008/50/EC included a new exposure-reduction approach for PM_{2.5} that was introduced in recognition of PM as a non-threshold pollutant. This new approach is based on the concept that greater benefits could be obtained from a general reduction in exposure than by a policy aimed at reducing concentrations at hot spots. The approach aims at a general reduction of concentrations in the urban background to ensure that large sections of the population benefit from improved air quality. However, to ensure a minimum degree of health protection everywhere, the new approach is combined with a limit value (see **Section 4.2.1**).

The EU exposure-reduction approach is based on monitoring. Member States are required to establish a minimum of one sampling station per million inhabitants, summed over the agglomerations in excess of 100,000 inhabitants. Exposure is assessed using an average exposure indicator (AEI). The AEI is calculated as a three-year running¹⁸ annual mean PM_{2.5} concentration, averaged over all urban background sampling sites in a Member State. The exposure-reduction target¹⁹ applicable to each Member State is a percentage reduction by 2020, relative to the reference year AEI in 2010, as shown in **Table 4.4**. A lower threshold level at 8.5 µg/m³ was selected as the AEI concentration below which no additional reduction would be required. This was selected, in part, to reflect the 'natural background' level across much of Europe, below which actions by individual Member States would have very limited effect in reducing concentrations further.

The Directive also sets an 'Exposure Concentration Obligation', expressed as an AEI of 20 µg/m³, to be met by 2015 (calculated as the three-year running mean concentration averaged over all sampling points for the years 2013, 2014 and 2015). This sets a minimum obligation on all Member States.

A number of legislative approaches are being taken to reduce exposure to PM_{2.5}. These include controls on motor vehicle emissions, controls on industrial sources and controls introduced by local authorities to address individual hot spots. As noted above, the NEC Directive and CLRTAP both aim to reduce emissions at the national level, and influence background concentrations of PM_{2.5}.

¹⁸ For example, the 2010 AEI is calculated as the three-year running mean concentration averaged over all sampling points for the years 2008, 2009 and 2010.

¹⁹ Targets within EU Directives have a different legal status from limit values. Limit values are legally enforceable upon Member States, whereas there is no mandatory requirement to comply with target values.

Table 4.4: EU exposure-reduction targets for PM_{2.5}

| Initial concentration in 2010 (µg/m ³) | Reduction target by 2020 (%) |
|--|--|
| ≤ 8.5 | 0% |
| >8.5 to <13 | 10% |
| 13 to <18 | 15% |
| 18 to <22 | 20% |
| ≥ 22 | All appropriate measures to achieve 18 µg/m ³ |

In the UK the government has set an annual mean objective for PM_{2.5} of 25 µg/m³ which applies at all relevant locations in England, Wales and Northern Ireland from 2020. This is likely to be achieved throughout the UK. The Air Quality Strategy has also set an exposure-reduction objective, which is a 15% reduction between 2010 and 2020. This will either be the same as, or possibly more stringent than the EU target. In Scotland the annual mean objective for PM_{2.5} has been set at 12 µg/m³ to be achieved by 2020 at all relevant locations. Given that the measured kerbside concentration in Glasgow was 23 µg/m³ in 2010, it is highly likely that the objective is currently being exceeded at roadside sites in major urban areas in Scotland. There is thus a risk that the Scottish objective for PM_{2.5} may still be exceeded in 2020 (**AQEG 2012**).

Whilst not representing a formal exposure-reduction approach, the Canada-Wide Standards (CWS) for PM and ozone include the implementation of ‘continuous improvement’ (CI) and ‘keeping-clean-areas-clean’ (KCAC) programs where ambient concentrations are below the CWS levels. This is not a mandatory requirement, but jurisdictions with ambient concentrations below the CWS levels are expected to focus implementation measures on CI/KCAC (**CCME 2006, 2007**).

CI/KCAC programs are required to address the following pollutants:

- in the ambient environment: ozone and PM_{2.5}
- in emissions: direct PM_{2.5} emissions, the PM_{2.5} and ozone precursors NO_x and VOCs, and the PM_{2.5} precursors SO₂ and NH₃.

Specific targets for reductions in pollutant concentrations or emissions have not been set, but the Canadian jurisdictions are required to provide comprehensive reports at five-year intervals (including progress on CI/KCAC), and should include all significant emission-reduction actions.

4.2.2.4 Air pollution indices

The NSW Air Quality Index (AQI) is a derived value based on hourly pollutant readings. The AQI is calculated for each pollutant on an hourly basis. The ‘Site AQI’ that is reported is the highest calculated AQI value from all of the pollutants measured over the preceding 24 hours at each individual monitoring station. The ‘Region AQI’ is the highest site AQI for all monitoring stations in the region.

The UK Daily Air Quality Index (DAQI) operates in a similar manner to the NSW system. The UK system uses an index numbered 1–10, divided into four bands (‘Low’, ‘Moderate’, ‘High’ and ‘Very High’) to provide information in a simple manner. The overall air pollution index for a site or region is determined by the highest concentration of five pollutants (NO₂, SO₂, O₃, PM₁₀ and PM_{2.5}). The index is updated every hour. The primary function of the DAQI is to provide information to members of the public, specifically with regard to health alerts for at-risk individuals. However, the DAQI also provides information that is used to support the UK Government’s annual reporting on the air quality indicator for sustainable development.

Whilst air pollution indices are useful in conveying information to members of the public, they are primarily focused on short-term pollutant concentrations, whereas the focus of exposure reduction for PM_{2.5} is focused on a reduction in long-term (e.g. annual mean) exposure. Where air pollution indices are used to support reporting of improvements to annual mean PM_{2.5} concentrations, no attempt is made to apply any form of population weighting to the data, which is an important consideration for exposure reduction.

4.2.2.5 Damage cost approaches

Damage costs are used as a means of approximating the impacts of changes in air pollution (and exposure to it). These costs estimate the marginal health benefits, or external cost savings, associated with each tonne of pollutant emission that is reduced. Damage costs for a specific country or jurisdiction are usually generated via a full impact pathway approach utilising location-specific inputs and data (i.e. using emission estimates, regional air quality modelling, monitoring data and population statistics). This approach provides the most robust and accurate damage costs for that region.

A recent study was completed for the NSW Environment Protection Authority (NSW EPA) that reviewed international approaches for determining damage costs and derived a damage cost function for air pollution in Australia (**Aust et al. 2013**). The review found that Australia currently lacks sufficient and readily available PM emission modelling information to permit a full impact pathway process and, by extension, to generate a set of accurate, location-specific damage costs. Consequently, an alternative/interim method was provided for calculating damage costs which can be used until more reliable data are available for Australia. The alternative method was based on transferring Defra/IGCB²⁰ damage costs from the UK. It is important to note that the proposed damage cost method does not include damage costs for secondary PM due to the lack of information regarding secondary PM formation in Australia. This is important as the secondary component is likely to represent some 25–50% of the total PM_{2.5} exposure burden.

4.2.2.6 Requirements

To understand and quantify population exposure accurately requires information on both the long-term average spatial distribution of air pollution and the spatial distribution of the population in the area of interest. **NEPC (2011a)** points out that the tools and data that would be required to develop such an exposure-reduction system include:

- detailed emissions inventories based on a relatively fine spatial grid
- comprehensive airshed models. The role of modelling should be strengthened and appropriate modelling approaches to generate reports on population exposure patterns be incorporated into the AAQ NEPM
- high-quality consistent data from the existing AAQ NEPM monitoring networks. The current AAQ NEPM monitoring networks alone cannot give sufficient spatial coverage of all urban airsheds to provide detailed information on the exposure of all the population. Rather, they can only provide an indication of the exposure in the area represented by each performance monitoring site.

If these were to be adopted they would require significant investment. For example, **Bawden et al. (2012)** estimated that it would cost around \$750,000 for a jurisdiction to establish a regional emissions inventory, and then around \$150,000 per year to update and maintain it.

²⁰ Defra: UK Department for Environment, Food and Rural Affairs/IGCB: UK Interdepartmental Group on Costs and Benefits

Key Points from Chapter 4

Air quality management in Australia

- The AAQ NEPM provides a consistent framework for the monitoring and reporting of ambient air quality in Australia. The AAQ NEPM standards for PM are based on measurements at sites that reflect the general exposure of populations in large metropolitan areas. All Australian states and territories report annually against the AAQ NEPM.
- Jurisdictions also have legislation or guidance on air quality which includes design goals, licence conditions, etc. Individual jurisdictions can employ complementary methods to inform development applications for proposed infrastructure and industrial proposals in a variety of locations and contexts.
- The first stage of the AAQ NEPM Review focuses on PM, due to the current levels in the atmosphere, the current population exposure, the size of the health benefits to be gained, and the range of available cost-effective actions for reducing emissions and concentrations.

NEPM standards

- There is currently no annual mean PM₁₀ standard in the AAQ NEPM. The increasing evidence for the adverse effects on health of coarse particles suggests that an annual mean PM₁₀ standard should be introduced in Australia.
- The WHO guideline for 24-hour PM₁₀ of 50 µg/m³ has been adopted in Australia.
- The advisory annual mean standard for PM_{2.5} in Australia is 8 µg/m³. The WHO 24-hour guideline for PM_{2.5} of 25 µg/m³ has already been adopted as the advisory standard in the AAQ NEPM.

Exposure reduction

- Overall health outcomes (and costs) are driven by large-scale population exposure to the prevailing background PM concentration. Where there are no exceedances of air quality standards there is currently no driver to implement measures to reduce exposure to PM.
- The scientific support for the exposure-reduction approach to managing PM air quality has been strengthened by the latest health findings.
- The tools and data that would be required for a precise understanding of exposure to PM across Australia would include detailed source inventories, comprehensive airshed models and high-quality consistent data from the existing AAQ NEPM monitoring networks. These would require significant investment.
- However, undertaking first steps towards characterising exposure based on the existing monitoring network would require little or no investment on the part of the jurisdictions.

Proposed questions for consultation: Policy context and legislation

- Have all aspects of the current air quality management framework in Australia been adequately described? If not, please provide further details.
- Have any significant regulatory developments, local or international, been overlooked? Please provide information.
- What are your views on the feasibility of an exposure-reduction framework for PM in Australia?

5 AIRBORNE PARTICULATE MATTER IN AUSTRALIA

5.1 Sources

When characterising anthropogenic air pollutants in Australia a distinction has often been made between emissions from point sources and emissions from diffuse sources. A classic point source would be a stack at an industrial plant or power station. For some pollutants – such as SO₂ – these types of source dominate regional emissions. Diffuse sources include motor vehicles, bush fires, various types of planned burning, fugitive dust from industrial, transport and agricultural activities, domestic and commercial solvents, service stations, and domestic lawnmowers. Diffuse sources are important contributors to PM₁₀ and PM_{2.5}, and their nature means that they are also generally more challenging to address through regulation. Motor vehicles in particular have a large impact on air quality and human health in urban areas, where they are ubiquitous and close to the population. Discharges from major industrial and power-generation facilities are elevated and thus have less influence at ground level (**SEC 2011**).

The differences in the contributors to total anthropogenic PM emissions in non-urban and metropolitan areas are illustrated by references to the NSW GMR in **Figure 5.1**. For both PM₁₀ and PM_{2.5} the main contributor in non-urban areas is industry (mainly coal mines in the NSW GMR). Other common natural non-urban sources of PM (not shown in the figure) are wild fires and windblown dust (**SEC 2011**). In Sydney, domestic-commercial and on-road mobile sources become much more important, especially for PM_{2.5} in the case of the former. There are also significant temporal variations in emissions. For example, in the cooler southern regions of Australia domestic wood combustion is an important source of PM during the autumn and winter months.

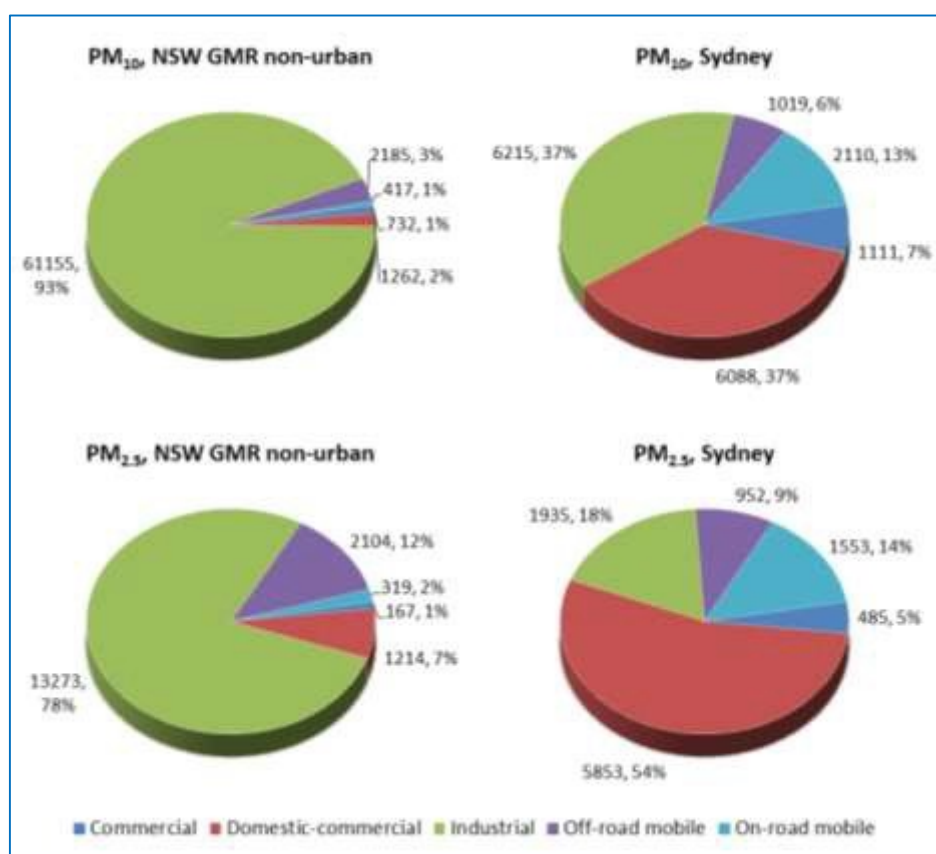


Figure 5.1: Anthropogenic emissions of PM₁₀ and PM_{2.5} in the NSW GMR and Sydney during 2008 (each pie chart shows tonnes emitted per year and percentage contribution to total anthropogenic emissions) (adapted from NSW EPA 2012)

5.2 Emissions of PM

5.2.1 Emissions inventories

The emissions of air pollutants to the atmosphere are quantified in emissions inventories. In Australia there are two main types of inventory: the National Pollutant Inventory (NPI) and regional (state-based) inventories. The current status of these was reviewed by **Bawden et al. (2012)**.

5.2.1.1 NPI

Australia's National Pollutant Inventory (NPI) is a broad-based mechanism for collecting data on pollutant emissions to air, land and water. The legislative framework underpinning it is the National Pollutant Inventory NEPM (NPI NEPM). The main purpose of the NPI is to collect and publish information about emissions of substances on a geographical basis to help environmental decision-making and to provide the public with information.

Data are collected and published annually from industrial facilities that trigger certain reporting thresholds (such as fuel used or total pollutant emitted). The number of pollutants reported to the NPI varies depending on the reporting thresholds that are triggered. Only PM_{2.5} emissions from combustion sources are reportable under the NPI. PM_{2.5} from other industrial sources, such as wind erosion or material handling at coal mines are not reported or covered by the NPI. Emissions from diffuse sources are reported by jurisdictions on a period agreed by each jurisdiction. The NPI reporting facilities, airsheds and catchments in Australia are shown in **Figure 5.2**. Regions included in the diffuse studies cover more than 75 per cent of Australia's population (**DEWHA 2009**).

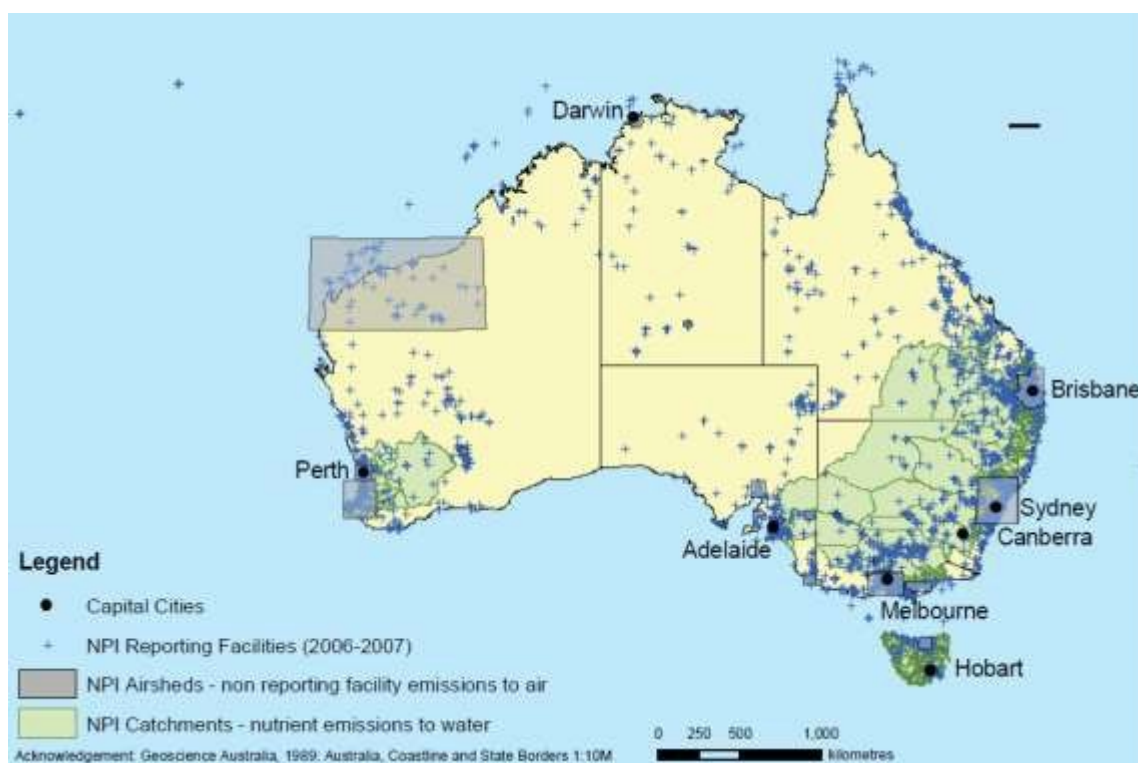


Figure 5.2: NPI reporting facilities, airsheds and catchments (DEWHA 2009)

The NPI emissions data do not, in general, have the temporal and spatial variation that would be required for detailed air quality modelling purposes. There is also no requirement within the NPI for data suppliers to provide the source parameters that are needed for air quality modelling, such as stack height, exit temperature, exit velocity or stack diameter (**Bawden et al. 2012**).

5.2.1.2 Regional inventories

Regional air emissions inventories are maintained by some jurisdictions to inform air quality management decisions and policy analysis, to determine the effectiveness of regulation, and to facilitate air pollution modelling. Five jurisdictions in Australia – including the major urban centres (i.e. Sydney, Melbourne, Brisbane, Perth and Adelaide) – currently use emissions inventories to manage air quality in some way.

A summary of the current status of each regional inventory is provided in **Table 5.1**. The remaining jurisdictions (Tasmania, Northern Territory and ACT) have developed inventories in the past, but these have been less detailed and are not being updated.

Table 5.1: Summary of current status of emissions inventories for major Australian urban centres (Bawden et al. 2012)

| NSW GMR ^(a) | Victoria | SEQ ^(b) | Perth | Adelaide |
|--|---|--|---|--|
| Base year | | | | |
| 2008 | 2006 | 2000 | Motor vehicles: 2006–07; Other sources: 1998–99 | Motor vehicles: 2006; Other sources: 1998–99 |
| Projection years | | | | |
| 2011, 2016, 2021, 2026, 2031, 2036 | 2030 | 2005 and 2011 for some source groups | None | None |
| All major sources included | | | | |
| Yes | No The most significant source not included is marine aerosol. | No No fugitive windborne, marine aerosols, paved road dust. | No Fugitive windborne and marine aerosols were not included. | No Biogenic/geogenic emission sources have not been estimated for the Adelaide airshed. |
| Model ready | | | | |
| Yes Inventory suitable for regional air quality modelling and readily exportable in model-ready formats. | Yes EPA Victoria currently updating inventory to a base year of 2011. | No Inventory will be in a format suitable for regional air quality modelling when current update is completed. | No Inventory designed for diffuse sources only. Spatial and temporal variation of emissions not assigned. | No Inventory designed for diffuse sources only. Spatial/temporal variation of emissions not assigned. Significant emission sources (e.g. biogenic) excluded. |
| Primary pollutants | | | | |
| Yes TSP, PM ₁₀ , PM _{2.5} | Yes TSP, PM ₁₀ , PM _{2.5} | Yes TSP, PM ₁₀ , PM _{2.5} | No PM ₁₀ and PM _{2.5} are included, but not TSP. | No PM ₁₀ and PM _{2.5} are included, but not TSP. |
| Secondary precursor pollutants | | | | |
| No Does not include elemental/organic carbon. | Yes Includes emissions of all substances. | No Does not include SO ₃ or elemental/organic carbon. | No Does not include SO ₃ or elemental/organic carbon. | No Does not include SO ₃ or elemental/organic carbon. |

(a) NSW GMR: NSW Greater Metropolitan Region

(b) SEQ: South-East Queensland

No official methodology or guidebook exists for compiling regional air emissions inventories in Australia, although manuals for specific sources are published by the Commonwealth Government for estimating emissions for the NPI. These manuals have facilitated a certain level of consistency in constructing regional emissions inventories; however, for some sources the techniques are out of date. Consequently, some jurisdictions now prefer to use more up-to-date methodologies, typically from overseas.

At present there is no consistency across the inventories; the methodology used to estimate emissions from each source is likely to differ significantly, and some inventories are not suitable for regional air quality modelling. The substances included in each inventory also vary from jurisdiction to jurisdiction (**Bawden et al. 2012**).

5.2.2 Emission projections

Projecting emissions into the future is very important for enabling policymakers to develop air quality management strategies. However, the quality of the emission projections in the different Australian jurisdictions varies substantially. Emission projections for PM₁₀ and PM_{2.5} in each jurisdiction under a 'business-as-usual' (BAU) scenario for the period 2011–2036 were derived in the Economic Analysis project (**Boulter & Kulkarni 2013**). The BAU scenario defined a base case against which the impacts of measures to reduce anthropogenic emissions could be evaluated. In the BAU scenario existing emission controls and expected trends in economic activity, population growth and various other factors were allowed to continue, and there were no additional interventions to reduce air pollution.

The approaches for NSW and Victoria were more sophisticated than those for the other jurisdictions, and were based upon the projections supplied by the respective EPAs. To fill any gaps in the NSW and Victoria data²¹, and also to determine the projections for the other jurisdictions, some basic assumptions were made concerning future activity and emissions relative to the original inventories. Emissions were estimated using a combination of the following:

- population projections for the states and the main conurbations from **ABS (2008)**
- economic growth based on historical 'gross value added' (GVA) by industry from Australian Bureau of Statistics (ABS) Catalogue 5220.0 (*Australian National Accounts – State Accounts*)²². Annual average changes in GVA were determined for each state and for each type of industry
- national projections of PM₁₀ and PM_{2.5} emissions from **BITRE (2010)**, which were used to fill gaps for road vehicles and other transport modes.

The projections are shown in Figure 5.3 to Figure 5.10. It should be noted that the nomenclature used in the emissions inventory varied from jurisdiction to jurisdiction. Consequently, the sectors of activity in the graphs are not always directly comparable between jurisdictions.

It can be seen that in all jurisdictions emissions of PM₁₀ and PM_{2.5} were projected to increase between 2011 and 2036, although the projections varied considerably. In some jurisdictions the projections indicated a substantial increase in emissions between 2011 and 2036. For example, in NSW, Queensland and WA there was an increase in PM₁₀ emissions of around 65%, whereas in Victoria and SA it was around 10%. The increase in PM_{2.5} emissions ranged from 8% in Victoria to around 65% in WA.

In addition, the most important sectors of activity were different in each jurisdiction. In NSW the most important source of PM₁₀ and PM_{2.5} was coal dust, and this sector was responsible for most of the projected growth in emissions. Domestic/commercial sources (notably wood heaters) were the most important in Tasmania. In Victoria, the largest sources are wood heaters, industry and diesel vehicles. Mobile sources were also important contributors to PM₁₀ and PM_{2.5} in some jurisdictions.

²¹ The main requirement was to extend the time period for the Victoria projections from 2030 to 2036.

²² <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5220.02010-11>

Figure 5.3: Projected emissions of PM10 and PM2.5 in NSW (Sydney GMR airshed)

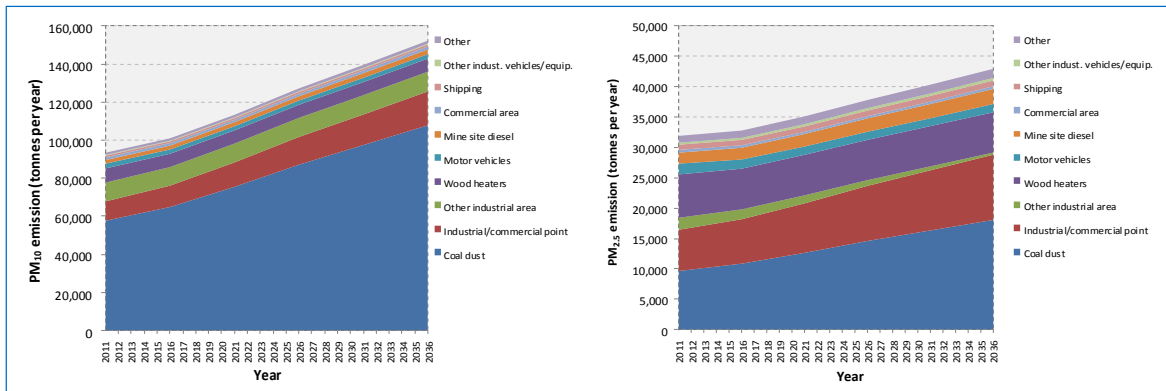


Figure 5.4: Projected emissions of PM10 and PM2.5 in VIC (Port Phillip airshed)

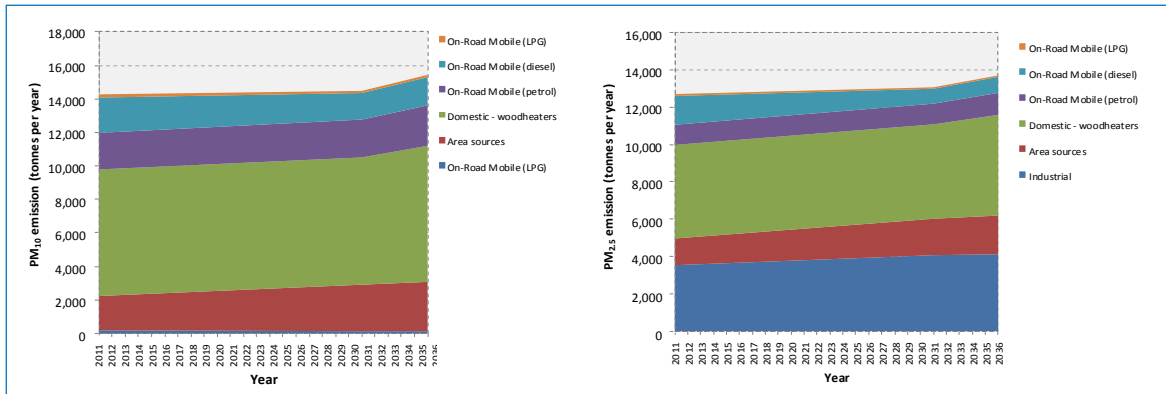


Figure 5.5: Projected emissions of PM10 and PM2.5 in QLD (SEQ airshed)

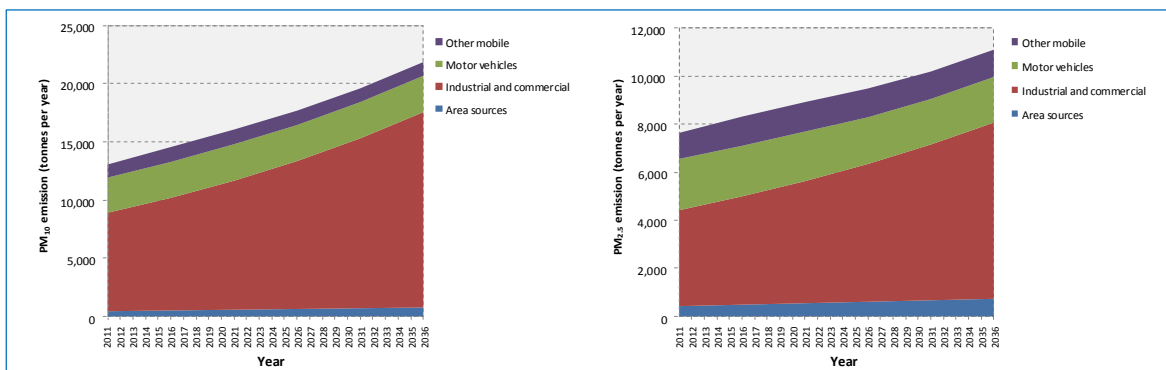


Figure 5.6: Projected emissions of PM10 and PM2.5 in SA (Adelaide airshed)

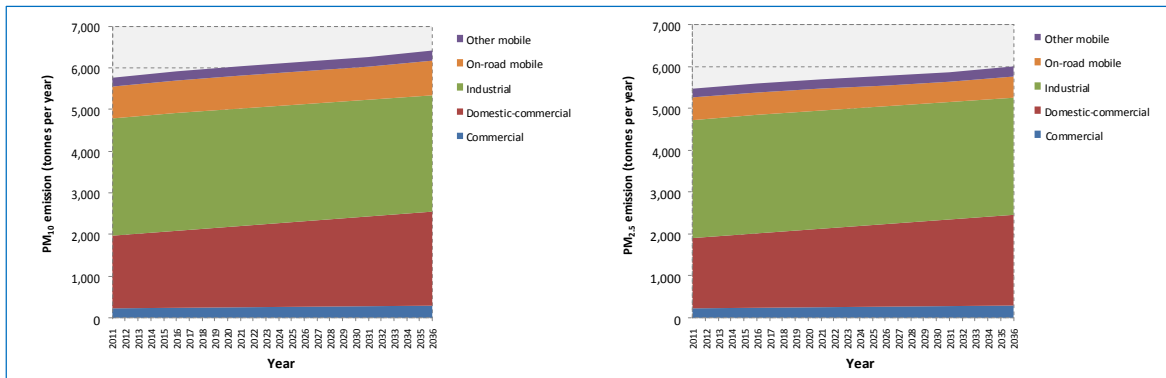


Figure 5.7: Projected emissions of PM10 and PM2.5 in WA (Perth airshed)

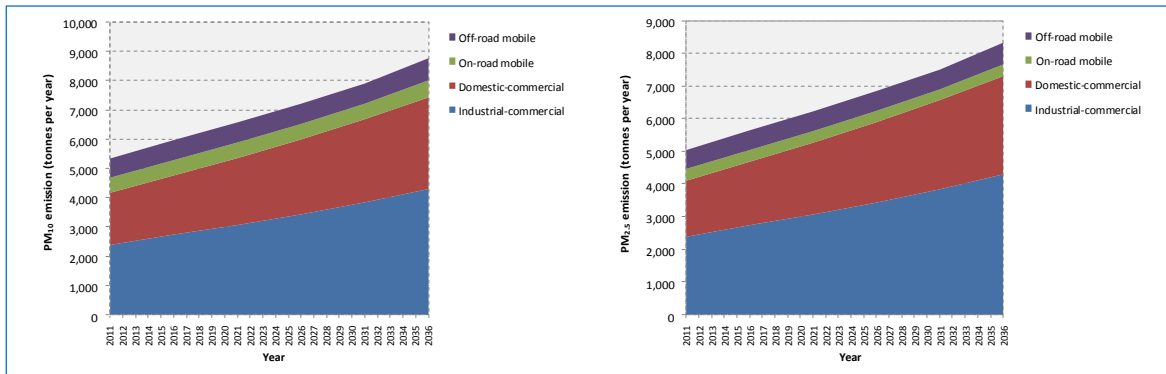


Figure 5.8: Projected emissions of PM10 and PM2.5 in TAS (Hobart airshed)

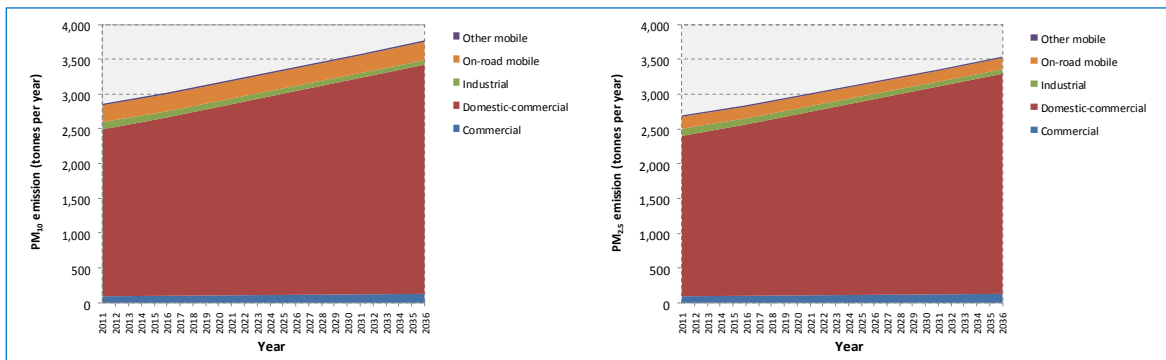


Figure 5.9: Projected emissions of PM10 and PM2.5 in NT (Darwin airshed)

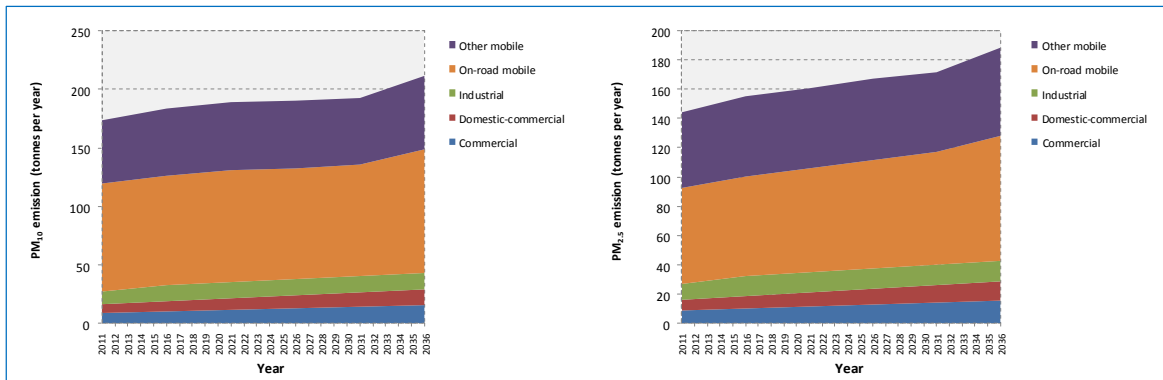
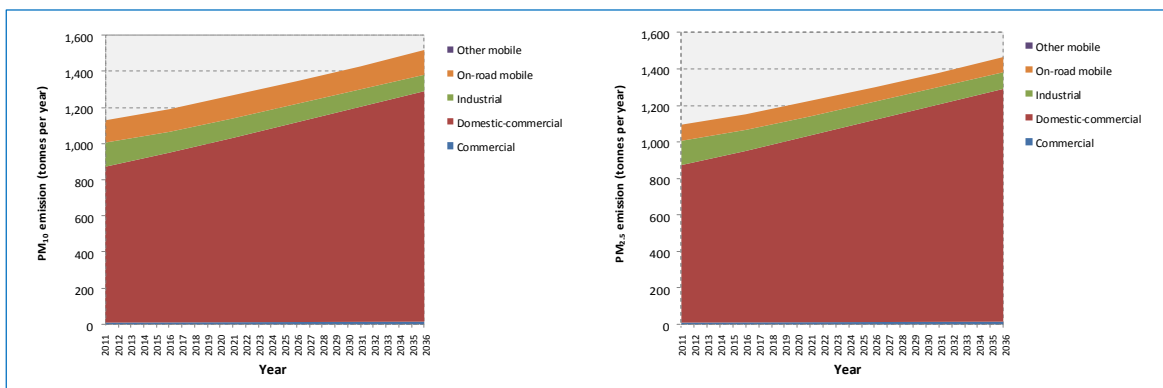


Figure 5.10: Projected emissions of PM10 and PM2.5 in ACT (Canberra airshed)



5.3 Ambient PM concentrations

5.3.1 Overview

PM concentrations in Australia vary both temporally and spatially as a consequence of many different influencing factors. In population centres the size of the urban area and the presence of pollution sources – such as major industrial facilities – shape the air quality (**SEC 2011**). Short-term meteorological conditions and local topography are also important. In inland centres such as Canberra, cold nights and clear skies frequently occur in autumn and winter, creating temperature inversions. These trap air pollution (such as wood smoke in winter) near ground level, leading to PM levels above the AAQ NEPM 24-hour standards. In centres such as Launceston, local valley topography can increase the frequency and strength of inversions, compounding the problems. Regional topography and the presence of the sea affect the movement of air in coastal cities such as Sydney and Melbourne, recirculating pollution (**SEC 2011**).

On a day-to-day basis PM concentrations are very variable. Extreme events (notably natural bush fires and dust storms) are often associated with the highest levels of pollution. In addition, the smoke generated by planned burning activities has the potential to affect health and amenity if they are not well executed. However, although the potentially adverse impacts of planned burns need to be recognised and managed, they should be considered in the context of potential benefits, such as a reduction in the risk of wild fires (**SEC 2011**).

These effects, together with a relatively short historical monitoring record at many sites, and changes in monitoring methods, can make the identification of long-term trends problematic. It is also worth noting that different emission sources have different effects on PM. For example, exhaust emissions from road vehicles are almost entirely in the PM_{2.5} fraction, whereas non-exhaust particles arising from processes such as tyre wear and brake wear are more likely to be in the coarse fraction. Dust storms tend to have high PM₁₀ levels but only moderate effects on those of PM_{2.5}, whereas bush fires tend to have high levels of PM_{2.5} but only moderate levels of PM₁₀.

5.3.2 Analysis of monitoring data

5.3.2.1 Overview

For this Impact Statement it was considered important to characterise the existing air quality environment in Australia with respect to PM₁₀ and PM_{2.5}, so that the options for the AAQ NEPM variation could be framed in an appropriate context. This required an analysis of the PM₁₀ and PM_{2.5} data from the air pollution monitoring stations in the various jurisdictions.

The rationale for monitoring air pollution, and the characteristics of the monitoring framework in Australia were described by **Bawden et al. (2012)**. Various methods are used to measure PM₁₀ and PM_{2.5}, and these vary from state to state. A summary of the methods used in each jurisdiction is provided in **Table 5.2**. Further details of the actual monitoring stations in the Australian jurisdictions are provided in **Appendix D**.

Monitoring data were obtained from the state authorities as 24-hour average concentrations between 2003 and 2012 inclusive. The treatment of the data and the detailed results are presented in **Appendix E**. Several aspects were investigated, including inter-annual trends, seasonal patterns, the effect of day of the week, geographical variations and exceedances of air quality standards. In the context of this Impact Statement, the most important of these are the inter-annual trends and the exceedances of the air quality standards. Brief summaries of the results for these are provided below.

An additional analysis in relation to the options for the AAQ NEPM is provided in **Chapter 8**.

Table 5.2: Main PM monitoring methods used by jurisdictions

| Jurisdiction | PM ₁₀ | PM _{2.5} |
|--------------|--|--|
| NSW | Gravimetric reference method TEOM | TEOM BAM |
| VIC | TEOM | Gravimetric reference method TEOM |
| QLD | FDMS TEOM, TEOM | FDMS TEOM, TEOM |
| SA | TEOM | TEOM |
| WA | TEOM | TEOM |
| TAS | Gravimetric reference method TEOM DustTrak | Gravimetric reference method TEOM DustTrak |
| NT | Partisol dichotomous sampler TEOM | Partisol dichotomous sampler |
| ACT | Gravimetric reference method BAM | Gravimetric reference method BAM |

5.3.2.2 Inter-annual trends

Inter-annual trends were based on annual mean concentrations in each jurisdiction, averaged across all monitoring sites. An example for PM₁₀ in NSW is shown in **Figure 5.11**. In most jurisdictions there was a general reduction in the overall annual mean PM₁₀ and PM_{2.5} concentrations between 2003 and 2012, although in some jurisdictions concentrations did not decrease significantly.

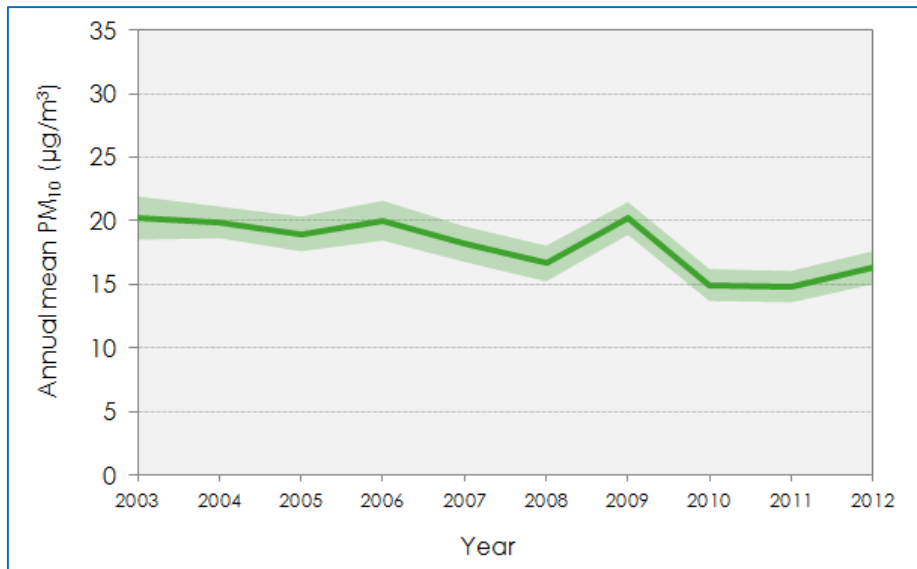


Figure 5.11: Trend in annual mean PM₁₀ concentration – NSW example (shading shows 95% confidence interval)

It should be noted that the trends can be affected significantly by changes in instrumentation at a site (e.g. one type of instrument can give results that are consistently lower or higher than another), the relocation of a monitoring site, or a change in the number/distribution of sites. Some caution is therefore needed when interpreting the trends.

5.3.2.3 Exceedances of air quality standards

In terms of exceedances of the current standards and goals for PM₁₀ and PM_{2.5} between 2003 and 2012, these main observations apply to the data:

For the 24-hour mean PM₁₀ standard (50 µg/m³, with five exceedances allowed per year):

- Weather, climate and natural events are major factors affecting exceedances. Many monitoring sites had more than five exceedances in 2009. This was mainly due to warm, dry conditions, combined with an extreme dust event in September. Conversely, there were relatively few exceedances in the cool, wet La Niña years of 2010 and 2011.
- There are no strong inter-annual trends in the patterns of exceedance. There appear to have been fewer exceedances per year between 2010 and 2012 than in earlier years, but this is probably linked to the effects described above. Any trends are, however, difficult to determine given the changes in instrumentation and monitoring locations.
- Victoria and SA appear to have a higher frequency of exceedances than the other jurisdictions.

For the advisory annual mean PM_{2.5} standard (8 µg/m³):

- There have been some exceedances of the standard in most jurisdictions.
- With the exception of NT, the overall average annual mean PM_{2.5} concentration in 2012 was below the advisory reporting standard of 8 µg/m³ in the AAQ NEPM.

For the advisory 24-hour mean PM_{2.5} standard (25 µg/m³, with an assumption of no allowed exceedances)²³:

- There have been exceedances of this standard at most of the monitoring sites.
- Several jurisdictions have exceedances at all sites and in most years.
- There are no strong year-on-year patterns in terms of exceedances of the standard.

²³ Different conclusions might be drawn if the form of the standard involved allowed exceedances.

5.4 PM composition and source apportionment

5.4.1 Methods

In practice there are several difficulties associated with identifying the different components of PM in ambient measurements and allocating them to sources, a process which is commonly termed 'source apportionment'. For example, whilst the gaseous precursors of inorganic secondary PM are largely anthropogenic it is very difficult to know what fractions of SOA result from anthropogenic and natural sources; the theoretical borderline between these two source types effectively disappears when SOA formation processes are considered (**Gelencsér et al. 2007**).

The term 'receptor modelling' covers several approaches to the source apportionment of PM which use PM composition to estimate contributions. The four types of receptor model that have been used in Australia (and New Zealand) are Chemical Mass Balance (CMB), Target Transformation Factor Analysis (TTFA), Principal Component Analysis (PCA) and Positive Matrix Factorisation (PMF) (**Friend et al. 2013**). CMB uses knowledge of source profiles and measured concentrations to calculate source contributions. TTFA involves factor analysis to identify the number and composition of sources, with target transformation being used to determine concentrations. PCA determines scores and loadings for each factor, and these are then used to determine the source profiles and contributions. PMF involves the application of an iterative algorithm to find an optimum solution to the mass balance equation. The methods used to identify the most likely locations of sources include wind rose analysis, back trajectory analysis and dispersion modelling (**Friend et al. 2013**).

In source apportionment studies the elements that are used to identify marine aerosol (often a significant source) are sodium (Na) and chlorine (Cl). A reduction in Cl and an increase in sulfur (S) has been used to distinguish fresh sea salt from aged sea salt. Soil is usually characterised by aluminium (Al), silicon (Si), potassium (K), calcium (Ca), titanium (Ti) and iron (Fe). Most Australian studies have pointed to a soil-related source, but with a wide range of contributions. Motor vehicles are a source of elemental carbon, as well as various metals. PM from manufacturing and industry has often been characterised by heavy metals such as vanadium (V), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), Ti, Ca, and Fe. Secondary aerosols are characterised by nitrate, ammonium, sulfate and organic carbon (**Friend et al. 2013**).

The main activities relating to PM composition and source apportionment in Australia are summarised below. Most of the available information relates to PM_{2.5}, and much of that has been obtained by the Australian Nuclear Science and Technology Organisation (ANSTO). There is still little information on PM₁₀ (or coarse PM) composition, and there have been relatively few studies of secondary PM – and in particular SOA – in urban areas of Australia.

5.4.2 Measurements by ANSTO

The main body of information on PM_{2.5} composition in Australia has been collected by ANSTO, which has been sampling PM_{2.5} – mainly along the east coast of Australia – since 1991. During this time fine particles have been routinely collected at selected urban, rural and industrial sites. PM_{2.5} has been collected on filters every Wednesday and Sunday over a 24-hour period, with subsequent analysis using ion beam analysis techniques. Positive matrix factorisation has also been used to characterise particles and to identify sources. This long-term program is the only one of its kind in Australia (**ANSTO 2010**).

The PM_{2.5} composition data for the ANSTO sites in NSW are available from the ANSTO web site²⁴. The following components (as well as total mass) are reported:

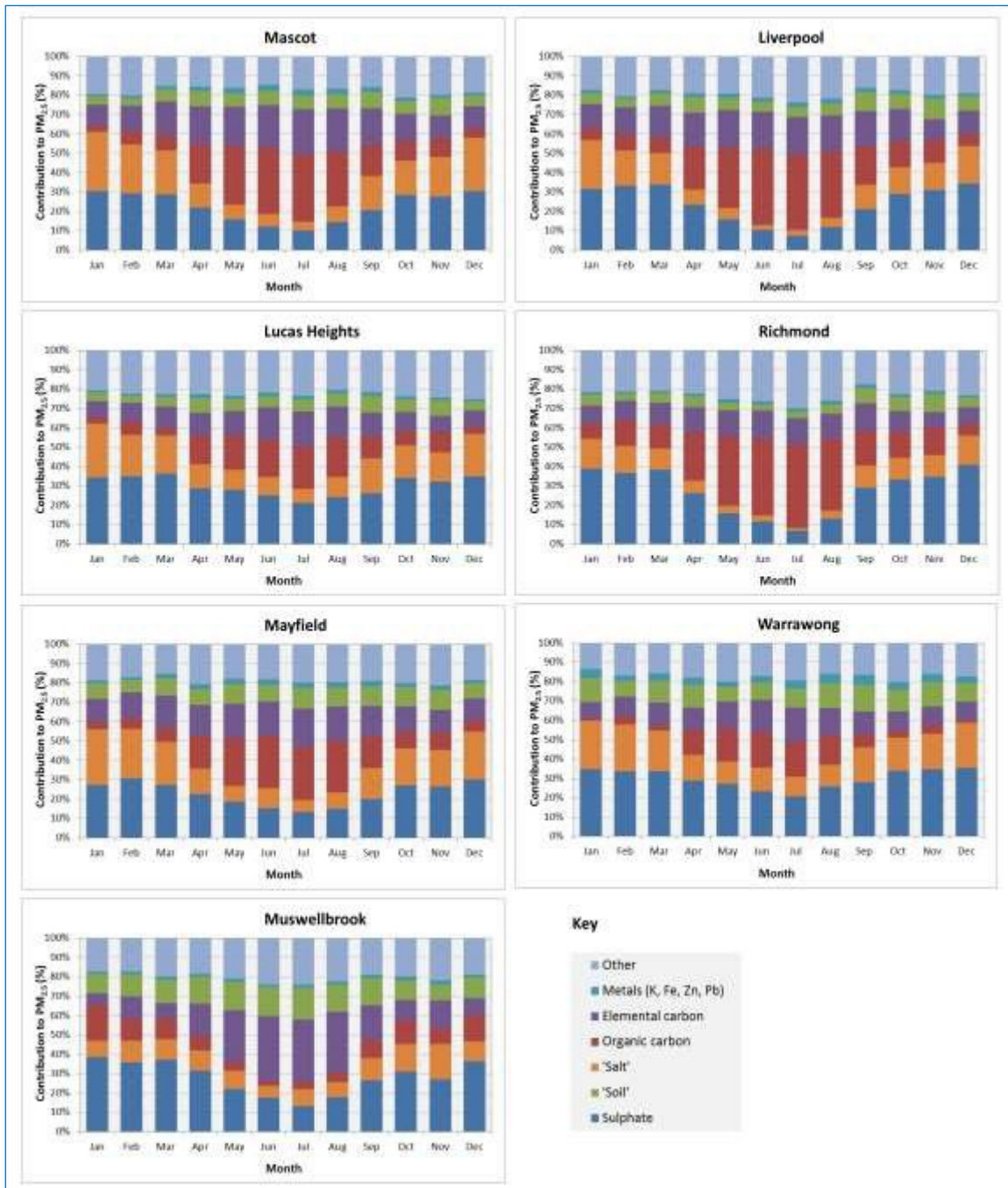
- sulfate (stated as 'NH₄SO₄')
- 'soil'
- 'salt'
- organic carbon
- black (elemental) carbon
- metals (K, Fe, Zn and Pb).

²⁴ http://www.ansto.gov.au/discovering_ansto/what_does_ansto_do/live_weather_and_pollution_data/aerosol_sampling_program

According to ANSTO the residual mass (i.e. the total less the sum of the above components) is likely to be mainly water and nitrates. ANSTO does not report nitrates, as these are not well retained on the Teflon filters that are used. The total mass may therefore be under-reported.

Figure 5.12 shows the percentage contributions of each component to the total PM_{2.5} concentration at each ANSTO site in NSW, averaged over the period 2005–2011. Each component is shown separately to illustrate site-by-site variation in **Figure 5.13**.

Figure 5.12: Composition of PM_{2.5} by month (average 2005–2011) for ANSTO sites ('other' = residual mass)



One of the largest PM_{2.5} components is ammonium sulfate. Between 1998 and 2008 the average ammonium sulfate concentration at 10 sites was 25% (range 18–31%) (ANSTO 2008). Cohen et al. (2012) also note that secondary sulfate and aged industrial sulfate were the highest percentage contributors to PM in Sydney. Figure 5.13 shows that the sulfate component is very consistent across the ANSTO monitoring sites, indicating an even geographical distribution. However, there is a strong seasonal effect. Sulfate concentrations are more than twice as high in the summer months than in the winter months, probably as a consequence of increased photochemical activity and higher energy demand (Chan et al. 2008). The relatively slow formation of SIA (hours to days) means that concentrations tend to be smoothly distributed over large areas. Reductions in emissions of SO₂ should lead to a reduction in secondary sulfate. AQEG (2012) note that in the UK the nitrate component of SIA is now larger than that of sulfate owing to major reductions in sulfur dioxide emissions in the UK and elsewhere in Europe in recent decades.

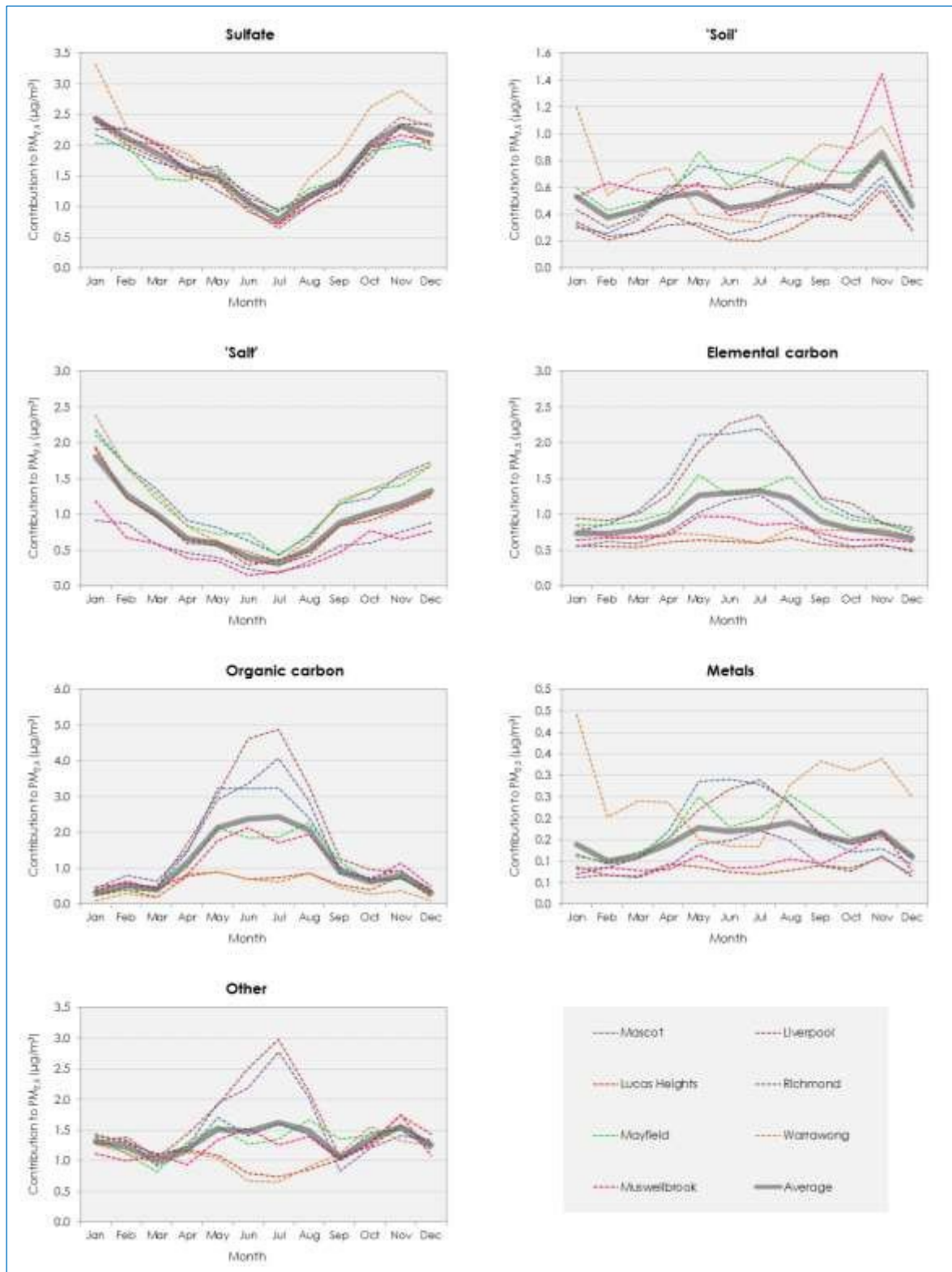


Figure 5.13: Contribution of each component to PM_{2.5} by month (average 2005–2011) for ANSTO sites ('other' = residual mass)

The 'soil' component varies considerably from site to site. There is a peak contribution in late spring, which is probably related to increased wind erosion and prevailing westerly winds during this period (Chan et al. 2008), but overall the contribution is relatively steady during the year when averaged over all sites. It is likely that this source would have a more substantial contribution to the coarse fraction.

The 'salt' component is very similar to the sulfate component, with a summer maximum and a winter minimum. This pattern for sea salt has also been observed in other studies (e.g. **Wilton et al. 2009**), and is commonly attributed to the higher wind speed (stronger sea breezes) during the summer season (**Friend et al. 2011a**).

The profiles for elemental carbon, organic carbon and 'other' components (assumed here to be water and nitrates) are rather similar in shape. The contribution peaks in winter, and the site-to-site variation during the winter months is much more pronounced than during the summer months. The contributions of these components at Liverpool and Richmond (and Mascot in the case of organic carbon) are much higher in winter than at Lucas Heights and Warrawong. The winter peak may be related to combustion, and in particular to domestic wood burning.

The contribution of metals is relatively small and rather variable from site to site.

5.5 Other studies

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has investigated the 'natural'²⁵, 'primary' and 'secondary' contributions to PM_{2.5} at Westmead, NSW, and how they vary seasonally (**Cope 2012**). Some results from this work are shown in **Figure 5.14**.

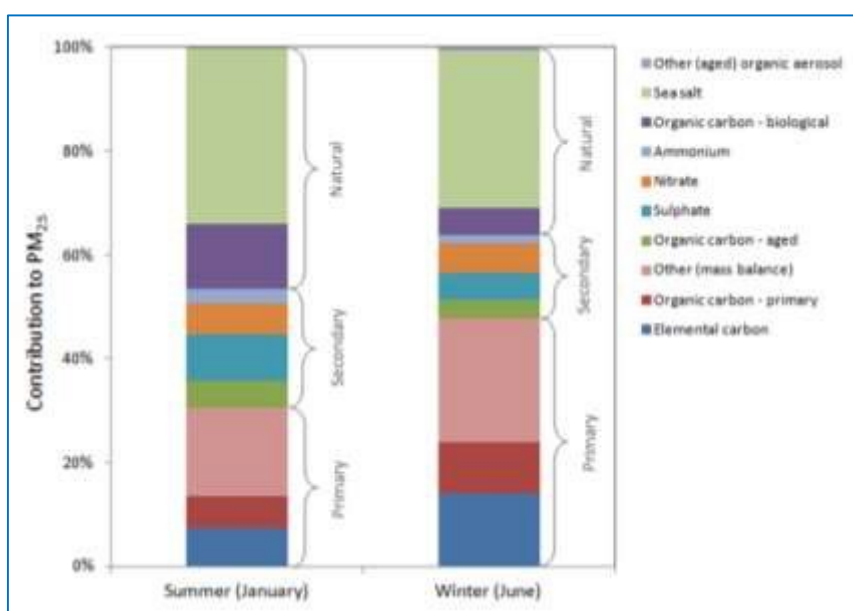


Figure 5.14: Modelled breakdown of PM_{2.5} during summer and winter months at Westmead NSW (adapted from Cope 2012)

The component labelled 'Other (mass balance)' in the figure is used to conserve mass between the estimates of PM_{2.5} in the NSW GMR emissions inventory and the estimated breakdown of PM_{2.5} from the monitoring data. This component will include dust emissions from industrial sources such as mining. In the summer months, the primary PM component constitutes about 30% of the monthly mean particle mass, and in June this rises to 50% (**Cope 2012**). This partial contribution complicates the policy-based management of PM concentrations.

ANSTO and CSIRO have recently completed an extensive particle characterisation study in the Upper Hunter Valley of NSW (**Hibberd et al. 2013**). The study provided a detailed analysis of the composition of PM_{2.5} in the two main population centres in the region (Singleton and Muswellbrook) during 2012. The authors identified the most important PM sources and their relative contributions to PM_{2.5}. The dominant factors are summarised in **Table 5.3**.

²⁵ As noted earlier, natural PM can also be either primary or secondary in origin.

Table 5.3: Percentage contributions of different sources to PM_{2.5} concentrations at Singleton and Muswellbrook in 2012 (Hibberd et al. 2013)

| Component | % contribution to PM _{2.5} | |
|------------------------------|-------------------------------------|--------------|
| | Singleton | Muswellbrook |
| Secondary sulfate | 20 ± 2% | 17 ± 2% |
| Industry aged sea salt | 18 ± 3% | 13 ± 2% |
| Vehicle/industry | 17 ± 2% | – |
| Wood smoke ^(a) | 14 ± 2% | 30 ± 3% |
| Biomass smoke ^(b) | – | 12 ± 2% |
| Soil | 12 ± 2% | 11 ± 1% |

(a) From domestic wood burning

(b) From biomass burning in bush fires and hazard-reduction burns

Seasonal changes in the contributions of the different sources to PM_{2.5} were also described. There was some significant seasonal variation in the contributions from some factors. Wood smoke was the dominant source during the winter, making up an average of 62% of the PM_{2.5} in Muswellbrook and 38% of the PM_{2.5} in Singleton. Secondary sulfate made the highest contributions during the summer months, along with industry aged sea salt. Both of these factors included secondary particles formed as a result of photochemical reactions in the atmosphere. The study provided evidence of sulfate as a pollutant at regional scales. A unique fingerprint for fugitive coal dust emissions was not found in the study. However, elemental carbon in the soil fingerprint may have resulted from the contribution of fugitive coal dust or non-road diesel vehicles at coal mines. Nevertheless, elemental carbon represented only 1% of total PM_{2.5} at Singleton and 4% of total PM_{2.5} at Muswellbrook (Hibberd et al. 2013).

Extensive receptor modelling studies have been undertaken in Brisbane – and to a lesser extent in Melbourne, Sydney and Adelaide – by Griffith University (Chan et al. 1997, 1999, 2000, 2008, 2011). These studies have shown that secondary PM forms a significant component of PM₁₀ and PM_{2.5}. It was observed by Chan et al. (1999) that secondary organic compounds and secondary sulfates accounted for 21% and 14% of PM_{2.5} respectively at a suburban site in Brisbane. Most of the secondary products were related to motor vehicle exhaust. In a study in the four cities mentioned above, Chan et al. (2008) found that, on average, secondary nitrates/sulfates contributed about 25% of the mass of the PM_{2.5} samples. Secondary sulfates and nitrates were found to be spread out evenly within each city. The average contribution of secondary nitrates to fine particles was also quite uniform in different seasons, rather than higher in winter as found in other studies. It was suggested that this could be due to the low humidity conditions in winter in the Australian cities, which makes the partitioning of the particle phase less favourable in the NH₄NO₃ equilibrium.

The composition of PM_{2.5} was determined by Friend et al. (2011b) for two sites in the South-East Queensland region (Rocklea and South Brisbane), and sources were analysed using a receptor model. The five common sources of PM_{2.5} at both sites were motor vehicle emissions, biomass burning, secondary sulfate, sea salt and soil. Secondary sulfate was the most significant contributor (up to 40%) to PM_{2.5} aerosols at the South Brisbane site, and the second most important at the Rocklea site. Biomass burning was the most significant source at the Rocklea site. In addition, dust storms that caused the PM_{2.5} concentration to exceed the AAQ NEPM standard were observed at both sites.

The earliest estimates of the contribution of SOA to particulate mass (PM) in Australian cities were obtained by Gras et al. (1992) and Gras (1996), although SOA was grouped with secondary inorganic aerosol. The first study to determine the specific contribution of SOA to PM_{2.5} in an Australian urban context (Melbourne) was by Keyword et al. (2011). SOA was estimated indirectly using the elemental carbon tracer method. The median annual SOA concentration was found to be 1.1 µg/m³, representing 13% of PM_{2.5}. Significantly higher SOA concentrations were determined when bush fire smoke affected the airshed, and SOA displayed a seasonal cycle. The SOA fraction of PM_{2.5} was greatest during the autumn and early winter months when the formation of inversions allowed build-up of particles produced by domestic wood heater emissions. Keyword et al. (2011) also suggested that biogenic VOCs are a source of SOA both at urban and non-urban sites. During summer the

biogenic VOC oxidation is the most likely source of SOA, whereas during winter the oxidation of volatile species associated with wood smoke emissions are a probable source of non-fossil SOA.

An important issue in Australia is biomass burning. In rural towns smoke from biomass burning – such as prescribed burning of forests, wild fires and stubble – is often claimed to be the major source of air pollution. Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) has identified biomass burning as a significant PM source in Brisbane, as forest back-burning to prevent forest fires in the summer is a usual occurrence around the city (**SEC 2011**). **Reisen et al. (2011)** measured PM_{2.5} at two rural locations in southern Australia. Monitoring clearly showed that, on occasions, air quality in rural areas was significantly affected by smoke from biomass combustion, with PM_{2.5} showing the greatest impact. Biomass burning emits a complex mixture of air pollutants, both as gases and particulate matter. Gaseous species include carbon dioxide, carbon monoxide, hydrocarbons and a large range of trace gases. Significantly higher SOA concentrations have been observed when bush fire smoke affects an airshed.

The literature shows that secondary PM can be responsible for a large fraction of PM_{2.5} and PM₁₀. On the whole, secondary PM is distributed more evenly than primary PM on a regional scale, with fewer differences between urban and rural areas. However, the contribution of different components of secondary PM to total PM₁₀ and PM_{2.5} still varies substantially both spatially and temporally. Between-site differences are strongly influenced by factors such as the emissions of precursor gases, the different processes involved in the formation of inorganic and organic secondary particles, the local levels of other pollutants, and the specific meteorological conditions.

Data on secondary particles at Australian sites are rather limited. **Watkiss (2002)** noted that within Australia nitrate formation will be extremely site-specific, with significant variations between different states and cities. In order to evaluate the role of nitrates a detailed assessment is needed to understand the levels of particulate nitrate aerosol in urban PM₁₀ levels, the types of aerosol species present, the background concentrations of other pollutants involved (e.g. ammonia) and the regional-scale photochemical production of particulate nitrate.

In Europe and the United States the contribution of SOA to PM has been found to be especially variable. Few studies in Australia have dealt with SOA.

Notwithstanding the above, there are some broad similarities between Europe, the United States and Australia in terms of PM_{2.5} composition and the contribution of secondary particles. For example, the sulfate contribution to PM_{2.5} in eastern Australia seems to be similar to that in the western United States. However, the formation of secondary particles is complex, the understanding is incomplete, and the variability in the data is large. Some different metrics and reporting formats are in use. There may be some important differences in how secondary particles are formed in the three regions, but these cannot yet be quantified (**Aust et al. 2013**).

Key points from Chapter 5

Emissions inventories and projections

- Five jurisdictions in Australia – including the major urban centres (Sydney, Melbourne, Brisbane, Perth and Adelaide) – have developed emissions inventories.
- There is limited consistency across the jurisdictional inventories and projections in terms of nomenclature and methodology, and the quality varies.
- The most important sectors of activity differ by jurisdiction. In NSW the most important source of PM₁₀ and PM_{2.5} is coal mining. Domestic/commercial sources (notably wood heaters) are the most important in Tasmania. In Victoria, the largest sources are wood heaters, industry and diesel vehicles
- In all jurisdictions emissions of PM₁₀ and PM_{2.5} are projected to increase between 2011 and 2036, although the projections vary considerably from jurisdiction to jurisdiction.

Ambient PM concentrations

- Various methods are used to measure PM in Australia. Any observed trends can be affected significantly by changes in instrumentation, the relocation of a monitoring site, or a change in the distribution of sites. All of these have occurred in Australia.
- Notwithstanding the above, in most jurisdictions there has been a general reduction in the overall annual mean PM₁₀ and PM_{2.5} concentrations between 2003 and 2012.
- For the 24-hour mean PM₁₀ standard (50 µg/m³), weather, climate and natural events are major factors affecting exceedances.
- Overall state-average annual mean PM_{2.5} concentrations in 2012 were below the advisory reporting standard of 8 µg/m³.
- For the advisory 24-hour mean PM_{2.5} standard (25 µg/m³), there have been exceedances at most of the monitoring sites and in most years (assuming no allowed exceedances).

PM composition

- Secondary and natural PM contribute significantly to measurements of PM₁₀ and PM_{2.5}. The primary anthropogenic PM_{2.5} component typically represents around 30%–50% of PM_{2.5}. This partial contribution complicates air quality management.
- One of the largest PM_{2.5} components is ammonium sulfate. The relatively slow formation rate means that sulfate acts as a pollutant on regional scales. Sea salt is also an important natural component.
- In inland regional centres of NSW, wood smoke is the dominant source of PM_{2.5} during the winter.

Proposed questions for consultation: Airborne PM in Australia

- Do you think that any additional information on emissions and ambient PM concentrations in Australia is required to inform the actions being considered for reducing airborne PM?
- Are there any issues that have not been considered or have not been attributed sufficient weight in the discussion?

6 STATEMENT OF THE PROBLEM AND THE CASE FOR GOVERNMENT INTERVENTION

This chapter of the Impact Statement identifies the fundamental problems that need to be addressed, and establishes the case for government involvement.

6.1 Statement of the problem

The requirement to reduce atmospheric concentrations of PM derives principally from its well-recognised and quantified effects upon human health, including premature mortality, hospital admissions, allergic reactions, lung dysfunction, cardiovascular diseases and cancer. The short-term and long-term impacts of PM₁₀ and PM_{2.5} on health, and the lack of evidence for thresholds for health impacts, have been reinforced by the recent REVIHAAP report (**WHO Regional Office for Europe 2013**). The non-threshold nature of the health response to PM means that sensitive individuals – such as people with respiratory or cardiovascular disease – may be affected even where concentrations are relatively low. There is therefore still a health benefit (and cost saving) to be gained from any reduction in PM concentrations and overall population exposure.

The data presented in **Chapter 5** show that annual mean PM₁₀ and PM_{2.5} concentrations have shown a tendency to decrease in some jurisdictions in recent years, whereas in other jurisdictions they appear to have stabilised or increased. In most jurisdictions the annual mean PM_{2.5} concentration in 2012 was below the AAQ NEPM advisory reporting standard of 8 µg/m³. However, there continue to be exceedances of the 24-hour standards and goals at many monitoring sites, although these are often attributed to exceptional (and uncontrollable) natural events.

Where PM concentrations have historically been below air quality standards/goals, there is no guarantee that this will continue in the future, especially given that the projections in state inventories show that PM₁₀ and PM_{2.5} emissions are likely to increase under a BAU scenario, in spite of controls on emissions from several sectors. For example, the data from the NSW GMR emissions inventory show that total anthropogenic emissions of PM₁₀ and PM_{2.5} in the GMR will increase by 63% and 35% respectively between 2011 and 2036, largely as a result of growth in coal mining activity. Anthropogenic emissions of secondary PM precursors such as NO_x, SO₂, NH₃ and VOCs are also predicted to increase in the future. Higher temperatures associated with global warming may well result in increased biogenic emissions of the VOC precursors of SOA. These increases in emissions would be likely to lead to increases in ambient PM concentrations, increases in the incidence of adverse health outcomes, and increases in the monetary costs of air pollution to society, especially when combined with a projected increase in population. **ABS (2008)** predicts that the Australian population will increase by around 80% between 2010 and 2050, and the largest increases will probably occur in urban centres where people are most likely to be exposed to air pollution.

In addition, monitoring and assessment to date has largely been directed towards evaluating compliance with air quality standards and goals at specific locations. However, overall health outcomes are driven by large-scale population exposure to the prevailing urban background PM concentration. In Europe, for example, this has been addressed by adding an exposure-reduction framework to the air quality legislation.

These factors will probably make it more difficult for the national air quality standards and goals for PM to be met in the future without further intervention. Updating the AAQ NEPM should go some way to reducing these adverse effects by highlighting potential problems and assisting jurisdictions in the formulation of air quality policies to reduce emissions from different sectors.

6.2 Why the AAQ NEPM PM standards need to be updated

An update of the AAQ NEPM standards for PM is appropriate and timely for a number of reasons. These include the following:

- There is a **statutory provision** to review the AAQ NEPM, and in particular the advisory reporting standards for PM_{2.5}.
- There is an **expectation on the part of the public** that environmental legislation will provide a sufficiently high level of protection against the adverse effects of air pollution on health.

-
- Environmental legislation needs to reflect the **current scientific understanding**. In recent years the understanding of the health effects of airborne PM has improved markedly (in particular the strengthening of the evidence for there being no threshold for health effects). There is also a better understanding of concentrations across Australia, notably for PM_{2.5} for which the data were lacking at the time of the AAQ NEPM variation in 2003.
 - The **projected growth in population and emissions** will make it more difficult to achieve sustained improvements in air quality due to increased transport demand, domestic emissions and energy use (in spite of actions to reduce emissions, such as emission standards and carbon policy).
 - There is a need for **more consistency across jurisdictions** in the application of the AAQ NEPM. For example, the current form of the standards – notably the characterisation of exceedances of the 24-hour standard for PM₁₀ – is open to interpretation. There is a need to better understand and characterise the contribution of different sources (especially natural events) to exceedances.

6.3 Risks of not revising the standards

The risks of not updating the AAQ NEPM standards for PM can be effectively stated in terms of the health impacts and associated costs to society under the BAU scenario. These are explored further in **Chapter 8**. More generally, the ongoing risk of not revising the standards will be that Australian public health is not protected to a level that is based on contemporary science and evidence.

6.4 Rationale and objectives of government intervention

The principal reason for intervention is to protect the population from the wide-ranging adverse health effects of PM. Emission projections suggest that the recent trend of decreasing ambient concentrations of PM₁₀ and PM_{2.5} is likely to be reversed if action is not taken, with subsequent increases in the incidence of adverse health outcomes, and increases in the monetary cost of air pollution to society. The extent to which government needs to intervene is informed by environmental and economic data.

Government involvement should aim to reduce ambient concentrations of PM₁₀ and PM_{2.5}, especially in populated areas, taking into account the practical limitations on what can be achieved using traditional methods (i.e. reducing primary anthropogenic emissions). This needs to be guided by data on PM concentrations and composition. It is known, for example, that a significant proportion of PM is natural and/or secondary in nature. Measures to reduce primary anthropogenic PM emissions should therefore be accompanied by measures to reduce emissions of the precursors of secondary particles.

There is a case for government intervention when market failures are present²⁶. With respect to air quality the primary market failure is a negative externality. Negative externalities exist where the actions of a party result in a cost to a third party not directly involved in that action. In the case of air pollution, the party responsible for causing the pollution does not bear all of the health costs associated with it. While negative externalities are the most prominent of market failures, some secondary market failures could be addressed through the implementation of abatement measures. For example, it has been argued that some households may not be aware that the way in which they operate wood heaters increases air pollution, preventing them from voluntarily adjusting their behaviour (**BDA Group 2013**). Air quality abatement measures all comprise some form of intervention, either through regulation (emission standards), disincentives to pollute (e.g. financial penalties) or incentives (grants or subsidies) to take actions that reduce emissions. In doing so, the measures are designed to increase societal welfare.

In the AAQ NEPM the primary objective of government is to attain 'ambient air quality that allows for the adequate protection of human health and wellbeing'. The absence of a threshold for the health effects of fine particles has prompted support for more stringent air quality standards and for the adoption of an exposure-reduction approach which seeks to gradually reduce general exposures to fine particle concentrations.

²⁶ A market failure is where, in the absence of government intervention, the free market does not allocate goods and services in a way that maximises welfare for all of society. Therefore, government intervention to address the market failure can improve the efficiency of resource allocation.

This Impact Statement indicates that current policy interventions are not limiting emissions and concentrations in line with policy objectives. Government intervention is considered necessary to prompt and accelerate policies and measures to reduce population exposure to particulate air pollution.

The Economic Analysis project provided an economic rationale for revising the PM standards in the AAQ NEPM.

6.5 Issues to be addressed in AAQ NEPM variation

Where PM concentrations have historically been below air quality standards/goals, there is no guarantee that this will continue in the future, especially given that the projections in state inventories show that PM₁₀ and PM_{2.5} emissions are likely to increase under a BAU scenario. It is therefore likely that it will be more difficult to meet the national air quality standards and goals for PM in the future without further intervention. Updating the AAQ NEPM should assist jurisdictions in the formulation of air quality policies to reduce emissions.

As discussed in the AAQ NEPM review, several issues need to be addressed when considering a variation to the AAQ NEPM. It has not been possible to cover every issue in exhaustive detail in this Impact Statement, but an attempt has been made to address the main points. These are:

- **status** of the PM standards (formal standards or advisory reporting standards)
- **PM metrics and averaging periods** that should be included in the AAQ NEPM standards. These should be based primarily on the health evidence, and should ensure that short-term and long-term health is protected
- **numerical values** for the PM standards. These should take into account the health evidence as well as the achievability of the standards in the different Australian jurisdictions and regions (e.g. urban and rural areas). The latter should consider the prevailing ambient PM concentrations and trends in Australia. In addition, it should address the relationship between the standards. For example, where separate PM metrics are applied together is one standard exceeded more frequently than the other?
- **form of the standards** (e.g. allowed exceedances)
- feasibility of an **exposure-reduction framework**.

Key points from Chapter 6

- Due to the projected increases in population, activity and emissions, the recent trend of decreasing ambient concentrations of PM₁₀ and PM_{2.5} is likely to be reversed in the future. This would make it more difficult to meet the national air quality standards and goals for these metrics. There is therefore a risk that Australian public health will not be sufficiently protected, with potential increases in the incidence of adverse health outcomes as well as increases in the monetary cost of air pollution to society.
- Current policy interventions are not limiting emissions and concentrations in line with policy objectives. Government intervention is considered necessary to prompt and accelerate policies and measures to reduce population exposure to particulate air pollution. The extent to which government needs to intervene is informed by environmental and economic data.
- The following issues have been considered in this Report:
 - the status of the PM standards (formal standards or advisory reporting standards)
 - the PM metrics and averaging periods that should be included in the AAQ NEPM standards
 - the numerical values for the PM standards
 - the form of the standards (e.g. allowed exceedances)
 - the feasibility of an exposure-reduction framework.

Proposed question for consultation: The problem and the case for government intervention

- Do you agree that further government involvement is required to address the potential future health impacts and costs of airborne PM?

7 DISCUSSION OF POSSIBLE APPROACHES AND OPTIONS

7.1 General air quality management framework

Several types of framework have the potential in theory to address the problems identified in **Chapter 6**. The main alternatives for a general framework are:

- variation of the AAQ NEPM
- Commonwealth legislation
- voluntary guidelines
- inter-governmental agreement or memorandum of understanding
- no change to the current framework (BAU scenario).

These alternatives will now be considered in turn.

7.1.1 Variation of the Ambient Air Quality AAQ NEPM

The existing AAQ NEPM framework has now been in place for 15 years. The framework has overcome the limitations of the previous voluntary guideline approach, and has facilitated a collaborative process that has included all jurisdictions in national air quality management. It has allowed for a nationally consistent framework for the setting and implementation of air quality standards and goals, and for the monitoring and reporting of air quality against those standards and goals. The establishment of standards and goals through the AAQ NEPM has overcome potential conflicts or inconsistencies between individual state or territory-based regulations, as all jurisdictions have been subject to identical criteria.

Whilst the AAQ NEPM review identified several areas for improvement, some of which are addressed in this Impact Statement, the framework has served a useful purpose. Although reporting against the AAQ NEPM standards is not strictly enforceable²⁷, there have still been considerable benefits associated with their introduction. As mentioned earlier, it could reasonably be argued that the AAQ NEPM has represented a significant advance in terms of air quality management in Australia, and has resulted in numerous policies and initiatives to improve air quality. There is compelling evidence that the population needs to be protected from particulate air pollution on health grounds, as well as evidence that providing such protection would result in substantial economic benefits. The process of reviewing and developing the AAQ NEPM standards does, in itself, highlight these potential benefits.

On balance, it is considered that the most effective way to ensure future consistency in national air quality management and data collection will be the development of a variation to the existing AAQ NEPM, with jurisdictions adopting the AAQ NEPM provisions in their own regulations. For the remainder of this Impact Statement it has therefore been assumed that a variation of the AAQ NEPM will be the preferred approach; however, for completeness, the remaining approaches are also outlined below.

7.1.2 Commonwealth legislation

Establishing national emission standards through Commonwealth regulation would result in a nationally consistent approach to air quality management. However, the impact statements for the original AAQ NEPM and the revision for PM_{2.5} argued against the development of Commonwealth legislation to achieve the desired air quality outcomes (**NEPC 1998, 2002**). One of the main reasons for this was that the Commonwealth has no constitutional powers in relation to air quality. It was also suggested that the Commonwealth would be unlikely to pursue a unilateral approach given the existing cooperative approach in relation to environmental issues; unilateral Commonwealth action could have alienated state and territory environment agencies with responsibility for air quality management. The Commonwealth was also not well placed to assume a hands-on role in data collection, analysis and reporting of air quality data, and would have had to invest significant resources to

²⁷ There are no sanctions specified in the AAQ NEPM against jurisdictions that do not provide reports or do not comply with the standards and goals.

duplicate systems that were already in place at the state and territory level. The AAQ NEPM was developed to overcome the inherent difficulties of the Commonwealth legislation on air quality. This logic still applies, and therefore Commonwealth legislation is not considered to be a feasible approach and has not been included in the impact analysis.

7.1.3 Voluntary guidelines

Prior to the introduction of the AAQ NEPM, voluntary guidelines on air quality in Australia were available from the National Health and Medical Research Council (NHMRC) and the Australian and New Zealand Environment and Conservation Council (ANZECC). However, there were a number of different approaches in the application of the NHMRC guidelines between jurisdictions. This led to inconsistency in monitoring and reporting throughout Australia, making cross-jurisdictional comparisons difficult and possibly creating compliance difficulties for industries with operations in more than one jurisdiction (**NEPC 1998, 2002**). Such factors significantly reduced the level of certainty with which voluntary guidelines afforded environmental protection. It is reasonable to assume that any new voluntary guidelines of this type would have similar problems. These factors would make it difficult to achieve the desired environmental outcomes at the national level. The use of voluntary guidelines would represent a retrograde step in air quality management in Australia. Therefore, voluntary guidelines are not considered a feasible approach and have not been included in the impact analysis.

7.1.4 Inter-governmental agreement or memorandum of understanding

Inter-governmental agreements were also considered as part of the impact assessment for the variation to include PM_{2.5} in the AAQ NEPM (**NEPC 2002**). However, it was concluded that this approach would not necessarily provide a sufficient degree of uniformity in the standard-setting process, or in the monitoring and reporting requirements necessary to make the standards meaningful. This approach offers no obvious advantage over the AAQ NEPM variation approach; a similar process would be required, but without the likelihood of achieving uniformity in practice. Therefore, this approach is not considered feasible and has not been included in the impact analysis.

7.1.5 No change to the current framework

For the BAU approach to be considered it is important to understand how successful the legislation has been to date, and the extent to which it is likely to be successful in the future.

The AAQ NEPM represents a harmonised national framework for the management of ambient air quality. The air quality standards and goals in the AAQ NEPM are intended to achieve equity, in that they provide an equivalent minimum level of protection from the adverse health effects of air pollutants. The AAQ NEPM has successfully imposed a responsibility on the jurisdictions to monitor air quality and to report progress towards meeting the air quality standards and goals. It could also be argued that it has stimulated significant advances in air quality management in Australia, and that there has been a general downward trend in PM₁₀ and PM_{2.5} concentrations in recent years. However, there continue to be exceedances of the PM standards and, given the projected increases in emissions, concentrations may well increase overall in the future.

Should the AAQ NEPM continue in its current form, this framework will continue. The current standard and goal for 24-hour PM₁₀ will remain in place. However, there will continue to be only advisory standards for PM_{2.5} and, importantly, there will be no annual mean standard for PM₁₀. This suggests that not changing the legislation will lead to inadequate protection against the adverse long-term health effects of coarse particles, which are known to be of considerable importance in Australia. There will be no exposure-reduction framework.

The existing AAQ NEPM has been an important catalyst for change in air quality management in Australia; however, to leave it in its current form would be to risk losing some of the progress made and miss the opportunity to prepare in good time for the projected increases in emissions.

7.2 Status of air quality standards

Assuming that an AAQ NEPM variation is going to be the preferred approach, the only choice to be made here is whether the PM standards should be of an advisory nature or should be formally adopted. In either case, an implication of varying the AAQ NEPM will be that the PM standards will remain non-binding (i.e. compliance will not be mandatory). This is arguably one of the main drawbacks of the AAQ NEPM in its current form.

7.3 PM metrics and averaging periods

The AAQ NEPM currently specifies a 24-hour standard for PM₁₀ concentrations, and advisory reporting standards for 24-hour and annual mean PM_{2.5} concentrations. The following elements of varying the AAQ NEPM have been considered in this Impact Statement:

- addition of an annual mean standard for PM₁₀
- inclusion of metrics other than PM₁₀ and PM_{2.5}, such as PM_{0.1}, particle number
- inclusion of limits for specific PM components
- inclusion of secondary standards (as in the United States) for non-health impacts.

The revocation of the existing metrics has not been considered.

The addition of an annual mean standard for PM₁₀ is strongly favoured on health grounds.

There are currently insufficient monitoring data in Australia to allow for the consideration of options relating to metrics other than PM₁₀ and PM_{2.5} (e.g. ultrafine particles). Moreover, there is still insufficient health evidence to support the setting of standards for these other metrics.

Similarly, there are no Australian health studies for the coarse particle (PM_{2.5-10}) size fraction. There are very limited monitoring data available in Australia for PM_{2.5-10}, and the available data are not sufficient to support the setting of specific standards at this time (although the simultaneous implementation of standards for PM₁₀ and PM_{2.5} effectively addresses this). However, given that this size fraction is significant in Australia due to the significant contribution from windblown dust to PM₁₀, further monitoring of the coarse fraction and studies into the associated health effects may be prudent to inform the setting of standards in the future (**NEPC 2011a**).

The option of 'secondary standards' has not been considered given the lack of Australian literature. Such standards are used in the United States to reduce non-health impacts (including protection against decreased visibility and damage to animals, crops, vegetation and buildings). In the United States the primary and secondary standards are generally the same. The main exception is annual mean PM_{2.5}, for which the secondary standard is slightly higher than the primary standard.

Consequently, the options that have been considered here relate solely to the metrics PM₁₀ and PM_{2.5}, and to annual and 24-hour averaging periods in each case. The numerical values of these metrics are discussed in the following Section.

7.4 Numerical values of standards

In a separate project, potential new air quality standards for both PM₁₀ and PM_{2.5} were identified. These also included the existing standards. The options and sub-options that have been assessed here, including the numerical values of the ambient air quality standards for PM₁₀ and PM_{2.5}, are shown in **Table 7.1**. The options are based on international guidance (e.g. from WHO and USEPA), but were informed by Australian conditions. The most stringent standards were considered to reflect minimum realistic values for Australia, taking into account natural background and current air quality trends.

Table 7.1: Options and sub-options – numerical values of air quality standards

| Action | Options | Sub-option ^(a) | Standard ^(b) |
|----------------------------------|--------------------------------|---------------------------|-----------------------------|
| Numerical values of PM standards | PM ₁₀ annual mean | A20 _{PM10} | 20 µg/m ³ |
| | | A16 _{PM10} | 16 µg/m ³ |
| | | A12 _{PM10} | 12 µg/m ³ |
| | PM ₁₀ 24-hour mean | D50 _{PM10} | 50 µg/m ³ |
| | | D40 _{PM10} | 40 µg/m ³ |
| | | D30 _{PM10} | 30 µg/m ³ |
| | PM _{2.5} annual mean | A10 _{PM2.5} | 10 µg/m ³ |
| | | A08 _{PM2.5} | 8 µg/m ³ |
| | | A06 _{PM2.5} | 6 µg/m ³ |
| | PM _{2.5} 24-hour mean | D25 _{PM2.5} | 25 µg/m ³ |
| | | D20 _{PM2.5} | 20 µg/m ³ |
| | | D15 _{PM2.5} | 15 µg/m ³ |

- (a) A = annual mean; D = daily mean
(b) Current standards are shown in bold

Health effects occur at levels of exposure currently experienced in Australia. There is evidence that health improvements will be achieved by reducing exposure below these levels. No standard could therefore completely eliminate the risk of adverse health impacts. Because of this, enHealth’s position is that the numeric values should be set as low as reasonably achievable, taking into account social and economic factors (see **Appendix C**).

As with previous national regulation impact statements that have considered iterative change, these options and sub-options are necessarily considered against a baseline situation or a BAU scenario. In impact statements for specific sectors it has been comparatively straightforward to define the BAU scenario; for example, future emissions for a given sector (say, road vehicles) can be calculated based on an assumption that no further (more stringent) emission standards would be introduced. However, the baseline/BAU situation is more difficult to define when dealing with ambient air quality, and different approaches were used in the HRA and Economic Analysis projects (see **Chapter 8**).

7.5 Form of the 24-hour PM standards

7.5.1 Background

The ‘form’ of a standard refers to the approach that is used to obtain a value from the measurements that can be compared with the numerical value of the standard. For the annual mean concentration this is relatively straightforward, as only one value is obtained from the measurements. For the 24-hour standard it is more complicated, as there is a need to decide which of the 365 measurements in a year (assuming a non leap year and no loss of data) should be compared with the standard. In the US, the form of the standard relates to the use of descriptive statistics, and in the case of the 24-hour standard for PM_{2.5} the 98th percentile (averaged over three years) is used. The 98th percentile was selected as it represents a balance between limiting peak pollutant concentrations and providing a stable regulatory target (**USEPA 2011**).

One of the greatest challenges in air quality management is to separate human-made PM from natural PM. This situation is, however, not unique to Australia; a recent report has highlighted a similar problem in Europe (**EEA 2012**) (see **Section 4.2.1.4**). In the US and Europe there is the possibility for jurisdictions to remove the data for natural or exceptional events (such as bush fires and dust storms) prior to comparing measurements with the standard.

The form of the 24-hour standard should also result in an appropriate balance between the annual mean and 24-hour standards. For example, where these two metrics are applied together there may be a tendency at a given monitoring site for one of them to be exceeded more frequently than the other. From a health and economic perspective – and hence in terms of policy – it is advisable to place more emphasis on the annual mean standard than on the 24-hour standard. As long as separate annual and 24-hour standards are in place, this should not present a practical problem. However, if the numerical value and form of the 24-hour standard are defined so that it is exceeded more frequently than the annual mean standard, this could lead to the perception that the 24-hour standard is the more important one, with the potential for disproportionate action on short-term concentrations.

In this context the AAQ NEPM review dealt in some detail with the current approach in Australia of allowing a fixed number of exceedances for 24-hour average PM₁₀. It was noted that the exceedance rule is often misused, and has been applied to urban air pollution and, in some cases, individual sources (**NEPC 2011a**). There was also strong support in the review process for the jurisdictional AAQ NEPM reports to demonstrate through trend analysis whether improvements have been made over time and, accordingly, whether there is decreasing risk associated with population exposures with respect to air pollution.

The alternatives have been considered below.

7.5.2 Alternative forms

7.5.2.1 Fixed number of days (current AAQ NEPM approach)

The AAQ NEPM review considered the implications of allowing or not allowing exceedances of a specified numerical value (e.g. the number of exceedance days per year). Exceedances may be permitted to allow for events that are known to occur but which cannot be managed (e.g. emissions from bush fires or dust storms). Alternatively, a stringent numerical value may be chosen for a particular pollutant due to the risk it poses, but with a relatively large number of allowed exceedances to reflect current ambient concentrations, allowing for a tightening over time to drive improvements in air quality. However, the larger the number of allowed exceedances, the higher the overall average concentration can be, leading to greater risk to the community (**NEPC 2011a**).

The AAQ NEPM currently allows five exceedances of the 24-hour standard for PM₁₀, and no exceedances of the 24-hour advisory standard for PM_{2.5} (although this is only because of the advisory nature of the standard, and may change if it is formally adopted). The AAQ NEPM requires the jurisdictions to report all exceedances of the standards and provide a description of the circumstances that led to the exceedances. However, it does not require the jurisdictions to provide information in annual reports on management actions that are being implemented where concentrations exceed the standards/goals (**NEPC 2011a**).

The AAQ NEPM review found that some jurisdictions were reporting only the sixth highest PM₁₀ concentration, without any indication of whether the five top events were natural or anthropogenic. It was argued that appropriate attribution to sources was not being undertaken and that the reporting requirements should be strengthened in this area. Detailed reasons for all exceedances are needed to determine if a pollution event is beyond the normal management capabilities of the jurisdiction.

7.5.2.2 Percentile value

The USEPA has established the form of the 24-hour PM_{2.5} standard as the 98th percentile of 24-hour concentrations at each monitoring site in an area, averaged over three years. The 98th percentile was selected as an appropriate balance between limiting peak pollutant concentrations and providing a stable regulatory target for risk management programs. The 98th percentile value was also found to be a more stable metric than the 99th percentile value (**USEPA 2011**). By comparison, the five exceedance days for 24-hour mean PM₁₀ that are currently allowed in the AAQ NEPM equates to a 98.6th percentile value.

The advantages of a 98th percentile rule (or any similar rule) include that it is straightforward to calculate the statistic (various percentile values have been reported by the Australian jurisdictions for some time), and it has few if any resource implications. A drawback of the percentile approach is that it is essentially arbitrary and does not, in itself, improve the understanding of air quality without a separate analysis of the events leading to exceedances of standards and goals. In the US the percentile rule is supported by an 'exceptional events' rule (see below).

7.5.2.3 Not-to-be-exceeded standards

There was support during the AAQ NEPM review process for the removal of allowed exceedances and the introduction of not-to-be-exceeded standards. The review noted that not-to-be exceeded standards imply a threshold, and that once concentrations are below this threshold there may be a perception that no further action is required. However, this reasoning could apply equally to other approaches (e.g. a percentile rule). Perhaps of more concern is that, to be realistically achievable, a not-to-be-exceeded value would tend to be higher than the alternatives, and it could be argued that this would offer less protection.

7.5.2.4 Natural/exceptional events rule

During the AAQ NEPM review process there was support for the introduction of a 'natural events rule' that would exclude the impacts of bush fires and major dust storms from the assessment against the standards (although data would still be reported). This could supplement the current concept of allowable exceedances, or an alternative percentile rule, and would focus attention on sources of air pollution that can realistically be managed.

The definition of a natural air pollution event could address the following aspects:

- A breach of air quality standards has occurred at a monitoring station.
- The primary cause of the breach has been identified with a reasonable degree of certainty.
- The primary cause is beyond any plausible influence of air quality management effort (e.g. bush fires, dust storms, emergency back-burning, long-range transport of pollution from outside a jurisdiction).

The following types of event would not be categorised as natural events:

- planned hazard-reduction burns
- agricultural burns
- waste burning
- wind-blown dust from poorly maintained industrial, commercial, agricultural or private land
- industrial fires and gas releases
- domestic or commercial fires.

For the purpose of annual AAQ NEPM reporting jurisdictions would need to identify any natural air pollution events during the reporting year, and then exclude these from the annual count of exceedances. Any natural or trans-boundary air pollution events could be itemised in a separate section of the jurisdictional AAQ NEPM report.

The natural events rule is not intended to create a significant burden of investigative work; however, it would need to be tested in practice to ensure it could be applied rigorously. Natural events could be identified based on a combination of records, satellite images, analysis of meteorology and pollution data (including both PM₁₀ and PM_{2.5} to aid source identification), or first-hand observer reports from the affected region.

A broadly similar approach has been adopted in Europe and the United States, and it is worth noting that some difficulties have been encountered. **EEA (2012)** found that it was hard to detect a common Europe-wide strategy on how to deal with the natural emissions and their contributions to limit value exceedances when analysing Member State submissions for the Air Quality Directive. The eleven countries that reported natural contributions to PM₁₀ limit value exceedances used quite different approaches. This suggests that strict guidelines would need to be developed and trialled prior to consideration of a natural events rule in Australia.

7.5.3 Summary of options for the form of the 24-hour standards

Four options for the form of the 24-hour standards are to be considered for the AAQ NEPM:

- Business as usual option. A rule that allows a fixed number of exceedances of a PM standard in a given year (as is currently the case for PM₁₀), but with no exclusion of data for exceptional events. The fixed number of allowable exceedance days (e.g. five days per year) would be based on an estimated number of exceptional events. For reporting purposes the occurrence of exceptional events will be recorded, and various statistics will be presented (including percentiles), but these will not be used when comparing measured concentrations with the standard.
- A rule that allows a fixed number of exceedances of a PM standard in a given year based on the exclusion of data for actual exceptional events. This is similar to the approach used in the EU.
- A rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with no exclusion of data for exceptional events. For reporting purposes the occurrence of exceptional events will be recorded and various statistics will be presented (including percentiles), but these will not be used when comparing measured concentrations with the standard.
- A rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with the exclusion of data for exceptional events. This is similar to the approach used for PM_{2.5} in the US.

The form of the 24-hour standard should also result in an appropriate balance between the annual mean and 24-hour standards. As discussed above, the situation in which the numerical value and form of the 24-hour standard leads to the perception that it is more important than the annual standard needs to be avoided, due to the potential for a disproportionate focus on short-term concentrations.

7.6 Applicability of standards

The approach whereby the AAQ NEPM standards for PM are based on measurements at sites that reflect the general exposure of populations in large metropolitan areas is planned to be maintained. Under this general exposure approach the standards and goals are applicable to urban sites away from sources of pollution, such as busy roads and industrial stacks. Individual jurisdictions can employ complementary methods to inform development applications for proposed infrastructure and industrial proposals in a variety of locations and contexts.

7.7 Exposure-reduction framework

Bawden et al. (2012) recommended the establishment of an exposure-reduction framework within the AAQ NEPM. The framework would consist of three main tasks.

- *Task 1 – Development of emission-reduction programs.* This would introduce a requirement for jurisdictions to develop programs to reduce emissions so as to reduce exposure to PM. There is potential for the requirements to be tailored to the scale of the problems within the different jurisdictions. National guidance would need to be developed.
- *Task 2 – Development of PM_{2.5} monitoring networks and regional emissions inventories.* This would involve a requirement to focus monitoring on PM_{2.5} and to carry out a minimum level of monitoring following appropriate national guidance. This task would also encourage the jurisdictions to develop emissions inventories according to national guidance. A monitoring metric would need to be developed so that population exposure for major urban areas could be quantified.
- *Task 3 – Development of exposure-reduction targets.* Work would be required at a national level using available information to identify sources and suitable cost-effective control programs, and thus to define realistic targets. A substantial part of this work was undertaken in the Economic Analysis project.

The introduction of an exposure-reduction framework into the AAQ NEPM has been considered as a 'co-option'. It is assumed that progress towards reducing exposure would be framed in terms of the monitored PM_{2.5} concentration (as in the AEI approach used in the EU), or an equivalent modelling approach. Two options have been considered for dealing with population exposure in major urban areas, as shown in **Table 7.2**. In option ER1 the target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 has been included, as this was assessed in the Economic Analysis. Option ER2 would involve a similar approach, but there would be no numerical target but an implicit aim of continual improvement and/or no deterioration of air quality.

Table 7.2: Options and sub-options – exposure-reduction

| Option | Sub-option | Description ^(a,b) | Target |
|--|------------|---|--|
| Exposure-reduction framework co-option | ER1 | 'Exposure index' based on average PM _{2.5} concentration at metropolitan AAQ NEPM monitoring sites within a jurisdiction | 10% reduction in the annual mean PM _{2.5} concentration between 2015 and 2025 |
| | ER2 | 'Exposure index' based on average PM _{2.5} concentration at metropolitan AAQ NEPM monitoring sites within a jurisdiction | Continual improvement and/or no deterioration. Exposure index is used to assess progress in terms of reducing exposure |

- (a) The 'exposure index' could either be specified as a single year average or a multi-year average (for example, a three-year average is used in the EU).
- (b) There is no explicit population weighting in the options, although population-weighted exposures were calculated for option ER1 in the Economic Analysis, as concentrations were estimated in both urban and rural areas. The population-weighted concentrations were biased towards urban areas, and therefore broadly equivalent to an exposure index for such areas.

In **Section 4.2.2.6** it was indicated that a complete understanding of population exposure in Australia would involve significant investment. However, undertaking the first steps towards characterising exposure based on the existing monitoring network would require little or no investment on the part of the jurisdictions. The robustness of the exposure index in a given jurisdiction would increase as jurisdictions monitor PM_{2.5} at more sites.

Key points from Chapter 7

- The AAQ NEPM framework has allowed for a nationally consistent framework for the setting and implementation of air quality standards and goals, and for the monitoring and reporting of air quality against those standards.
- The most effective way to ensure future consistency in national air quality management and data collection will be the development of a variation to the existing AAQ NEPM, with states and territories using the AAQ NEPM provisions in their own jurisdiction, as is currently done.
- Potential new air quality standards for both PM₁₀ and PM_{2.5} are to be considered as options for varying the AAQ NEPM.
- Four options for the form of the 24-hour standard are to be considered:
 - no change, where there is an existing standard (i.e. for PM₁₀), and no exclusion of exceptional events
 - a rule allowing a fixed number of exceedances of a PM standard in a given year, based on exclusion of exceptional events
 - the 98th percentile PM₁₀ concentration in a given year is compared with the standard with no exclusion of exceptional events
 - the 98th percentile PM₁₀ concentration in a given year is compared with the standard and exceptional events are excluded.
- There are several different ways in which the jurisdictions can (and do) guide air quality in relation to developments. However, a further discussion of the advantages and disadvantages of the different approaches is required, and should be addressed in the first instance during the consultation process.
- Exposure-reduction has been considered as a 'co-option'. It is assumed that progress towards reducing exposure would be framed in terms of monitored PM_{2.5} concentrations, or an equivalent modelling approach. Two options have been considered for dealing with population exposure in major urban areas, one with a specific target, and one with an aim of continual improvement and/or no deterioration of air quality.

Proposed questions for consultation: Statement of options

- Do you agree that the AAQ NEPM framework is an important element in the management actions to address ambient air quality in Australia?
- Have any options for the metrics, averaging times, and values of the standards been overlooked?
- Do you agree that the PM standards selected for analysis (including metrics, averaging times and values) are appropriate for Australia?
- Do you consider the options outlined for the form of the standards to be feasible for Australia? Have any options been overlooked?
- Is there any other information relating to the options for an exposure-reduction framework that should be considered?

8 IMPACT ANALYSIS

8.1 Overview

The impact analysis considered the potential effects of the various options and sub-options outlined in **Chapter 7**. Information on the options and sub-options with respect to PM concentrations, health benefits and monetary benefits was available from the following sources:

- PM₁₀ and PM_{2.5} concentrations from monitoring sites in Australia. Any new air quality standards would have to be achievable based on the understanding of trends in concentrations, but they should also promote action to reduce PM concentrations
- Health Risk Assessment project (**Frangos & DiMarco 2013**)
- Economic Analysis project (**Boulter & Kulkarni 2013**).

The information from these sources is summarised in **Sections 8.2 to 8.4**, and the main findings are brought together in **Section 8.5**. Other considerations for jurisdictions are discussed in **Section 8.6**.

Whilst the analysis of the monitoring data, the HRA project and Economic Analysis project examined the same options, the focus was different in each case (with different baseline conditions and assumptions). It is therefore not possible to completely reconcile the data. The HRA provides an assessment of the attributable²⁸ health impacts due to current air pollution levels, together with a 'what if' analysis using a number of scenarios in which pollution levels were adjusted to meet various standards. In contrast, the Economic Analysis examined the costs and benefits of interventions to reduce PM emissions and concentrations by mapping likely future changes in PM levels under a BAU case and also with a package of abatement measures in place.

8.2 Analysis of monitoring data and achievability of the standards

The historical trends and patterns in PM₁₀ and PM_{2.5} concentrations between 2003 and 2012 were examined in **Section 5.3**. The following sections explore the achievability of the different options and sub-options across Australia with respect to these data and trends. The approach is quantitative, but some judgement has been required. For example, 'achievability' has been judged in terms of the likelihood that concentrations will meet a given standard/goal within a reasonable time period (say, 10 years), based on the historical trends. This work is complementary to the assessment that was conducted for future concentrations in the Economic Analysis project.

The approach also involved identifying more stringent PM standards/goals that could be achieved incrementally rather than as a result of some dramatic improvement, the idea being that the values of the standards and goals could subsequently be revised if they were being met as a matter of course in all jurisdictions.

In the Economic Analysis (see **Section 8.4**) some options were found to be unfeasible in most jurisdictions because the standard was very close to, or below, the regional background concentration. Such conclusions were based on some generalisations about PM composition which were made to ensure a consistent approach across jurisdictions. The distinction between different PM components has not been explicitly considered in the analysis in this section of the Impact Statement, as insufficient local data on PM composition were available in all jurisdictions. However, the different PM components are implicitly included in the measurements.

The achievability of each of the PM standard sub-options, including form, is assessed below.

8.2.1 PM₁₀ annual mean standard

The achievability of each sub-option for the annual mean PM₁₀ concentration was examined in terms of the percentage of monitoring sites across Australia with a value above the corresponding standard. This percentage was calculated for each year between 2003 and 2012, and the results are shown in **Figure 8.1**. The overall

²⁸ The concept of 'attributable' health impacts due to air pollution exposure is an important one. The impacts of air pollution on health cannot be determined directly, and must be estimated in an exposed population by applying health risk values from the scientific literature.

results for Australia are influenced by the jurisdictions with the most monitoring sites (NSW, Victoria, Queensland).

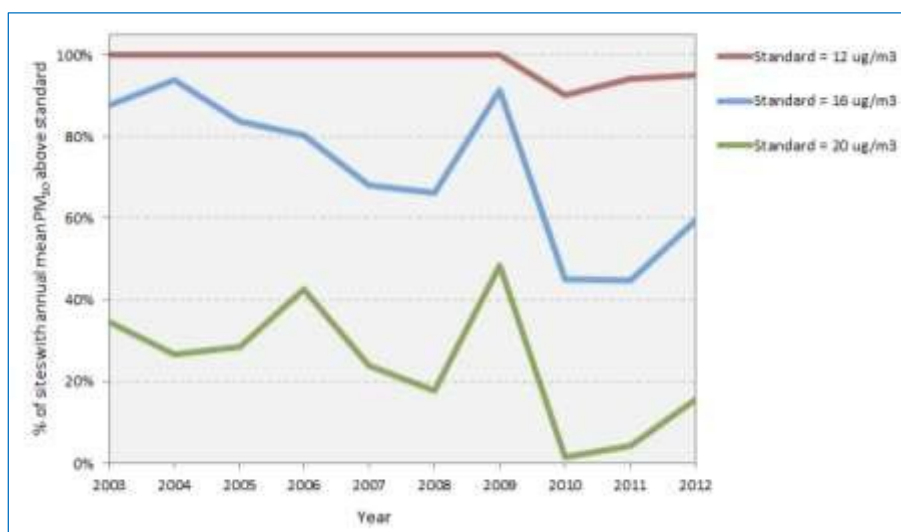


Figure 8.1: Percentage of monitoring sites with annual mean PM₁₀ concentration above standard

The results clearly show that a standard of 12 µg/m³ would not be feasible in Australia in the near future. Prior to 2010 this value was exceeded at all monitoring sites, and continued to be exceeded after 2010 at more than 90% of monitoring sites. The proportion of sites which would not have met a standard of 16 µg/m³ decreased between 2003 and 2012, but the standard would still be exceeded at 60% of sites in 2012 and would therefore also not represent a realistic target. The most realistic sub-option would be the standard of 20 µg/m³. Again, the number of exceedances of this value has decreased with time and the trend suggests that it will be exceeded at between around 10% and 20% of sites in the coming years, but beyond 2020 it could be the case that few sites exceed 20 µg/m³. This suggests that there is still scope for this sub-option to drive further improvement, but also that there may be a case for lowering the standard within the next 5–10 years.

Another feature of the results is the peak in exceedances observed during the warm, dry year of 2009. Meeting any air quality standard based on more representative data would clearly be a challenge under such circumstances. The low concentrations in the *La Niña* years of 2010 and 2011 are also apparent. The increase in exceedances in 2012 is due in part to the inclusion of new monitoring sites in the Hunter Valley region of NSW, where annual mean PM₁₀ concentrations are generally above 20 µg/m³ (see **Appendix E**).

8.2.2 PM₁₀ 24-hour mean standard

The sub-options relating to the standards for the 24-hour mean PM₁₀ concentration were treated slightly differently to those for the annual mean. There is a large amount of temporal variability (changes over time at a site) and spatial variability (differences between sites) in terms of exceedances of the 24-hour standard. The metric used here to gauge the achievability of the different sub-options was the average number of exceedance days per year and per site.

The results are shown in **Figure 8.2**. The original goal of the Air AAQ NEPM (to be achieved by 2008) involved a target of no more than five exceedances of the 50 µg/m³ standard per year. It can be seen that, on average across Australia, the current standard of 50 µg/m³ (with five allowed exceedance days) is being achieved. Of course, this masks a great deal of temporal and spatial variation in exceedances, and some locations are more problematic than others. Notwithstanding the fact that 2009 was associated with exceptionally high PM concentrations across all sites, exceedances are more common (more than 20 per year) in the Upper Hunter Valley (again, this explains in part the increase in 2012), regional NSW (notably Wagga Wagga) and Whyalla in SA. Launceston used to have relatively high numbers of exceedances, but has had far fewer in recent years. The Palmerston site in Darwin also had more than 20 exceedances in 2012. Further information on exceedances is provided in **Appendix E**.

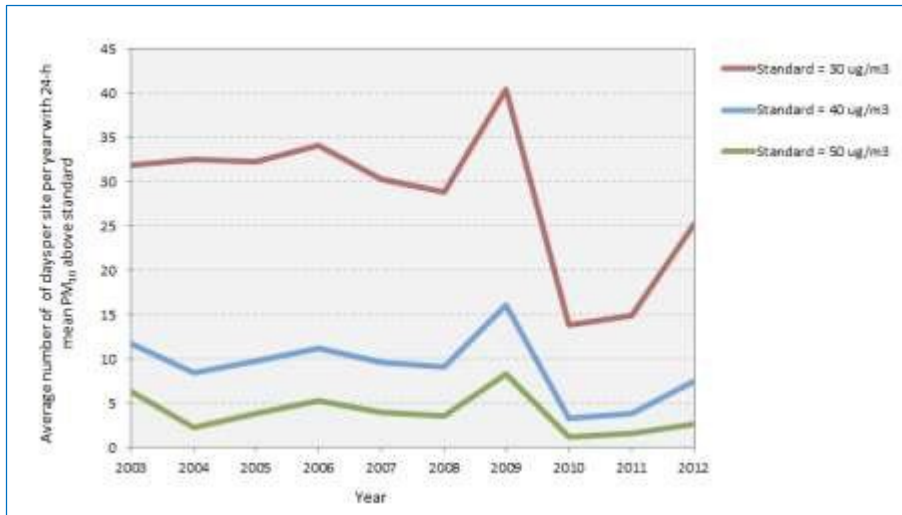


Figure 8.2: Average number of days per site per year with 24-hour mean PM₁₀ concentration above standard

The data therefore suggest that a tightening of the 24-hour standard for PM₁₀ could encourage future improvements in air quality. The sub-option of 30 µg/m³ appears to be unrealistic in the near term (assuming that the data for 2009–2011 are anomalous), and so a change to a standard of 40 µg/m³ would represent a more logical step. However, it would be advisable to retain the 50 µg/m³ standard as a sub-option. Because the difference between 40 µg/m³ and 50 µg/m³ is quite large, and moving to the lower value could present some difficulties in certain jurisdictions, an alternative would be to consider an intermediate sub-option of 45 µg/m³. The analysis above does not address the severity of exceedances. This could be investigated through the use of a metric such as the sum of the concentration exceedances over the year.

8.2.3 PM_{2.5} annual mean standard

The percentage of monitoring sites across Australia with a value above each sub-option for the annual mean PM_{2.5} concentration is shown in **Figure 8.3**. In this case a standard of 6 µg/m³ would not be feasible in Australia. This was also a finding of the Economic Analysis, which showed that large reductions in primary anthropogenic emissions would be required in several jurisdictions because the standard is only slightly higher than the typical combined contribution of natural and secondary particles.

Most monitoring sites would meet a standard of 10 µg/m³, and therefore the adoption of such a standard would be unlikely to drive future improvements in air quality. The sub-option of 8 µg/m³ – the current advisory level in the AAQ NEPM – would therefore appear to be the most suitable one. However, whilst the state average annual PM_{2.5} concentration in 2012 was below 8 µg/m³ in most jurisdictions (see **Figure E.4** in **Appendix E**), the percentage of sites exceeding the standard has only shown a slight downward trend between 2003 and 2012, and therefore it is unlikely that it would be met at all sites in the near future without policy intervention to reduce emissions.

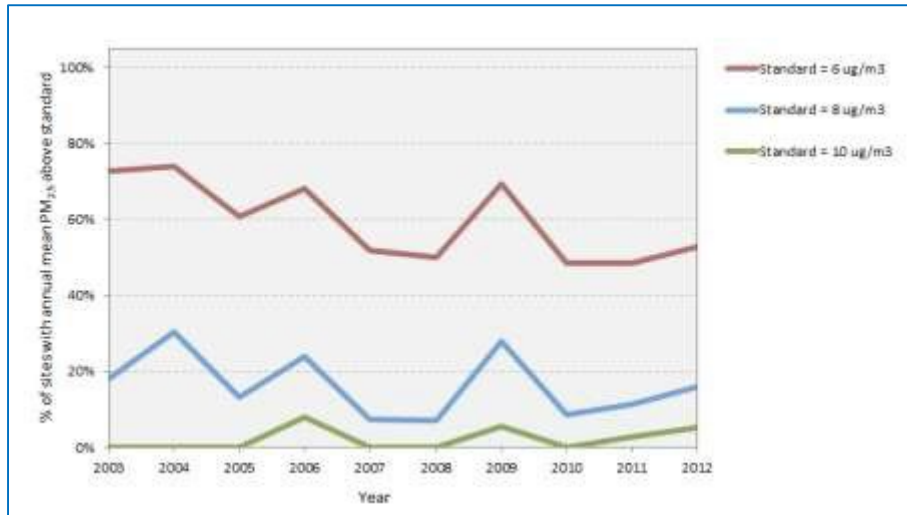


Figure 8.3: Percentage of monitoring sites with annual mean PM_{2.5} concentration above standard

8.2.4 PM_{2.5} 24-hour mean standard

The 24-hour PM_{2.5} concentration was treated in a similar way to the 24-hour PM₁₀ concentration, except in this case there were assumed to be no allowed exceedances in the advisory AAQ NEPM standard (25 µg/m³). The results, shown in **Figure 8.4**, indicate that a standard of 15 µg/m³ would be unrealistic given the historical trend in exceedances. The adoption of a standard of either 20 µg/m³ or 25 µg/m³ could be justified based on these data. If a zero-exceedance rule were to be applied it would be more realistic to retain the 25 µg/m³ standard, whereas a standard of 20 µg/m³ would be a reasonable target with five allowed exceedance days.

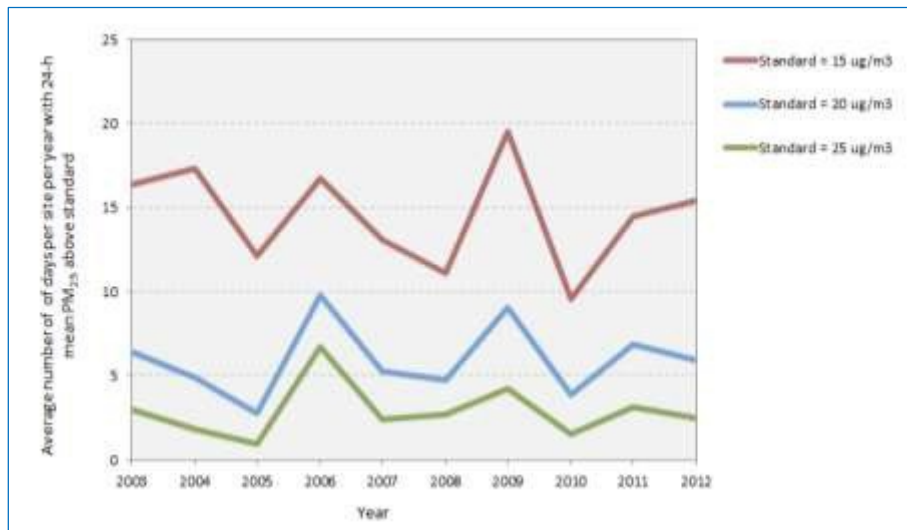


Figure 8.4: Average number of days per site per year with 24-hour mean PM_{2.5} concentration above standard

As with PM₁₀, there is substantial spatial variability in exceedances, but for PM_{2.5} there is less temporal variability. The most problematic sites are Launceston and Palmerston, which have had more than 20 exceedances of the current AAQ NEPM standard in some years.

8.2.5 Form of 24-hour standards

Four options for the form of the 24-hour standards are to be considered for the AAQ NEPM:

- business as usual option; a rule that allows a fixed number of exceedances of a PM standard in a given year, but with no exclusion of data for exceptional events
- a rule that allows a fixed number of exceedances of a PM standard in a given year, with exclusion of data for exceptional events
- a rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with no exclusion of data for exceptional events
- a rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with exclusion of data for exceptional events.

There is no single analysis that can be done to confirm whether any one form of a 24-hour standard is systematically 'better' than any other form of the standard. The most suitable form depends on the objective of the monitoring and the required level of stringency. For example:

- If the objective is to report trends in air quality and progress towards a target, then a simple and stable statistical metric, such as the 98th percentile concentration, or a combination of statistical metrics would probably be sufficient.
- If the objective is to enforce the standards then there is a greater need to understand the contributions of different sources to airborne PM and the reasons for exceedances. This would require a more thorough analysis of concentrations, PM composition and meteorology.

Some of the advantages and disadvantages of the different options in relation to definitions, implementation and resourcing are summarised in **Table 8.1**.

The current approach used in the AAQ NEPM – a fixed number of allowed exceedances per year – is straightforward in terms of definition and application, but is arbitrary in nature. It is also difficult to compare results across jurisdictions. For example, the geographical size of Australia means that there are very different climatic influences on PM concentrations in different jurisdictions, and the scale of human activity is vastly different in say, Sydney and Darwin. There can also be more than the permitted number exceedances in one year due to natural events alone.

A percentile rule is simple to apply, and the Australian jurisdictions are already calculating percentile values in their AAQ NEPM submissions. Percentiles provide stable and practical reference points for tracking trends in air quality, although they do not aid the understanding of the causes of high-pollution events. When selecting a percentile value it is important to consider the variability of the measurements and the stability of the metric. Maximum (100th percentile) concentrations are highly variable, but the stability of a percentile metric increases as the percentile decreases. This can be seen in **Figure 8.5** and **Figure 8.6**, which show different percentile values plotted against annual mean values for all sites and years included in the analysis of the ambient PM data. A similar approach (based on the coefficient of variation) was used by the USEPA to select the 98th percentile in preference to the 99th percentile. However, the stringency of the standard decreases as the percentile decreases; it is easier to achieve a given standard as the 98th percentile of a series of measurements than as the 99th percentile. The 98th percentile was selected as an appropriate balance between limiting peak pollutant concentrations and providing a stable regulatory target for risk management programs.

Table 8.1: Options for form of standards – advantages and disadvantages

| Form | Definition | | Implementation | | Resources | |
|--|--|---|--|---|---|---|
| | Advantages | Disadvantages | Advantages | Disadvantages | Advantages | Disadvantages |
| Fixed number of allowed exceedances (including zero) | Simple to define. | Arbitrary definition. | Easy to apply in principle. | Could result in unfair comparisons between jurisdictions, as some have more natural and trans-boundary events than others. | Current approach – no additional resources required | None. |
| | | | Minimal change in reporting process. | Requires development of simple and clear guidelines on classification of pollution events. | | |
| Percentile rule | Simple definition. Provides stable and practical reference point. | Does not aid the understanding of high-pollution events. | Simple calculation based on existing data. No additional data required. Easy to average over several years. | Could result in unfair comparisons between jurisdictions, as some suffer more natural & trans-boundary events than others. | Few or no additional resources required. | None. |
| | Focuses on providing protection for people residing in or near areas of high average concentration rather than extreme events. | | Consistency with some USEPA air quality standards. | AAQ NEPM reports would not support an assessment of effort and progress in anthropogenic air pollution control. Potentially complex to explain to non-specialists. | | |
| Natural events rule (in combination with either a fixed number of allowed exceedances or a percentile) | Exceedances stated in relation to real and defined pollution events. | Definition of thresholds is currently unclear. How are small-scale events treated? Do natural events affect non-exceedance periods? | All breaches of standards caused by human activity are accounted for. | Potentially impractical for jurisdictions with large land areas where bush fires and planned burning are prevalent but data are very limited (e.g. NT). | None. | Potentially resource intensive. Likely to require additional analysis of data. Difficult to fund for smaller jurisdictions. |
| | Fairer comparison of anthropogenic pollution across jurisdictions. | | Allows a direct assessment of the success of policy efforts to control anthropogenic pollution. | Lack of transparency. Elements are likely to be open to interpretation and 'gaming'. | | |
| | Removes confusion concerning the concept of allowable exceedances. | | | | | |

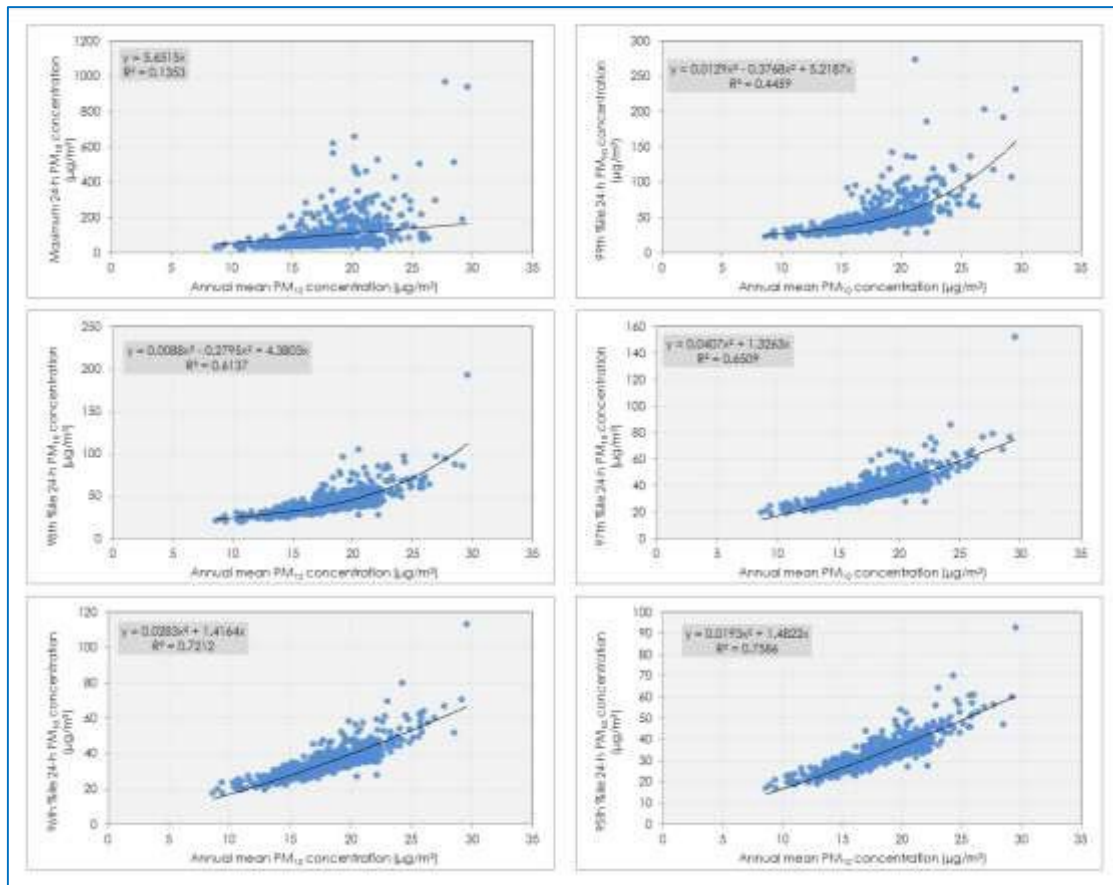


Figure 8.5: Percentile vs annual mean concentrations: PM₁₀, all monitoring sites, 2003–2012

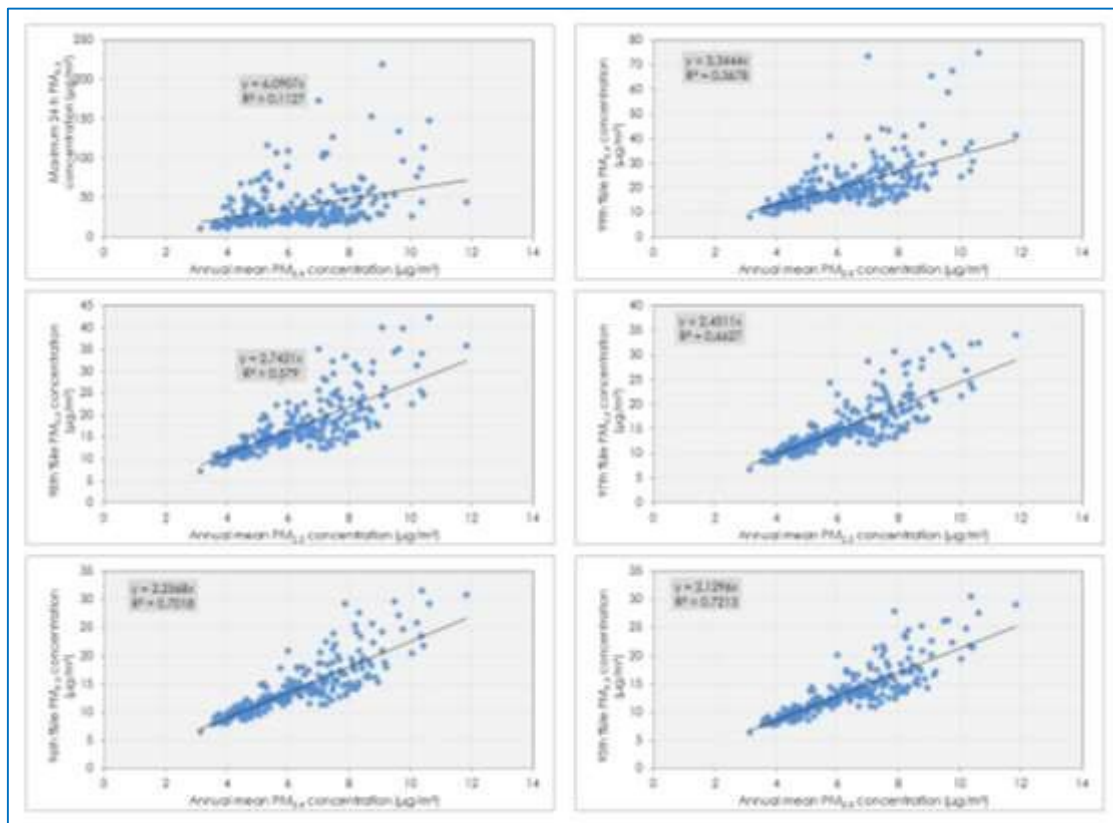


Figure 8.6: Percentile vs annual mean concentrations: PM_{2.5}, all monitoring sites, 2003–2012

A natural or exceptional events rule can overcome some of the confusion concerning the concept of allowable exceedances (either in terms of a fixed number of days or through a percentile) by identifying the real-world causes of pollution events. In theory this allows breaches of standards caused by human activity to be accounted for, thus assisting policy efforts to control anthropogenic pollution. However, this approach could be impractical and disproportionately expensive for jurisdictions with large land areas where bush fires and planned burning are prevalent but data are limited. There is also the concern that this approach could be open to ‘gaming’, in the sense that elements of it are likely to be open to (advantageous) interpretation on the part of jurisdictions.

Another factor that needs to be considered is the basis for any calculation. In other words, would a 98th percentile or similar be valid for a low annual data capture rate for a monitoring site? Are there any more general implications of a low data capture rate?

8.2.6 Comparison between PM₁₀ and PM_{2.5} standards

As previously discussed in Chapter 7, where two separate PM metrics are applied together – such as an annual mean for PM₁₀ and an annual mean for PM_{2.5}, or an annual mean for PM₁₀ and a 24-hour mean for PM₁₀ – there may be a tendency at a given site for one standard to be exceeded more frequently than the other, perhaps even making one of the standards redundant. The form of the 24-hour standards should result in an appropriate balance between the annual mean and 24-hour standards, and from a health and economic perspective, it is advisable to place more emphasis on the annual mean standard than on the 24-hour standard. While this issue does not present a problem if separate annual and 24-hour standards are in place, if the numerical value and form of the 24-hour standard are defined so that it is exceeded more frequently than the annual mean standard, this could lead to the perception that the 24-hour standard is the more important one, with the potential for disproportionate action on short-term concentrations.

The possibility of such imbalances occurring with the options for PM₁₀ and PM_{2.5} was investigated based on the data from sites across Australia at which both PM₁₀ and PM_{2.5} were measured. The earlier analysis indicated that annual mean PM₁₀ and PM_{2.5} standards of 20 µg/m³ and 8 µg/m³ respectively, and 24-hour mean PM₁₀ and PM_{2.5} standards of 40 µg/m³ and 25 µg/m³ respectively, would currently be the most appropriate sub-options for Australia. These values have been considered below. It has also been assumed that the allowed exceedances (five days) of the 24-hour PM₁₀ standard would remain unchanged, and (to enable an analysis) that there would be either zero allowed exceedances per year for PM_{2.5}, or five allowed exceedances. The implications of these analyses in terms of the options to be taken forward for further consideration are discussed in **Chapter 9**.

Whilst this analysis indicates which forms of the standards would likely be achievable, it provides no information on the division between those exceedances resulting from human activity and those resulting from natural events. Whilst the jurisdictions already provide basic information on the reasons for exceedances, the formal inclusion of a natural/exceptional events rule in the air quality standards would require the development of a consistent and more advanced approach. A trial could be conducted to test such an approach.

8.2.6.1 Annual mean PM_{2.5} versus annual mean PM₁₀

Figure 8.7 shows the annual mean concentrations of PM₁₀ and PM_{2.5} during the period 2003–2012. The nature of the data means that different conclusions would be drawn for the different jurisdictions, but here the intention is to provide an analysis at the national level. A linear regression function fitted to all the data and forced through the origin has a gradient (PM_{2.5}:PM₁₀ ratio) of 0.37. Based on the regression, a PM₁₀ concentration of 20 µg/m³ equates, on average, to a PM_{2.5} concentration of around 7.4 µg/m³. This suggests that there should be a slight tendency for the PM₁₀ standard to be exceeded more frequently than the PM_{2.5} standard, but given the errors involved there is likely to be little systematic bias towards one standard or the other in practice (in other words, the probability of exceedance is approximately the same for both PM₁₀ and PM_{2.5}).

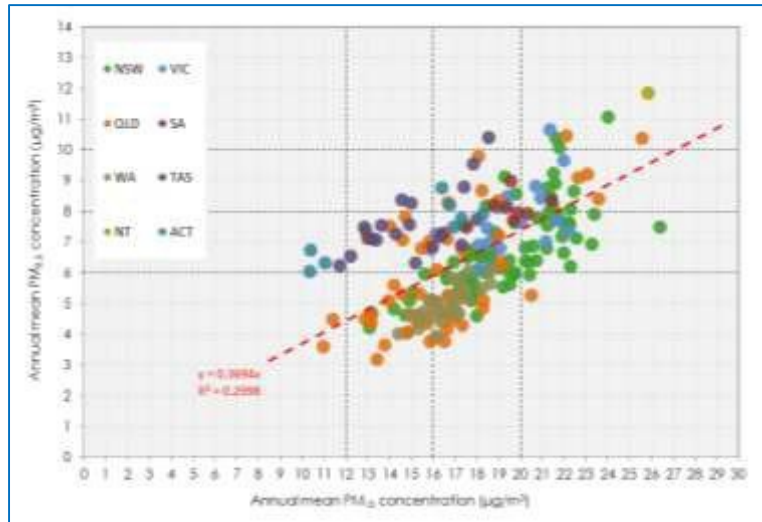


Figure 8.7: Annual mean PM_{2.5} vs annual mean PM₁₀

8.2.6.2 24-hour mean PM₁₀ versus annual mean PM₁₀

Figure 8.8 shows the 98.6th percentile 24-hour mean and annual mean PM₁₀ concentrations. In this case a third-order polynomial regression function fitted to the data and forced through the origin gives a higher R² value than a linear function. An annual mean PM₁₀ concentration of 20 µg/m³ equates to a 98.6th percentile value of 51 µg/m³. This suggests that a 24-hour mean of 40 µg/m³ would be exceeded at the 98.6th percentile level (i.e. with five allowed exceedances) more frequently than an annual mean of 20 µg/m³. The plots in Figure 8.5 show that an annual mean of 20 µg/m³ is approximately equivalent to a 24-hour mean of 40 µg/m³ at the 96th percentile level (i.e. with around 15 allowed exceedances per year). In terms of the options being assessed, if a 24-hour mean standard of 40 µg/m³ is used in conjunction with a 98th percentile rule then the 24-hour standard would be exceeded more frequently than the annual mean standard, which could lead to a perception that the 24-hour standard is the more important one (while the health and economic literature suggest otherwise).

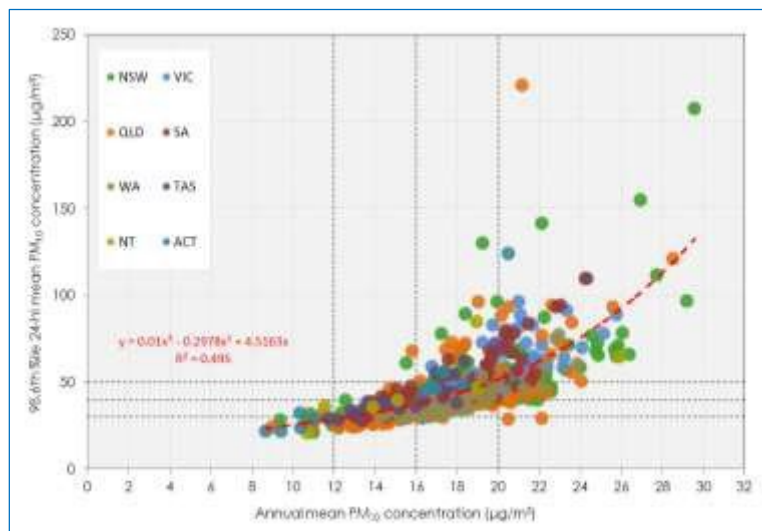


Figure 8.8: 98.6th percentile 24-h mean PM₁₀ vs annual mean PM₁₀

8.2.6.3 24-hour mean PM_{2.5} versus annual mean PM_{2.5}

Figure 8.9 shows the maximum 24-hour mean and annual mean PM_{2.5} concentrations. Because the relationship between the two metrics is not very stable it is difficult to draw firm conclusions. For an annual mean concentration of 8 µg/m³ the maximum 24-hour concentration would frequently be greater than 25 µg/m³. It can also be seen from the Figure that a 24-hour value of 25 µg/m³ can be exceeded for annual mean PM_{2.5}

concentrations far lower than $8 \mu\text{g}/\text{m}^3$. Again, this could lead to the perception of the 24-hour standard being the more important one.

It can be seen from **Figure 8.10**, which shows the 98.6th percentile $\text{PM}_{2.5}$ concentration, rather than the maximum, that if five exceedances are allowed per year then an annual mean of $8 \mu\text{g}/\text{m}^3$ would be equivalent to a 24-hour mean of around $24.5 \mu\text{g}/\text{m}^3$. In other words, with five allowed exceedances of the 24-hour $\text{PM}_{2.5}$ standard per year, there would be a broad equivalence between an annual mean standard of $8 \mu\text{g}/\text{m}^3$ and a 24-hour standard of $25 \mu\text{g}/\text{m}^3$.

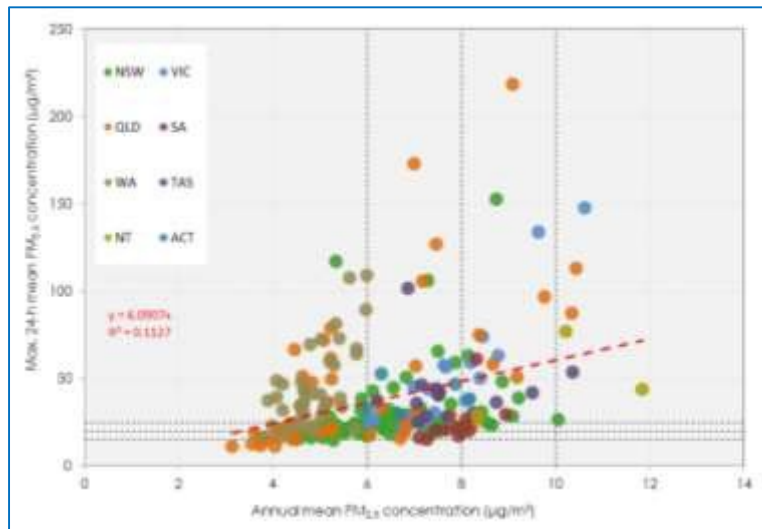


Figure 8.9: Maximum 24-h mean $\text{PM}_{2.5}$ vs annual mean $\text{PM}_{2.5}$

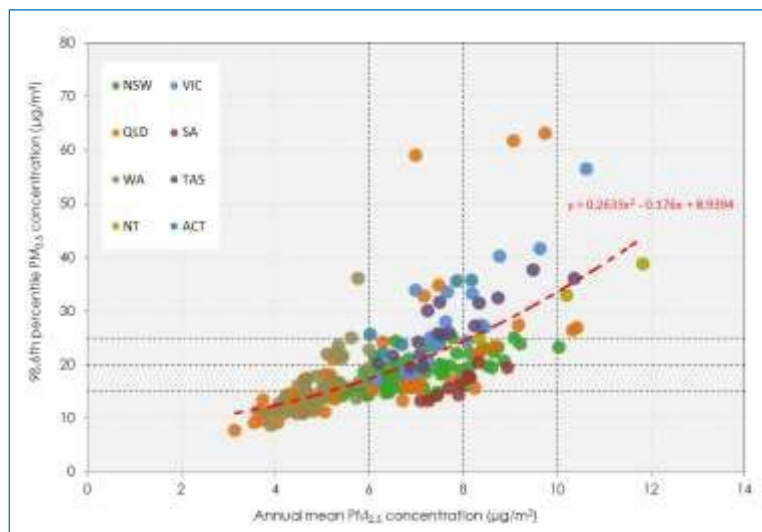


Figure 8.10: 98.6th percentile 24-h mean $\text{PM}_{2.5}$ vs annual mean $\text{PM}_{2.5}$

8.3 HRA project

8.3.1 Approach

The HRA project estimated the burden of exposure to air pollution (including PM₁₀ and PM_{2.5}) on health in Australia, expressed as the annual percentage and number of ‘attributable’ (or additional) deaths and hospitalisations (Frangos & DiMarco 2013). The HRA also addressed the impact on attributable mortality and hospitalisation of each sub-option in Table 7.1. A synopsis of the HRA work was provided in the Summary for Policy Makers by Morgan et al. (2013), and the description presented here draws mainly from that summary. Further details can be obtained from the Summary for Policy Makers.

The HRA project addressed the exposure to PM during the period 2006–2010 and the effects of the air quality standard options in relation to this current exposure. The key elements of the HRA were the following:

Hazard assessment which involved a review of the literature on the health effects of air pollution. One of the main pieces of epidemiological information is the change in the health outcome (e.g. mortality or hospitalisation) relating to a change in air pollution exposure, known as a concentration response function (CRF). An expert review of epidemiology studies identified the CRFs for mortality and hospitalisation to be applied in the HRA (Jalaludin & Cowie 2012).

Exposure assessment. All estimates of attributable mortality and hospitalisation due to baseline (actual current) exposures and exposures for each air quality standard sub-option were calculated for PM concentrations above national background levels (7.5 µg/m³ and 2.7 µg/m³ for PM₁₀ and PM_{2.5} respectively)²⁹. The HRA estimated exposure in 32 Australian cities, including the major metropolitan areas. In cities where there was more than one ambient air pollution monitoring site, exposure was estimated by averaging pollutant concentrations across all air pollution monitoring sites for each year in the relevant time period (2006–2010). It should be noted that the results of the HRA do not actually reflect the real-world impacts of setting standards. Rather, they reflect the impact of different exposure scenarios in which the ambient concentrations are set at the values of the options for the standards. However, the HRA assessment does provide a useful indication of what might happen in the future should projected increases in emissions lead to an increase in the PM_{2.5} concentration.

Risk characterisation. Population data, mortality data and hospitalisation data for the 32 cities were used to estimate city-specific deaths and hospitalisations attributable to the exposures for the baseline and the sub-options. The current burden of deaths and hospitalisations attributable to baseline (actual current) exposure compared with the national background levels was estimated. The potential health impacts of different exposure scenarios compared with baseline exposure were also assessed.

Attributable mortality and hospitalisation estimates were summarised for the following non-overlapping³⁰ health outcomes:

- long-term PM_{2.5} exposure and all-cause mortality in those aged 30 and above
- short-term PM_{2.5} exposure and hospital emergency department attendance for asthma in those aged between one and 14
- short-term PM_{2.5} exposure and all cardiovascular hospital admissions in those aged 65 and above
- short-term PM₁₀ exposure and all respiratory hospital admissions³¹ in those aged up to 14
- short-term PM₁₀ exposure and pneumonia and short-term bronchitis hospital admissions in those aged 65 and above.

²⁹ The 5th percentile of 24-hour concentration over the period 2006–2010 was adopted as a proxy for the region-specific background concentration, and these were subsequently averaged over all regions to give national values.

³⁰ The effects of long-term exposure to PM₁₀ were included in the original HRA but not in the Summary for Policy Makers, which focused on non-overlapping health outcomes. Long-term exposure to PM₁₀ is associated with mortality, but to avoid double counting the summary included only long-term exposure to PM_{2.5} and mortality, as the evidence indicates that this metric has the strongest association with mortality.

³¹ This could be overlap with short-term PM_{2.5} exposure and asthma emergency department visits.

Reducing air pollution levels affects future patterns of survival and death in the population by decreasing the mortality risk. This will initially lead to fewer deaths and a sustained increase in life expectancy. However, because everyone eventually dies, the total number of deaths in a given population cannot be changed by reducing levels of air pollution. Instead, a reduction in air pollution levels postpones deaths, so that on average people live longer. As a result, the mortality benefit of a sustained air pollution reduction can be assessed as both an immediate benefit in terms of fewer deaths in the first year (and in the early subsequent years) after the change in air pollution levels, and also a longer-term benefit of greater survival time (life years lived) and increased life expectancy across the population as a whole. Consequently, some HRAs estimate the long-term mortality benefits of pollution reduction in terms of life expectancy or in terms of gains in population survival time ('life-years'), rather than solely in terms of the number of deaths. An additional analysis was conducted in the Summary for Policy Makers to estimate the baseline number of years of life lost due to long-term exposure to PM_{2.5} in Sydney (**Morgan et al. 2013**).

8.3.2 Results

The results for the baseline case (relative to the background concentrations) are shown in **Table 8.2**, and the effects of each sub-option in turn are presented in **Table 8.3** to **Table 8.5**. **Morgan et al. (2013)** reported separate results for four major cities (Sydney, Melbourne, Brisbane and Perth) and for Sydney separately.

Decreasing short-term exposure to PM₁₀ would reduce attributable hospital admissions for childhood respiratory disease and pneumonia/bronchitis in people aged 65 and above. For the sub-options D50PM₁₀, D40PM₁₀ and D30PM₁₀ these health outcomes would be reduced by around 30%, 50% and 65% respectively over the four cities of Sydney, Melbourne, Brisbane and Perth (**Morgan et al. 2013**).

Morgan et al. (2013) commented that for long-term exposure to PM_{2.5} the HRA results are generally consistent with previous Australian and United States estimates. Baseline annual average PM_{2.5} exposure in the four cities ranged from 5.1 µg/m³ to 7.8 µg/m³. In the four major cities annual mortality attributable to baseline long-term PM_{2.5} exposures above background is estimated to be equivalent to approximately 1590 deaths (2.2%). The results were similar whether or not extreme days were included in the analysis. Only the sub-option A06PM_{2.5} would be associated with reductions in long-term mortality relating to PM_{2.5} compared with baseline exposures (equivalent to a reduction of approximately 530 deaths).

Decreasing short-term exposure to PM_{2.5} – as per the sub-options D25PM_{2.5}, D20PM_{2.5} and D15PM_{2.5} – would reduce attributable cardiovascular hospital admissions and attributable childhood asthma hospital emergency department attendance by around 30%, 45% and 60% respectively over the four cities. Because hospital emergency department treatment only forms a small proportion of childhood asthma treatment in the population, it is likely that the actual improvement in asthma incidence would be greater than that represented solely by hospital attendance (**Morgan et al. 2013**).

USEPA (2011) states that there is no evidence suggesting that the risks associated with long-term exposure to PM_{2.5} are likely to be disproportionately driven by peak 24-hour concentrations. Therefore, control strategies that focus primarily on reducing extreme days are less likely to achieve reductions in PM_{2.5} exposures that most contribute to health effects compared with an approach that focuses on reducing the middle range of the PM_{2.5} exposure distribution.

Table 8.2: The current burden of disease for baseline exposure levels (Source: Morgan et al. 2013)

| PM metric | Exposure ^(a) | Age group (outcome) | Geographical coverage | Attributable mortality (deaths per year) | Years of life lost (2008 only) | Reduction in life expectancy at birth | Attributable hospital admissions | | |
|-------------------|-------------------------|---|-----------------------|--|--------------------------------|---|----------------------------------|---------------------------------------|--|
| | | | | | | | Cardiovascular (cases per year) | Respiratory (cases per year) | Attributable hospital emergency department attendance (cases per year) |
| PM ₁₀ | Short-term | 0–14 years (respiratory) | Four cities | – | – | – | – | 1,130, or 2.2% (95% CI: 0.2% to 4.3%) | – |
| | | 65+ years (pneumonia and short-term bronchitis) | Four cities | – | – | – | – | 530, or 2.5% (95% CI: 0.3% to 5.0%) | – |
| PM _{2.5} | Long-term | All | Four cities | 1,590, or 2.2% (95% CI: 1.4% to 3.0%) | – | – | – | – | – |
| | | | Sydney | 520, or 2.0% (95% CI: 1.2% to 2.7%) ^(b) | 6,300 | – | – | – | – |
| | | | Sydney | – | – | 72 days for males and 65 days for females | – | – | – |
| | Short-term | 0–14 years (asthma) | Four cities | – | – | – | – | – | 120, or 0.6% (95% CI: 0.4% to 0.8%) ^(c) |
| | | All | Four cities | – | – | – | – | 2,070, or 1.4% (95% CI: 0.6% to 2.1%) | – |

- (a) Attributable cases estimated for baseline exposures above a background (or baseline) exposure for PM₁₀ and PM_{2.5} of 7.5 µg/m³ and 2.7 µg/m³ respectively.
- (b) Based on an additional analysis conducted by NSW Health to estimate the baseline number of years of life lost due to long-term exposure to PM_{2.5} in Sydney. The total number of years of life that would be saved over the next 100 years by reducing long-term PM_{2.5} exposure to background was estimated to be 916,000 life years.
- (c) There may be some overlap between asthma emergency department visits among 0–14 year olds associated with PM_{2.5} exposure and respiratory hospital admissions among 0–14 year olds associated with PM₁₀ exposure.

Table 8.3: Changes in health outcomes for 24-hour PM₁₀ sub-options (Source: Morgan et al. 2013)

| Sub-option | Change in exposure relative to baseline | Age group (outcome) | Geographical coverage | Change in attributable hospital admissions – respiratory (cases per year) |
|---------------------|---|---|-----------------------|---|
| D50PM ₁₀ | Reduction | 0–14 years (respiratory) | Four cities | –33% (–370 admissions) |
| | | 65+ years (pneumonia and short-term bronchitis) | Four cities | –33% (–180 admissions). |
| D40PM ₁₀ | Reduction | 0–14 years (respiratory) | Four cities | –49% (–560 admissions) |
| | | 65+ years (pneumonia and short-term bronchitis) | Four cities | –48% (–260 admissions) |
| D30PM ₁₀ | Reduction | 0–14 years (respiratory) | Four cities | –65% (–730 admissions) |
| | | 65+ years (pneumonia and short-term bronchitis) | Four cities | –65% (–340 admissions) |

Table 8.4: Changes in health outcomes for annual mean PM_{2.5} sub-options (Source: Morgan et al. 2013)

| Sub-option | Change in exposure relative to baseline | Age group (outcome) | Geographical coverage | Attributable mortality (deaths per year) | Years of life lost over 100 years | Change in life expectancy at birth |
|----------------------|--|---------------------|-----------------------|--|-----------------------------------|--|
| A10PM _{2.5} | Increase of 2.2 µg/m ³ in four cities | All | Four cities | +48% (+760 deaths) | – | – |
| | | | Sydney | – | +560,000 | – |
| | | | Sydney | – | – | Reduction of 43 days for males and 39 days for females |
| A08PM _{2.5} | Increase (0.6 µg/m ³) in 3 cities (small reduction in Perth) | All | Four cities | +7% (+110 deaths) | – | – |
| | | | Sydney | – | +153,000 | – |
| | | | Sydney | – | – | Reduction of 11 days for males and 11 days for females |
| A06PM _{2.5} | Decrease (1.0 µg/m ³) in 3 cities (small reduction in Perth) | All | Four cities | –34% (–530 deaths) | – | – |
| | | | Sydney | – | –255,000 | – |
| | | | Sydney | – | – | Increase of 20 days for males and 18 days for females |

Table 8.5: Changes in health outcomes for 24-hour PM_{2.5} sub-options (Source: Morgan et al. 2013)

| Sub-option | Change in exposure relative to baseline | Age group (outcome) | Geographical coverage | Attributable hospital admissions –cardiovascular (cases per year) | Attributable hospital emergency department attendance (cases per year) |
|----------------------|---|---------------------|-----------------------|---|--|
| D25PM _{2.5} | Reduction | 0–14 years (asthma) | Four cities | – | –27% (–30 cases) |
| | | All | Four cities | –23% (–480 admissions) | – |
| D20PM _{2.5} | Reduction | 0–14 years (asthma) | Four cities | – | –43% (–50 cases) |
| | | All | Four cities | –40% (–840 admissions) | – |
| D15PM _{2.5} | Reduction | 0–14 years (asthma) | Four cities | – | –59% (–70 cases) |
| | | All | Four cities | –58% (–1,190 admissions) | – |

8.4 Economic Analysis

8.4.1 Approach

The Economic Analysis project addressed the period 2011–2036, and therefore characterised potential future exposure (**Boulter & Kulkarni 2013**). The project examined the costs and benefits of introducing a package of potentially feasible national abatement measures (see **Section 4.1.5**) over a 25-year period relative to a BAU scenario. The actual air quality standard sub-options in **Table 7.1** were incidental to this process in the sense that there was no ‘forced agreement’ as in the HRA project. Rather, the project assessed the likely achievability of the sub-options by 2036 given the trends in emissions and the implementation of the abatement measures. The exposure-reduction target (option ER2) was assessed in a similar way.

The project estimated future population-weighted PM concentrations, both without the package of abatement measures in place (the BAU case) and with the package in place. For each abatement measure the monetised values of the following cost and benefit items were estimated:

- Costs
 - costs incurred by government in implementing and administering the measure
 - capital investment or ongoing expenditure incurred by industry
- Benefits
 - savings in fuel consumption associated with the implementation of the measure
 - reductions in PM associated with the implementation of the measure
 - reductions in NO_x associated with the implementation of the measure.

The analysis provided the monetary costs and benefits per year by measure. These were then aggregated across all years by calculating a ‘present value’ (PV)³². From these PVs, two metrics were calculated for each measure:

- Benefit:cost ratio (BCR): This is the economic value of benefits expected from implementation of a policy divided by the economic costs of implementation. A measure with a relatively high BCR delivers greater dollar benefits per dollar of costs, and can therefore be considered to be superior to a measure with a lower BCR (all else being equal).
- Net present value (NPV): This is the expected economic cost of implementing a policy, subtracted from the economic benefit. This metric also provides information of the scale of costs and benefits.

The costs and benefits of individual measures were additive (i.e. the costs and benefits of the package of measures were equal to the sums of the costs and benefits of the individual measures). This is because the relationship between emission reduction and health costs (all else being equal) is linear. Therefore, the costs or benefits of the package of measures were derived by summing the effects of the individual measures.

There was no feedback aspect to the analysis; for the package of abatement measures investigated there was either compliance with an air quality standard or there was not. Where a portfolio did not result in compliance with a hypothetical air quality standard an ‘emissions gap’ was calculated. This additional reduction was placed into context by quantifying it as a percentage of the ‘residual’ emissions (i.e. the total emissions in the area of each jurisdiction covered by the emissions inventory, minus the amount removed by the package of abatement measures). For the exposure-reduction target a similar approach was used, except that the ‘gaps’ related to the additional reductions required by 2025 to achieve a 10% reduction in the population-weighted PM_{2.5} concentration. The costs and benefits of implementing further abatement measures to bridge the gaps were then calculated.

³² The PV of a stream of monetary values over time is a metric that provides an aggregate total figure over the whole time horizon, taking into account that values in the future are worth less than values today (e.g. a dollar today is worth more than a dollar tomorrow).

Not all possible national and state-based abatement measures were considered in the Economic Analysis. The potential benefits would be greater if all possible abatement measures could be assessed. In other words, the benefits identified in the Economic Analysis are likely to be representative but are probably conservative.

Health benefits were estimated using the unit damage costs (\$ per tonne at 2011 prices) for primary PM_{2.5} developed for Australia by **Aust et al. (2013)**. The unit damage costs are proportional to population density and relate to specific geographical areas of Australia based on the ABS Significant Urban Area structure for urban centres with more than 10,000 people. However, the introduction of abatement can lead to co-benefits associated with reduced emissions of other pollutants (notably NO_x). A damage cost approach was also used to value these co-benefits. The benefits were a function of the magnitude of the emission reductions and their spatial distribution (with emission reductions in more populated areas carrying more benefit). This approach to calculating health benefits, which accounted for population density, improved the precision of estimates compared with assuming an 'average' damage cost.

In the Economic Analysis all costs and benefits were calculated as changes relative to a BAU scenario. Therefore, no costs and benefits for the BAU scenario itself were calculated.

8.4.2 Results

8.4.2.1 Air quality standards

Under the BAU scenario it was estimated that there would be overall increases in the population-weighted PM concentrations over the period 2011–2036 due to increases in emissions. It was found that the population-weighted annual mean PM₁₀ concentration would increase by between 0.2 µg/m³ and 2.4 µg/m³, depending on the jurisdiction. The population-weighted annual mean PM_{2.5} would increase by up to 1.5 µg/m³, depending on the jurisdiction; the exception was Victoria, where there would be a slight reduction in the PM_{2.5} concentration³³.

Future emission and concentration reductions were not estimated for the specific sub-options, but for the package of national abatement measures to reduce primary anthropogenic PM emissions. A national example of the concentration projections – in this case for annual mean PM_{2.5} – with and without the package of abatement measures is shown in **Figure 8.11**. The values in the figure are strongly influenced by the results for the most populous states – NSW and Victoria.

The increases in concentration under the BAU scenario would be offset in some jurisdictions by the introduction of the national abatement measures to reduce primary anthropogenic PM emissions. The scale of the concentration reductions was modest, but the monetised health benefits in the airsheds considered in the analysis were substantial. The scale of concentration reductions was also limited by the contribution of natural and secondary particles to PM_{2.5}. However, reductions in primary anthropogenic PM emissions are also likely to be associated with reductions in the emissions of secondary PM precursors, whereas in the Economic Analysis it was assumed (because of the absence of a suitable model) that the secondary PM contribution would be constant with time. This means that the benefits calculated in the Economic Analysis represent a conservative estimate.

By 2036 the health benefit of meeting each standard was estimated at around \$20.7 billion to \$21.7 billion, and the net benefit after the costs of abatement measures were included was around \$6.4 billion to \$7 billion). It should be noted that the health benefits for the individual standards are not additive. The overall results are summarised in **Table 8.6**

³³ As emissions increased slightly during 2011–2036, this reduction must be due to a change in the spatial distribution of population (i.e. people moving away from areas with higher concentrations to areas with lower concentrations).

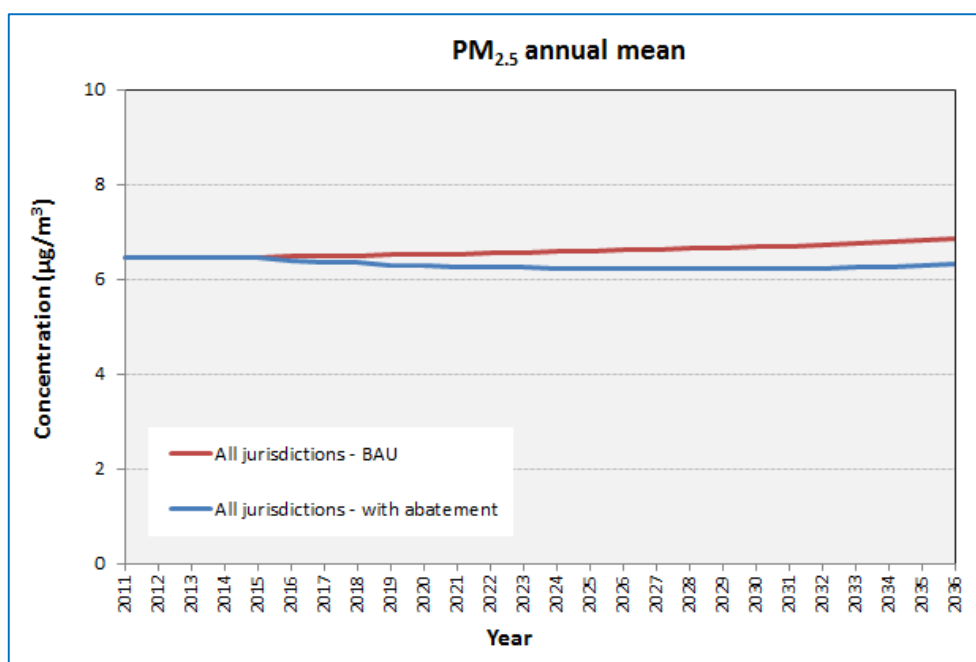


Figure 8.11: National population-weighted annual mean PM_{2.5} concentration for BAU scenario and all feasible measures

Table 8.6: Summary of results of the Economic Analysis

| Option | Sub-option | Feasibility in 2036 | Net benefit (\$ at 2011 prices) ^(a,b) |
|--------------------------------|----------------------|---|--|
| PM ₁₀ annual mean | A20PM ₁₀ | Feasible | \$6.4 billion |
| | A16PM ₁₀ | Unlikely given the large reductions in emissions that would be required in several jurisdictions over and above those associated with national measures | Not calculated |
| | A12PM ₁₀ | Unfeasible in most jurisdictions because standard is very close to or below regional background concentration | Not calculated |
| PM ₁₀ 24-hour mean | D50PM ₁₀ | Already compliant | Not calculated |
| | D40PM ₁₀ | Feasible | \$6.6 billion |
| | D30PM ₁₀ | Unfeasible in most jurisdictions because standard is very close to or below regional background concentration | Not calculated |
| PM _{2.5} annual mean | A10PM _{2.5} | Already compliant | Not calculated |
| | A08PM _{2.5} | Feasible | \$6.5 billion |
| | A06PM _{2.5} | Unlikely given the large reductions in emissions that would be required in several jurisdictions over and above those associated with national measures | Not calculated |
| PM _{2.5} 24-hour mean | D25PM _{2.5} | Feasible | \$6.9 billion |
| | D20PM _{2.5} | Unlikely given the large reductions in emissions that would be required in several jurisdictions over and above those associated with national measures | Not calculated |
| | D15PM _{2.5} | Unfeasible in some jurisdictions because standard is very close to or below regional background concentration | Not calculated |

(a) Calculated for the period 2011 to 2036. The costs and benefits of some abatement measures were estimated to 2055 to capture emission reductions beyond 2036 (e.g. for diesel engines with long working lifetimes).

(b) It should be noted that the health benefits for individual standards are not additive.

8.4.2.2 Exposure-reduction framework

It is assumed that progress towards reducing exposure would be framed in terms of monitored PM_{2.5} concentrations, or an equivalent modelling approach. Two options have been considered for dealing with population exposure in major urban areas, one with a specific target (option ER1), and one without (option ER2).

Figure 8.12 shows the change in exposure to PM_{2.5} (based on the population-weighted annual mean concentration) between 2015 and 2030 with the package of abatement measures in place. The target of a 10% reduction by 2025 would only be achieved in the Northern Territory, largely as a consequence of abatement measures relating to shipping. NSW would be close to meeting the target. There would also be net reductions in exposure between 2015 and 2025 in the ACT, Victoria and South Australia, but net increases in Western Australia, Queensland and Tasmania.

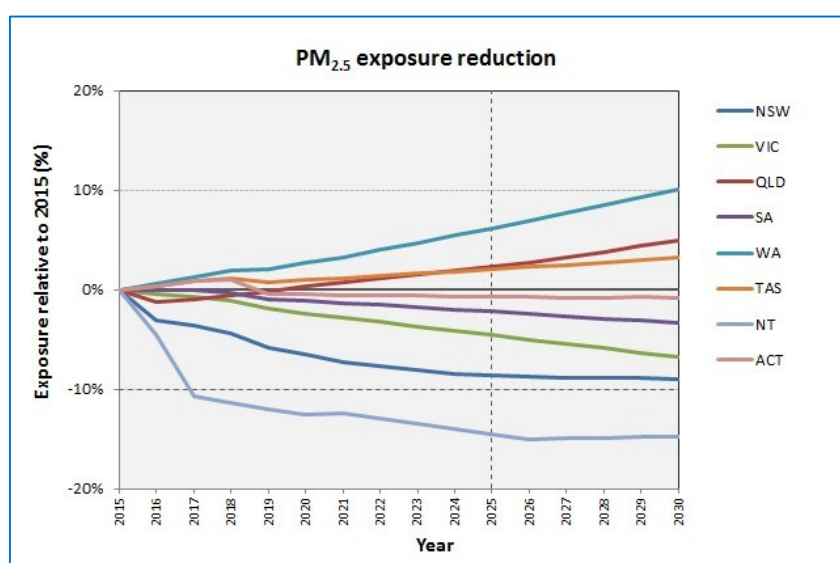


Figure 8.12: Reduction in population exposure to PM_{2.5} between 2015 and 2030 with all feasible abatement measures (target year 2025)

Meeting the target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 would require very significant additional abatement measures in most jurisdictions. It can therefore be concluded that the proposed exposure-reduction target is currently unlikely to be feasible in practice. Nevertheless, it is important to emphasise the likely benefits of an exposure-reduction framework. As noted in **Chapter 3**, long-term exposure to the prevailing background PM_{2.5} concentration is the most important determinant of health outcomes. Even where an AAQ NEPM standard is not exceeded there is a health benefit associated with reducing concentrations, and an exposure-reduction framework provides an appropriate mechanism for this. Therefore the incorporation of option ER2 into the AAQ NEPM should be considered. This would involve the development of an exposure index for PM_{2.5} for assessing progress, but without a formal target. It would involve little or no additional cost to the jurisdictions unless additional monitoring is conducted.

It is important to add that the real-world population exposure is the sum of all individual population exposures, taking into account the time individuals spend in different 'micro-environments'³⁴. However, in most situations there are insufficient data to allow a bottom-up calculation of population exposure. In the EU exposure-reduction framework, and in the options described above, the monitoring data from urban background sites are used as a proxy for actual population exposure. Variations of this approach, such as introducing population weightings for different monitoring sites, could be considered as potential refinements.

³⁴ Here, the term micro-environment is used to refer to a specific type of location (e.g. indoors at home, outdoors in a city centre) with specific pollutant concentrations.

8.4.2.3 Sensitivity analysis

Five types of sensitivity analysis were performed in the Economic Analysis project to test how the results would vary based on alternative sets of assumptions. Specifically, the sensitivity of the results to the following was examined:

- the cost and emission assumptions for the abatement measures
- the discount rate³⁵
- the assumptions relating to growth in emissions under the BAU scenario (Western Australia was taken to be representative of a jurisdiction with higher growth)
- the assumption relating to the value of a life year
- the method used to monetise the benefits of emission reductions.

The package of measures performed well in the sensitivity tests and carried the benefit of diversifying the risk of individual measures. The rationale for, and results of, the sensitivity analysis are presented in the Economic Analysis report (**Boulter & Kulkarni 2013**).

8.5 Summary of information for each sub-option

The information obtained for each of the sub-options for the numerical values of the PM₁₀ and PM_{2.5} standards is summarised in **Table 8.7**. The main aspects to note are:

- The latest health findings indicate that it would be advisable to include an annual mean standard for PM₁₀ in the AAQ NEPM. This is supported by enHealth. The historical PM₁₀ monitoring data and the future projections from the Economic Analysis indicate that a value for the standard of 20 µg/m³ would be appropriate.
- The PM₁₀ monitoring data and the Economic Analysis indicate that a tightening of the 24-hour standard for PM₁₀ (currently 50 µg/m³) could encourage future improvements in air quality. A change to a standard of 40 µg/m³ would be possible, particularly in most urban areas. However, it would be advisable to retain the 50 µg/m³ standard as a sub-option. As the difference between 40 µg/m³ and 50 µg/m³ is quite large, and moving to the lower value could present some difficulties in certain jurisdictions, an alternative would be to consider an intermediate sub-option of 45 µg/m³.
- For annual mean PM_{2.5} the monitoring data and the Economic Analysis indicate that a value for the standard of 8 µg/m³ would be appropriate. Most jurisdictions are already complying with this on an average basis. A move to a standard of 6 µg/m³ would however represent too great a step given the projected population growth and projected emissions growth in several sectors.
- The PM_{2.5} monitoring data indicate that the options for a 24-hour standard of 20 and 25 µg/m³ would be feasible. However, if the zero-exceedance rule is retained it would be more realistic to retain the 25 µg/m³ standard. In the Economic Analysis it was concluded that meeting a standard of 20 µg/m³ would be unlikely to be feasible given the large reductions in primary emissions that would be required in several jurisdictions.

³⁵ All costs are discounted by a factor that depends on the year in which they are incurred. Costs incurred further into the future are discounted more heavily than costs closer to the present.

Table 8.7: Summary of information for each sub-option

| Action | Option | Sub-option | Standard ^(a) | Feasibility based on analysis of ambient PM data ^(b) | Conclusions from HRA (change in current exposure) | Conclusions from Economic Analysis (2036) | | | Net benefit (\$, 2011 prices) |
|------------------------------|--------------------------------|----------------------|---|---|---|---|--|--|-------------------------------|
| | | | | | | Feasible in principle? ^(b) | Further emission reduction required (by state)? ^(c) | Emission reductions likely to be achievable? | |
| Air quality standards | PM ₁₀ annual mean | A20PM ₁₀ | 20 µg/m ³ | Likely | N/A | Yes | WA | Yes | \$6.4 billion |
| | | A16PM ₁₀ | 16 µg/m ³ | Unlikely | N/A | Yes | NSW, VIC, QLD, WA, NT | No | – |
| | | A12PM ₁₀ | 12 µg/m ³ | Very unlikely | N/A | No | – | – | – |
| | PM ₁₀ 24-hour mean | D50PM ₁₀ | 50 µg/m³ | Likely | Decrease | Yes | None | No reduction required | – |
| | | D40PM ₁₀ | 40 µg/m ³ | Likely | Decrease | Yes | TAS | Yes | \$6.6 billion |
| | | D30PM ₁₀ | 30 µg/m ³ | Unlikely | Decrease | No | – | – | – |
| | PM _{2.5} annual mean | A10PM _{2.5} | 10 µg/m ³ | Likely | Increase ^(d) | Yes | None | No reduction required | – |
| | | A08PM _{2.5} | 8 µg/m³ | Likely | Increase ^(d) | Yes | TAS | Yes | \$6.5 billion |
| | | A06PM _{2.5} | 6 µg/m ³ | Unlikely | Decrease | Yes | NSW, QLD, SA, WA, TAS, NT, ACT | No | – |
| | PM _{2.5} 24-hour mean | D25PM _{2.5} | 25 µg/m³ | Likely | Decrease | Yes | TAS, ACT | Possible | \$6.9 billion |
| | | D20PM _{2.5} | 20 µg/m ³ | Likely | Decrease | Yes | TAS, ACT | No | – |
| | | D15PM _{2.5} | 15 µg/m ³ | Unlikely | Decrease | No | – | – | – |
| Exposure-reduction framework | Co-option | ER1 | 10% reduction in exposure to PM _{2.5} between 2015 and 2025, based on monitoring | N/A | N/A | No | All except NT | No | N/A |
| | | ER2 | No target. Exposure index, based on monitoring | N/A | N/A | Yes | N/A | N/A | N/A |

(a) Current standards are shown in bold.

(b) On average for Australia (does not apply to individual sites).

(c) In addition to the reductions that could be achieved by implementation by package of all feasible of national measures.

(d) Equates to an increase in exposure based on current PM_{2.5} concentrations because annual mean PM_{2.5} concentrations at most monitoring sites are currently lower than 8 µg/m³.

No conclusions have been drawn in this Impact Statement on the form of the standard (e.g. whether a natural events rule or a percentile rule is applied) and, where appropriate, the number of allowed exceedance days.

It is likely that the stakeholders will want to identify local issues that affect these decisions, and therefore they have been left as considerations during the consultation phase.

The findings for the exposure-reduction options are also summarised in **Table 8.7**. Meeting the target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 (sub-option ER1) is unlikely to be feasible in practice. The incorporation of option ER2 into the AAQ NEPM should be considered. This would involve the development of an exposure index for PM_{2.5} for assessing progress, but without a formal target. It would involve little additional cost to the jurisdictions.

8.6 Other considerations

8.6.1 Resourcing implications for jurisdictions

The resourcing obligations imposed on the jurisdictions by varying the AAQ NEPM PM standards predominantly relate to monitoring and reporting requirements (as currently exist).

Monitoring and reporting costs are currently being incurred by jurisdictions and would not be expected to change simply by changing the numerical value of the standards, except perhaps if an annual average PM₁₀ standard is introduced. As PM₁₀ is already being measured under the AAQ NEPM, any such increase should be manageable. An expansion of the PM_{2.5} monitoring network, commensurate with adoption of formal standards should these be introduced, would be expected over time.

Costs associated with the phase-in of PM_{2.5} instrumentation, where it currently doesn't exist, would be staged with planned instrument upgrades, refurbishments and site establishment.

The establishment and management of an exposure-reduction framework according to the options defined in **Chapter 7** would entail little or no extra cost. Should the jurisdictions choose to assess population exposure in detail through an EU-style exposure-reduction system, then the costs associated with setting up emissions inventories, regional dispersion models and additional monitoring stations would become significant.

8.6.2 Costs to industry and business

Options for tighter AAQ NEPM monitoring and reporting standards for ambient particle emissions are presented.

The AAQ NEPM itself does not compel or direct pollution control measures. The application of AAQ NEPM standards is at the discretion of individual jurisdictions, and subject to jurisdiction's review processes.

Direct costs associated with the AAQ NEPM standards relate to monitoring and reporting levels of air pollution.

Meeting proposed monitoring and reporting standards for particles would result in significantly improved net economic benefits compared to current standards in terms of improved health outcomes. The proposals include a number of options.

If the tightest annual PM₁₀ option were supported in the consultation process, this could have implications for the way jurisdictions choose to manage future licence conditions for some industries.

8.6.3 Social impacts

The AAQ NEPM aims to guide policy formulation for the adequate protection of human health and wellbeing. The AAQ NEPM itself does not compel or direct pollution control measures accordingly there are no direct social impacts associated with the variation.

The application of AAQ NEPM standards is at the discretion of individual jurisdictions, and subject to jurisdiction's review processes. Meeting proposed monitoring and reporting standards for particles would result in significantly improved net economic benefits compared to current standards in terms of improved health outcomes.

Key points from Chapter 8

- It would be advisable to include an annual mean standard for PM₁₀ in the AAQ NEPM. The monitoring data and the future projections from the Economic Analysis indicate that a value for the standard of 20 µg/m³ would be achievable and economic.
- The PM₁₀ monitoring data and the Economic Analysis indicate that a tightening of the 24-hour standard for PM₁₀ (currently 50 µg/m³) could encourage future improvements in air quality.
- For annual mean PM_{2.5} the monitoring data and the Economic Analysis indicate that a value for the standard of 8 µg/m³ would be achievable and economic. A move to a standard of 6 µg/m³ would however represent too great a step given the background levels and the projected growth in population and emissions.
- The PM_{2.5} monitoring data indicate that of the options for a 24-hour standard, the most realistic approach would be to retain 25 µg/m³.
- It is likely that the jurisdictions will want to identify local issues that affect the form of the standards (i.e. treatment of exceedances), and therefore this issue has been left for the consultation phase.
- Meeting an exposure-reduction target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 is unlikely to be feasible in practice. The incorporation in the NEPM of an exposure index for PM_{2.5} for assessing progress should be considered.

Proposed questions for consultation: Impact analysis

- Have all health, environmental, economic and social impacts of PM in Australia been identified? If not, please provide reasons and suggestions for additional analyses.
- Have all key assumptions been correctly identified and included in the analysis? If not, please provide details.

9 PREFERRED OPTIONS

This chapter summarises the preferred options for varying the PM standards in the AAQ NEPM and the costs and benefits associated with these options.

9.1 PM metrics for inclusion in the AAQ NEPM

Based on the health evidence that long-term and short-term exposure to PM₁₀ and PM_{2.5} causes adverse health effects, the preferred metrics are as follows:

- **Annual mean PM₁₀.** The introduction of a long-term (annual mean) standard for PM₁₀ in the AAQ NEPM would be prudent, given (a) the increasing evidence for the adverse effects on health of coarse particles, (b) the uncertainty that all health effects would be eliminated by controlling PM_{2.5} only, (c) the observation that coarse particles pose a significant problem in some areas of Australia and (d) the currently sparse nature of PM_{2.5} monitoring in Australia. Moreover, there is not the same lack of data that necessitated the advisory standards for PM_{2.5}; there is a reasonably long history of PM₁₀ measurements. It could therefore be argued that there is no need for an advisory standard, and a formal standard could be introduced immediately.
- **24-hour PM₁₀.** There is increasing evidence that short-term exposure to PM₁₀ is independently associated with health effects, and it would therefore be advisable to retain a 24-hour average standard for PM₁₀ in the AAQ NEPM.
- **Annual mean PM_{2.5}.** It would be advisable to convert the advisory annual mean standard for PM_{2.5} concentration in the AAQ NEPM into a formal standard.
- **24-hour PM_{2.5}.** It would be advisable to convert the advisory 24-hour mean standard for PM_{2.5} concentration in the AAQ NEPM into a formal standard.

Whilst the subject of metrics should be discussed during the consultation phase, there is strong evidence on health grounds to support the inclusion of all four metrics listed above in the AAQ NEPM. Any reasons for excluding one or more of these metrics would therefore need to be justified.

9.2 Numerical values for the PM standards

The existing AAQ NEPM standards for PM₁₀ and PM_{2.5} are relatively stringent (in simple numerical terms, and ignoring the local context) compared with those in other countries. However, currently standards applying to monitoring and reporting of PM_{2.5} are advisory in nature. In addition, there is currently no annual mean PM₁₀ standard in the AAQ NEPM.

Long-term studies have not provided evidence of a threshold for health effects. There is also evidence that exposure to PM at levels experienced in Australian cities is associated with health effects. There would therefore be health benefits from reducing exposure below these levels, and setting standards as low as reasonably achievable.

The analysis of the PM monitoring data has indicated that the options for standards shown in **Table 9.1** would be the most feasible and achievable given the current monitoring networks (i.e. sites and instruments). These values have also been recommended by enHealth. Tighter standards than these are unlikely to be achievable in all jurisdictions. The Economic Analysis project also showed that these standards should be achievable in 2036 with a package of national abatement measures in place. The net benefit of meeting each standard, or variation thereof, by 2036 – taking into account the costs of abatement as well as the health benefits – would be similar, at around \$6.4 to \$7 billion.

No single preferred option has been selected for the 24-hour PM₁₀ standard, as achievability in the different jurisdictions needs to be discussed further. The PM₁₀ monitoring data and the Economic Analysis indicated that a tightening of the 24-hour standard for PM₁₀ (currently 50 µg/m³) could encourage future improvements in air quality. A change to a standard of 40 µg/m³ would be possible; however, moving to the lower value could present some difficulties in certain jurisdictions. An alternative would be to consider an intermediate option of 45 µg/m³.

Table 9.1: Preferred values of PM standards

| Metric | Averaging period | Current standards | Options for standards | Allowed exceedances |
|-------------------|------------------|---------------------------------|--|------------------------|
| PM ₁₀ | Annual mean | None | No standards with consideration of 20 µg/m ³ | N/A |
| | 24-hour mean | 50 µg/m ³ | 50 µg/m ³ , with consideration of 45 µg/m ³ and 40 µg/m ³ | See Section 9.3 |
| PM _{2.5} | Annual mean | 8 µg/m ³ (advisory) | 8 µg/m ³ | N/A |
| | 24-hour mean | 25 µg/m ³ (advisory) | 25 µg/m ³ | See Section 9.3 |

The PM_{2.5} monitoring data and Economic Analysis indicate that, of the options for a 24-hour standard, the most realistic approach would be to retain the 25 µg/m³ standard.

The preferred numerical values for the standards are based on the available evidence. The analysis of the monitoring data was not specific to the jurisdictions, but provided an average picture across Australia. The Economic Analysis was jurisdiction-specific, but included some broad assumptions. It would therefore be appropriate to discuss the preferred options in relation to each jurisdiction during consultation.

9.3 Form of the 24-hour standards

The four options for the form of the 24-hour standards (i.e. the treatment of exceedances) are:

- business as usual option; a rule that allows a fixed number of exceedances of a PM standard in a given year, with no exclusion of data for exceptional events
- a rule that allows a fixed number of exceedances of a PM standard in a given year, but with exclusion of data for exceptional events
- a rule in which the 98th percentile PM concentration in a given year is compared with a standard, with no exclusion of data for exceptional events
- a rule in which the 98th percentile PM concentration in a given year is compared with a standard, but with exclusion of data for exceptional events.

There is no single analysis that can be done to confirm whether any one form of a 24-hour standard is systematically 'better' than any other form of the standard. The most suitable form depends on the objective of the monitoring and the required level of stringency.

It is likely that the jurisdictions will want to identify local issues that affect the form of the standards and therefore this issue has been left for the consultation phase.

The Impact Statement examined specific combinations of standard and allowed exceedance days. This indicated which forms of the standards would be likely to be achievable, but provided no information on the division between those exceedances resulting from human activity and those resulting from natural events. Whilst the jurisdictions already provide basic information on the reasons for exceedances, the formal inclusion of a natural/exceptional events rule in the air quality standards would require the development of a consistent and more advanced approach. A trial could be conducted to test such an approach.

Further discussion is required on the form of the standards.

9.4 Other PM metrics for possible inclusion in the AAQ NEPM

The following conclusions have been drawn from this work:

- Whilst there is increasing epidemiological evidence of the association between short-term exposures to ultrafine particles and health, there are no routine monitoring data in Australia that could be used to set standards for such particles.

-
- There is currently no clear understanding of which particle properties, such as the presence of specific chemical substances, are most responsible for the toxic effects. Again, there are very few monitoring data available in Australia to support the setting of standards for individual PM components.
 - Notwithstanding the above information, additional detail on PM composition in Australia would be beneficial for a number of reasons, not least the potential contribution to the understanding of the reasons for exceedances of the standards. Consideration should be given to the routine collection of PM composition data using standardised methods.

The use of metrics other than PM₁₀ and PM_{2.5} is not currently feasible in all Australian jurisdictions, and the scientific understanding is incomplete. It is therefore not appropriate to introduce such metrics in the AAQ NEPM at this stage. However, a mechanism for future inclusion of alternative metrics (and measurements to support them) could be discussed during the consultation.

9.5 Form of an exposure-reduction framework

Meeting a target of a 10% reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 is unlikely to be feasible in practice. The issues and inconsistencies associated with the measurement of PM_{2.5}, coupled with the need to detect relatively small changes in concentrations, mean that checking progress towards any target would also be very challenging.

A more practical approach would involve the development of an exposure index based on monitoring to track population exposure for major urban areas (e.g. using a three-year rolling average PM_{2.5} concentration, as in Europe). This would provide the first step towards characterising exposure based on the existing monitoring network. There would be no impacts on industry in development of this initiative as it would only seek to enhance existing monitoring data.

9.6 Implementation of an AAQ NEPM variation

Under the NEPC Act a NEPM variation needs to address:

- the intended date for making the proposed measure
- the timetable for the implementation of the proposed measure
- the transitional arrangements in relation to the proposed measure.

Following a period of public consultation, and pending a decision by NEPC following consideration of submissions received, it is anticipated that the AAQ NEPM variation would be implemented by mid-2015.

Given that the proposals are not wide-ranging in scope, and will essentially involve only changes to existing monitoring and reporting procedures, the implementation of the AAQ NEPM variation should be straight forward. Similarly, transitional arrangements are not envisaged.

Proposed questions for consultation: Preferred options

- Do you agree with the introduction of an annual PM₁₀ standard, given the apparent adverse health effects of coarse particles and their prevalence in some regions?
- Do you support upgrading the current AAQ NEPM advisory reporting standards for PM_{2.5} to compliance standards?
- Do you support the preferred numerical values for new/revised 24-hour and annual PM_{2.5} and PM₁₀ standards? Which value for the 24-hour PM₁₀ standard do you consider to be the most appropriate, and why?
- What is your preferred option for the form of the 24-hour PM₁₀ and PM_{2.5} standards? Should the options be trialled?
- Do you have any comments regarding the possible inclusion of PM metrics, other than PM₁₀ and PM_{2.5}, in the future?
- Do you agree with the preferred form of the exposure-reduction framework under which an exposure index based on monitoring would be used to track population exposure for major urban areas?

10 CONSULTATION

Input is now sought from stakeholders on the options outlined in the Impact Statement.

Feedback is also welcomed on the analysis and conclusions and any other aspect of the Impact Statement. All submissions are public documents unless clearly marked 'confidential' and may be made available to other interested parties, including by being published on the NEPC website. Stakeholders should indicate if their submission is confidential or clearly indicate sections that may contain confidential or sensitive information that is not for publication.

Feedback received during the public comment period will be used to inform the development of the NEPM variation.

The NEPC Act requires that both the draft AAQ NEPM variation and the Impact Statement be made available for public consultation for a period of at least two months. The consultation period will occur over a ten week period from July to October 2014. The views of stakeholders on these documents are being sought through written and online submissions.

Online submissions are preferred and can be made via < www.nepc.gov.au >

Written submissions may also be made and can be sent to:

**The Executive Officer
National Environment Protection Council
Department of the Environment
GPO Box 787
Canberra ACT 2601**

Email: nepc@environment.gov.au

The closing date for submissions is Friday 10 October 2014.

Following the public consultation period, the NEPC is required to prepare a summary of the issues raised in submissions and responses to them. In deciding whether or not to make the NEPM variation, the NEPC must take both the Impact Statement and the summary of submissions and responses into account.

The following documents have been released by the NEPC to facilitate public consultation on the NEPM variation.

- Exposure Assessment and Risk Characterisation to Inform Recommendations for Updating Ambient Air Quality Standards for PM_{2.5}, PM₁₀, O₃, NO₂ and SO₂ (referred to in this Impact Statement as the Health Risk Assessment (HRA))
- Summary for Policy Makers of the Health Risk Assessment on Air Pollution in Australia
- Economic Analysis to Inform the National Plan for Clean Air (Particles) (referred to in this Impact Statement as the Economic Analysis)
- Evaluating Options for an Exposure Reduction Framework in Australia
- Methodology for Valuing the Health Impacts of Changes in Particle Emissions

11 LIST OF TECHNICAL TERMS AND ABBREVIATIONS

| Term or abbreviation | Description |
|---|--|
| AAQ NEPM | National Environment Protection (Ambient Air Quality) Measure |
| ABS | Australian Bureau of Statistics |
| ACT | Australian Capital Territory |
| Advisory Reporting Standard (in the AAQ NEPM) | A health-based standard to assess the results of monitoring for PM _{2.5} . These standards do not have a timeframe for compliance associated with them. |
| AEI | Average exposure indicator (as used in Europe) |
| AIHW | Australian Institute of Health and Welfare |
| Airshed | A body of air bounded by topography and meteorology in which a substance, once emitted, is contained. |
| Air TOG | Air Thematic Oversight Group |
| Al | Aluminium |
| Ambient air | The external air environment. Does not include the air environment inside buildings or structures. |
| ANSTO | Australian Nuclear Science and Technology Organisation |
| ANZECC | Australian and New Zealand Environment and Conservation Council |
| ANZSIC | Australian and New Zealand Standard Industrial Classification |
| BAM | Beta Attenuation Monitor |
| BAU | Business as usual |
| BCR | Benefit:cost ratio |
| BITRE | Bureau of Infrastructure, Transport and Regional Economics |
| Ca | Calcium |
| CBA | Cost-benefit analysis |
| CBD | Central Business District |
| Cl | Chlorine |
| CLRTAP | 1979 Geneva Convention on Long Range Transboundary Air Pollution |
| CO | Carbon monoxide |
| CO ₂ | Carbon dioxide |
| COAG | Council of Australian Governments |
| Cr | Chromium |
| CRF | Concentration-response function |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| Cu | Copper |
| Defra | (UK) Department for Environment, Food and Rural Affairs |
| DERM | Former (Queensland) Department of Environment & Resource Management |
| DEWHA | (Commonwealth) Department of Environment, Water, Heritage and the Arts (now Department of the Environment) |
| DPF | Diesel particulate filter |
| DSEWPC | (Commonwealth) Department of Sustainability, Environment, Water, Population and Communities (now Department of the Environment) |
| DSITIA | (Queensland) Department of Science, Information Technology, Innovation and the Arts |
| EC | Elemental carbon |

| | |
|---|--|
| EIA | Environmental Impact Assessment |
| EPA Victoria | Environment Protection Authority Victoria |
| EPHC | Environment Protection Heritage Council |
| EU | European Union |
| Fe | Iron |
| FDMS | Filter Dynamic Measurement System |
| GMR | (NSW) Greater Metropolitan Region |
| Goal (in AAQ NEPM) | Maximum allowable exceedances to be achieved within 10 years |
| GRUB | Generally representative upper bound – the upper bound of pollution levels likely to be experienced by the general population in a specified region while avoiding the direct impacts of localised pollutant sources |
| GVA | Gross value added |
| HRA | Health risk assessment |
| HVAS | High volume air samplers |
| IAWG | Impact Assessment Working Group (of the Air Thematic Oversight Group) |
| IGCB | (UK) Interdepartmental Group on Costs and Benefits |
| K | Potassium |
| Na | Sodium |
| NEPC | National Environment Protection Council |
| NEPC Act | National Environment Protection Council Act 1994 (Cwth) |
| NEPM | National Environment Protection Measure |
| NH ₃ | Ammonia |
| NH ₄ NO ₃ | Ammonium nitrate |
| (NH ₄) ₂ SO ₄ | Ammonium sulfate |
| NHMRC | National Health and Medical Research Council |
| NHSO ₄ | Sulfate |
| Ni | Nickel |
| NO ₂ | Nitrogen dioxide |
| NO _x | Oxides of nitrogen; the sum of NO ₂ and NO by convention |
| NPI | National Pollutant Inventory |
| NPV | Net present value |
| NSW | New South Wales |
| NT | Northern Territory |
| NSW EPA | New South Wales Environment Protection Authority |
| O ₃ | Ozone |
| OC | Organic carbon |
| Pb | Lead |
| PM | Airborne particulate matter |
| PM ₁₀ | Particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less. |
| PM _{2.5} | Particulate matter with an equivalent aerodynamic diameter of 2.5 micrometres or less. |
| Performance monitoring station | A monitoring station used to measure achievement against an air quality goal. The station is located to measure air quality likely to be experienced by the general population in a region or sub-region. |
| ppb | Parts per billion by volume |

| | |
|------------------------|---|
| ppm | Parts per million by volume |
| PRC | Peer Review Committee |
| QLD | Queensland |
| Reference method | The monitoring method used for collection of data that can be compared to the advisory reporting standards |
| REVIHAAP | Review of evidence on health aspects of air pollution |
| RMS | (NSW) Roads and Maritime Services |
| S | Sulfur |
| SA | South Australia |
| SCEW | Standing Council on Environment and Water |
| SEQ | South-East Queensland |
| Si | Silicon |
| SIA | Secondary inorganic aerosol |
| SO ₂ | Sulfur dioxide |
| SO _x | Sulfur oxides |
| SOA | Secondary organic aerosol |
| Standard (in AAQ NEPM) | The maximum concentration for a given averaging period |
| TAS | Tasmania |
| TEOM | Tapered Element Oscillating Microbalance |
| Ti | Titanium |
| TSP | Total suspended particulate |
| µg | Microgram (one millionth of a gram) |
| µg/m ³ | Micrograms per cubic metre. This is the unit used for concentrations of particles in the air, and is referenced to a temperature of 0 degrees Celsius and an absolute pressure of 101.325 kilopascals |
| µm | Micrometre (one millionth of a metre) |
| UHAQMN | Upper Hunter Air Quality Monitoring Network |
| UK | United Kingdom |
| US | United States |
| USEPA | United States Environment Protection Agency |
| V | Vanadium |
| VIC | Victoria |
| VOCs | Volatile organic compounds |
| VSL | Value of a statistical life |
| WA | Western Australia |
| WHO | World Health Organization |
| Zn | Zinc |
| | |

12 REFERENCES

- ABS (2008), *Population Projections, Australia, 2006 to 2101*, ABS Publication 3222.0, Australian Bureau of Statistics, Canberra,
www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3222.02006%20to%202101?OpenDocument#Time
- Access Economics (2008), *The Health of Nations: The Value of a Statistical Life*, report by Access Economics for Office of the Australian Safety and Compensation Council, Access Economics, 14 January 2008,
www.accesseconomics.com.au/publicationsreports/getreport.php?report=156&id=204
- AQEG (2005), *Particulate matter in the United Kingdom*, report of the Air Quality Expert Group, published by the Department for Environment, Food and Rural Affairs, London, UK.
- AQEG (2012), *Fine Particulate Matter (PM_{2.5}) in the United Kingdom*, report of the Air Quality Expert Group, published by the Department for Environment, Food and Rural Affairs, London, UK.
- ANSTO (2008), *Fine Particle Aerosol Sampling Newsletter*, Number 38, July 2008, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW
www.ansto.gov.au/data/assets/pdf_file/0019/39313/Newsletter38.pdf
- ANSTO (2010), *Fine Particle Aerosol Sampling Newsletter*, Number 40, May 2010, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW
www.ansto.gov.au/data/assets/pdf_file/0018/47133/Newsletter40.pdf
- Aust, N, Watkiss, P, Boulter, P and Bawden, K (2013), *Methodology for valuing the health impacts of changes in particle emissions – Final Report*, PAEHolmes Report 6695, PAEHolmes, Brisbane, QLD.
- Bawden, K, Aust, N, Moorcroft, S, Laxen, D and Williams, M (2012), *Evaluating Options for an Exposure Reduction Framework in Australia*, PAEHolmes Report 6808, PAEHolmes, Brisbane, QLD.
- BDA Group (2013), *Consultation regulation impact statement for reducing emissions from wood heaters*, report for National Environment Protection Council Service Corporation, 11 April 2013, BDA Group, Manuka, ACT.
- Begg, S, Vos, T, Barker, B, Stevenson, C, Stanley, L and Lopez, AD (2007), *The burden of disease and injury in Australia 2003*, PHE 82, Australian Institute of Health and Welfare (AIHW), Canberra, ACT,
www.aihw.gov.au/publications/hwe/bodaiia03/bodaiia03.pdf
- Bell, ML (2012), *Assessment of the Health Impacts of Particulate Matter Characteristics*, Research Report 161, Health Effects Institute, Boston, Massachusetts, USA <http://pubs.healtheffects.org/view.php?id=371>
- BITRE (2010), *Long-term Projections of Australian Transport Emissions: Base Case 2010*, Bureau of Infrastructure, Transport and Regional Economics, Canberra, ACT.
- Boulter, P and Kulkarni, K (2013), *'Economic analysis to inform the national plan for clean air (particles) – Final report'*, report prepared for NEPC Service Corporation, August 2013 (unpublished).
- Brook, RD, Rajagopalan, S, Pope, CA, Brook, JR, Bhatnagar, A, Diez-Roux, AV, Holguin, F, Hong, Y, Luepker, RV, Mittleman, MA, Peters, A, Siscovick, D, Smith, SC Jr, Whitsel, L and Kaufman, JD (2010), 'Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association', *Circulation*, vol. 121, pp. 2331–2378.
- BTRE (2005), *Health Impacts of Transport Emissions in Australia: Economic Costs*, BTRE Working Paper 63, Bureau of Transport and Regional Economics, Canberra, ACT
www.bitre.gov.au/publications/2005/files/wp_063.pdf

- Cambra-López, M, Aarnink, AJA, Zhao, Y, Calvet, S and Torres, AG (2010), 'Airborne particulate matter from livestock production systems: A review of an air pollution problem', *Environmental Pollution*, vol. 158(1), pp. 1–17.
- CCME (2006), *Canada-wide Standards for Particulate Matter and Ozone, Five Year Report 2000–2005*, PN 1374, Canadian Council of Ministers of the Environment, Canada, www.ccme.ca/assets/pdf/pm_oz_2000_2005_rpt_e.pdf
- CCME (2007), *Guidance Document on Continuous Improvement (CI) and Keeping-Clean-Areas-Clean (KCAC)*, PN 1389, Canadian Council of Ministers of the Environment, Canada, www.ccme.ca/assets/pdf/1389_ci_kcac_e.pdf
- Chan, YC, Simpson, RW, Mctainsh, GH, Vowles, PD, Cohen, DD and Bailey, GM (1997), 'Characterization of chemical species in PM_{2.5} and PM₁₀ aerosols in Brisbane', *Atmospheric Environment*, vol. 31, pp. 2061–2080.
- Chan, YC, Simpson, RW, Mctainsh, GH, Vowles, PD, Cohen, DD and Bailey, GM (1999), 'Source apportionment of PM_{2.5} and PM₁₀ aerosols in Brisbane (Australia) by receptor modelling', *Atmospheric Environment*, vol. 33(19), pp. 3251–3268.
- Chan, YC, Vowles, PD, Mctainsh, GH, Simpson, RW, Cohen, DD, Bailey, GM and McOrist, GD (2000), 'Characterisation and source identification of PM₁₀ aerosol samples collected with a high volume cascade impactor in Brisbane (Australia)', *The Science of the Total Environment*, vol. 262, pp. 5–19.
- Chan, YC, Cohen, DD, Hawas, O, Stelcer, E, Simpson, R, Denison, L, Wong, N, Hodge, M, Comino, E and Carswell, S (2008), 'Apportionment of sources of fine and coarse particles in four major Australian cities by positive matrix factorisation', *Atmospheric Environment*, vol. 42(2), pp. 374–389.
- Chan, YC, Hawas, O, Hawker, D, Vowles, P, Cohen, DD, Stelcer, E, Simpson, R, Golding, G and Christensen, E (2011), 'Using multiple type composition data and wind data in PMF analysis to apportion and locate sources of air pollutants', *Atmospheric Environment*, vol. 45(2), pp. 439–449.
- Charron, A, Harrison, RM, Moorcroft, S and Booker, J (2004), 'Quantitative interpretation of divergence between PM₁₀ and PM_{2.5} mass measurements by TEOM and gravimetric (Partisol) instruments', *Atmospheric Environment*, vol. 38, pp. 415–423.
- COAG (2007), *Best Practice Regulation – A Guide for Ministerial Councils and National Standard-Setting Bodies*, Council of Australian Governments, Canberra, ACT.
- COAG (2012), *Public statement on the development of the National Plan for Clean Air*, Council of Australian Governments Standing Council on Environment and Water, Canberra, ACT, 31 May 2012, www.scew.gov.au/strategic-priorities/national-plan-for-clean-air.html
- Cohen, DD, Crawford, J, Stelcer, E and Atanacio, A (2012), 'Application of positive matrix factorization, multi-linear engine and back trajectory techniques to the quantification of coal-fired power station pollution in metropolitan Sydney', *Atmospheric Environment*, vol. 61, pp. 204–211.
- COMEAP (2009), *Long-term exposure to air pollution: effect on mortality*, report by the Committee on the Medical Effects of Air Pollutants, Department of Health, London, UK.
- COMEAP (2010), *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*, Committee on the Medical Effects of Air Pollutants, Department of Health, London, UK.
- Cope, M (2012), 'Reflections on Domestic Wood Smoke Emissions – Effects, Concerns, Progress and Opportunities', presentation to NSW/ACT Branch Technical Meeting, Monday, 10 September 2012, Macquarie University.

Crouse, DL, Peters, PA, van Donkelaar, A, Goldberg, MS, Villeneuve, PJ, Brion, O, Khan, S, Odwa Atari, D, Jerrett, M, Arden Pope III, C, Brauer, M, Brook, JR, Martin, RV, Stieb, D and Burnett, RT (2012), 'Risk of Nonaccidental and Cardiovascular Mortality in Relation to Long-term Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National-Level Cohort Study', *Environmental Health Perspectives*, vol. 120(5), pp. 708–714,

<http://ehp.niehs.nih.gov/wp-content/uploads/120/5/ehp.1104049.pdf>

Defra (2007), *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*, Department for Environment, Food and Rural Affairs, London, UK,

<http://archive.defra.gov.uk/environment/quality/air/airquality/strategy/documents/air-qualitystrategy-vol1.pdf>

Defra (2009), *Local Air Quality Management Technical Guidance LAQM,TG(09)*, Department for Environment, Food and Rural Affairs, The Scottish Executive, Welsh Assembly Government and The Department of the Environment for Northern Ireland, UK.

DEWHA (2009), *National Pollutant Inventory, 2006–07 Summary Report*, Department of the Environment, Water, Heritage and the Arts, Canberra, ACT, www.npi.gov.au/system/files/resources/e0e7acda-fe12-9204-8134-6dd236ea134e/files/year9summaryreport.pdf

DSEWPC (2011), *State of the air in Australia 1999–2008*, Australian Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

EC (2011), 'Commission Staff Working Paper 6771/11 establishing guidelines for demonstration and subtraction of exceedances attributable to natural sources under the Directive 2008/50/EC on ambient air quality and cleaner air for Europe', European Commission, Brussels, Belgium,

<http://register.consilium.europa.eu/pdf/en/11/st06/st06771.en11.pdf>

EEA (2012), *Particulate matter from natural sources and related reporting under the EU Air Quality Directive in 2008 and 2009*, Technical report No 10/2012, European Environment Agency, Copenhagen, Denmark.

EPA Victoria (2013), *Legislation: Air legislation*, EPA Victoria, Carlton, VIC, viewed November 2013,

www.epa.vic.gov.au/about-us/legislation/air-legislation

EPHC (2010), *Expansion of the multi-city mortality and morbidity study – Final Report*, Environment Protection and Heritage Council, Canberra, ACT, September 2010,

www.scew.gov.au/sites/www.scew.gov.au/files/resources/220add0d-0265-9004-1d22-0c312998402c/files/aq-rsch-multi-city-mm-executive-summary-sept-final-201009.pdf

Frangos, J and DiMarco, P (2013), '*Exposure assessment and risk characterisation to inform recommendations for updating ambient air quality standards for PM_{2.5}, PM₁₀, O₃, NO₂, SO₂*', Report number 127643066-001-R-RevA, Golder Associates, Richmond, VIC (unpublished).

Friend, AJ, Ayoko, GA and Elbagir, S (2011a), 'Source apportionment of fine particles at a suburban site in Queensland, Australia', *Environmental Chemistry*, vol. 8(2), pp. 163–173.

Friend A J, Ayoko G A, Stelcer E and Cohen D (2011b), Source apportionment of PM_{2.5} at two receptor sites in Brisbane, Australia. *Environ. Chem.*, Vol. 8, pp. 569–580.

Friend, AJ, Ayoko, GA and Kokot, S (2013), 'Source apportionment of airborne particulate matter: An overview of Australian and New Zealand studies', *Air Quality and Climate Change*, vol. 47(2), pp. 13–19.

Gelencsér, A, May, B, Simpson, D, Sánchez-Ochoa, A, Kasper-Giebl, A, Puxbaum, H, Caseiro, A, Pio, C and Legrand, M (2007), 'Source apportionment of PM_{2.5} organic aerosol over Europe: Primary/secondary, natural/anthropogenic, and fossil/biogenic origin', *Journal of Geophysical Research*, vol. 112, D23S04, doi:10.1029/2006JD008094.

Gras, JG, Gillet, RW, Bentley, ST, Ayers, GP and Firestone, T (1992), 'CSIRO–EPA Melbourne Aerosol Study: Final Report', CSIRO Atmospheric Research, Melbourne, VIC, cited in Keywood et al. (2011).

- Gras, JG (1996), 'The Perth Haze Study: a report to the Department of Environmental Protection of Western Australia on fine-particle haze in Perth', CSIRO Atmospheric Research, Melbourne, VIC, cited in Keywood et al. (2011).
- Grover, BD, Kleinman, M, Eatough, NL, Eatough, DJ, Hopke, PK, Long, RW, Wilson, WE, Meyer, MB and Ambs, JL (2005), 'Measurement of total PM_{2.5} mass (nonvolatile plus semivolatile) with the Filter Dynamic Measurement System tapered element oscillating microbalance monitor', *Journal of Geophysical Research*, vol. 110, D07S03, doi:10.1029/2004JD004995.
- Harrison, RM, Giorio, C, Beddows, DC and Dall'Osto, M (2010), 'Size distribution of airborne particles controls outcomes of epidemiological studies', *Sci. Total Environ.*, vol. 409, pp. 289–293.
- Hibberd, MF, Selleck, PW, Keywood, MD, Cohen, DD, Stelcer, E and Atanacio, AJ (2013), *Upper Hunter Particle Characterisation Study*, CSIRO, Australia.
- IARC (2012), IARC WHO Press Release No. 213, 'IARC: Diesel Engine Exhaust Carcinogenic', 12 June 2012, World Health Organisation, International Agency for Research on Cancer, Lyon, France, www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf
- IARC (2013), IARC WHO Press Release No. 221, 'Outdoor air pollution a leading environmental cause of cancer deaths', 17 October 2013, World Health Organisation, International Agency for Research on Cancer, Lyon, France, www.iarc.fr/en/media-centre/pr/2013/pdfs/pr221_E.pdf
- Jalaludin, B, Morgan, G, Salkeld, G and Gaskin, C (2011), 'Health benefits of reducing ambient air pollution levels in the Greater Metropolitan Region', report for the NSW Ministry of Health and the NSW Office of Environment and Heritage (unpublished), December 2011.
- Jalaludin, B and Cowie, C (2012), *Health Risk Assessment – Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants*, report prepared for EPA Victoria, Respiratory and Environmental Epidemiology, Woolcock Institute of Medical Research, Glebe, NSW, 30 June 2012.
- Keywood, M, Guyes, H, Selleck, P and Gillett, R (2011), 'Quantification of secondary organic aerosol in an Australian urban location', *Environ. Chem.* vol. 8, pp. 115–126.
- Kroll, JH and Seinfeld, JH (2008), 'Chemistry of secondary organic aerosol: Formation and evolution of low-volatility organics in the atmosphere', *Atmospheric Environment*, vol. 42, pp. 3593–3624.
- Laxen, D, Moorcroft, S, Marner, B, Laxen, K, Boulter, P, Barlow, T, Harrison, R and Heal, M (2010), PM_{2.5} in the UK: Enhancing the general understanding of the issues relating to the regulation of fine particulate matter, published by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), Edinburgh, UK.
- Matthijsen, J and ten Brink, HM (2007), *PM_{2.5} in the Netherlands – consequences of the new European air quality standards*, MNP Report 500099001/2007, The Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.
- Morgan, G, Broome, R and Jalaludin, B (2013), *Summary for Policy Makers of the Health Risk Assessment on Air Pollution in Australia*, National Environment Protection Council Service Corporation, Canberra.
- NEPC (1998), *National Environment Protection (Ambient Air Quality) Measure – Revised Impact Statement*, National Environmental Protection Council, Adelaide, SA.
- NEPC (2002), *Impact statement for PM_{2.5} Variation – Setting a PM_{2.5} standard in Australia*, National Environmental Protection Council, Adelaide, SA.
- NEPC (2011a), *National Environment Protection (Ambient Air Quality) Measure Review*, National Environment Protection Council Service Corporation, Adelaide, SA, <http://www.scew.gov.au/system/files/resources/3405e986-afe9-bdb4-5d2c-383f3ea1e911/files/aaq-review-report-2011.pdf>

NEPC (2011b), *Methodology for Setting Air Quality Standards in Australia*, Part A, February 2011, National Environment Protection Council, Canberra, ACT.

NEPC (2012), *Annual Report 2011–2012*, National Environment Protection Council, Canberra, ACT.

NSW DEC (2005a), *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW*, NSW Department of Environment and Conservation, Sydney, NSW.

NSW DEC (2005b), *Air Pollution Economics - Health Costs of Air Pollution in the Greater Sydney Metropolitan Region*, NSW Department of Environment and Conservation, Sydney, NSW, www.environment.nsw.gov.au/resources/air/airpollution05623.pdf

NSW EPA (2012), *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales - 2008 Calendar Year, Technical Report No. 1 – Consolidated Natural and Human-Made Emissions: Results*, NSW Environment Protection Authority, Sydney South, NSW.

Pope, CA III and Dockery, DW (2006), 'Health effects of fine particulate air pollution: lines that connect', *J. Air Waste Management Assoc.*, vol. 56, pp. 709–742.

PRC (2001a), *National Environment Protection (Ambient Air Quality) Measure – Technical Paper No. 3 – Monitoring Strategy*, prepared by the Peer Review Committee (PRC) for the National Environment Protection Council (NEPC), Canberra, ACT.

PRC (2001b), *National Environment Protection (Ambient Air Quality) Measure – Technical Paper No. 5 – Data Collection and Handling*, prepared by the Peer Review Committee (PRC) for the National Environment Protection Council (NEPC), Canberra, ACT.

PRC (2001c), *National Environment Protection (Ambient Air Quality) Measure – Technical Paper No. 10 – Collection and Reporting of TEOM PM₁₀ Data*, prepared by the Peer Review Committee (PRC) for the National Environment Protection Council (NEPC), Canberra, ACT.

Queensland Department of Environment and Resource Management (2010), *State planning policy 5/10: air, noise and hazardous materials*, Department of Environment and Resource Management, Brisbane, QLD, available at www.cabinet.qld.gov.au/documents/2010/oct/spp%20air-noise%20and%20hazardous%20materials/Attachments/air-noise-hazard-policy%5B1%5D.pdf.

Queensland Government (2012), *Environmental Protection (Air) Policy 2008*, current as at 9 November 2012, Queensland Government, Brisbane, QLD, viewed November 2013, www.legislation.qld.gov.au/LEGISLTN/CURRENT/E/EnvProtAirPo08.pdf.

Reisen, F, Meyer, CP, McCaw, L, Powell, JC, Tolhurst, K, Keywood, MD and Gras, JL (2011), 'Impact of smoke from biomass burning on air quality in rural communities in southern Australia', *Atmospheric Environment*, vol. 45, pp. 3944–3953.

SEC (2011), *Australia state of the environment 2011*, independent report by the State of the Environment 2011 Committee to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

UNECE (1979), *Convention on Long-range Transboundary Air Pollution*, United Nations Economic Commission for Europe, Geneva, Switzerland, www.unece.org/env/lrtap/lrtap_h1.html

UNECE (2005), *Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone*, United Nations Economic Commission for Europe, Geneva, Switzerland, www.unece.org/env/lrtap/multi_h1.html

USEPA (2009), *Integrated Science Assessment for Particulate Matter*, EPA/600/R-08/139F, United States Environmental Protection Agency, Research Triangle Park, NC, USA, <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>

USEPA (2010), *Quantitative Health Risk Assessment for Particulate Matter – Final Report*, Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park, NC, USA, www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_risk.html

USEPA (2011), *Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards*, EPA 452/R-11-003, United States Environmental Protection Agency, Research Triangle Park, NC, USA, www.epa.gov/ttn/naaqs/standards/pm/data/20110419pmpafinal.pdf

USEPA (2013), Federal Register, vol. 78, no. 10 January 15, 2013 – Part II – Environmental Protection Agency – 40 CFR Parts 50, 51, 52 et al., National Ambient Air Quality Standards for Particulate Matter; Final Rule, United States Environmental Protection Agency, Research Triangle Park, NC, USA.

Watkiss, P (2002), *Fuel Taxation Inquiry: the Air Pollution Costs of Transport in Australia*, Report No. ED44525 to Commonwealth of Australia, AEA Technology Environment.

Wendt, C and Walsh, SF (2007), 'Use of Nephelometry as a long term measure of particle pollution', paper presented at 14th IUAPPA World Congress, Brisbane, QLD.

WHO Regional Office for Europe (2006), *Air quality guidelines – global update 2005*, WHO Regional Office for Europe, Copenhagen, Denmark.

WHO Regional Office for Europe (2013), *Review of evidence on health aspects of air pollution – REVIHAAP Project*, Technical Report, WHO Regional Office for Europe, Copenhagen, Denmark.

Wilton, E, Smith, J, Gimson, N and Phillips, J (2009), 'Source apportionment and modelling of PM₁₀ in Hastings, New Zealand', *Air Quality and Climate Change*, vol. 43(2), pp. 31–39.

Appendix A RECOMMENDATIONS FROM THE 2011 AAQ NEPM REVIEW

Table A.1: Recommendations from AAQ NEPM review, and treatment in Impact Statement

| Number in AAQ NEPM review | Aspect of AAQ NEPM | Review recommendation | Included in Information Impact Statement? |
|---------------------------|--------------------|--|--|
| 1 | AAQ NEPM goal | The (ambiguous) concept of 'adequate protection' does not address the health risks associated with exposure to air pollution. The desired outcome of the AAQ NEPM should be to 'minimise the risk from adverse health impacts from exposure to air pollution for all people wherever they may live'. | No. This is an overarching consideration for the AAQ NEPM. |
| 2 | | Revise the desired environmental goal to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants. | No. This is an overarching consideration for the AAQ NEPM. |
| 3 | Lead standard | Remove lead from the AAQ NEPM and include in the Air Toxics NEPM during the scheduled Air Toxics NEPM review of 2012. | No. Not relevant to PM standard-setting. |
| 6 | Ozone standard | Introduce an 8-hour standard for ozone. | No. Not relevant to PM standard-setting. |
| 4 | PM standards | The AAQ NEPM standards should be revised to take into account new evidence concerning the health effects of air pollution. There are significant health effects at the current levels of air pollution in Australian cities, indicating that the standards are not meeting the requirement for adequate protection of health. | Yes. Health evidence reviewed in detail (Section 3.1) |
| 5 | | Compliance standards for PM _{2.5} should be introduced. The initial introduction of advisory reporting standards (rather than compliance standards) was due to a lack of monitoring data. All jurisdictions have since been monitoring PM _{2.5} and there are now sufficient data to develop compliance standards. | Yes. Review of health evidence and monitoring data has led to same conclusion (Section 3.1 and Section 5.3) |
| | | For PM _{2.5} the current averaging periods are appropriate and should be retained. | Yes. Review of health evidence has led to same conclusion (Section 3.1) |
| 7 | | The current PM ₁₀ standard addresses short-term effects, and an annual average standard for PM ₁₀ should also be included in the AAQ NEPM. | Yes. Review of health evidence has led to same conclusion (Section 3.1) |
| 9 | | Allowable exceedances should be removed from the AAQ NEPM and a natural events rule should be introduced to account for major natural events, including the definition of these events and criteria for assessment and reporting. | Yes. Discussed in Section 7.5. Options are considered, but no conclusion is drawn at this stage. To be considered following consultation. |
| 8 | Exposure reduction | The current air quality standards do not provide sufficient protection for human health, and the implementation of a risk-based exposure-reduction framework should improve the AAQ NEPM's effectiveness. This would also align Australian air quality management policy with international best practice. | Yes. Sections 4.2.2 and 7.7. |
| 14 | | The development of nationally consistent approaches to emissions inventory compilation, modelling and estimating population exposure would be beneficial. In addition, protocols would be required for applying exposure-reduction targets and reporting on progress towards meeting them, including what should happen if they are not met. | No. Considered to be outside the scope of Impact Statement. |

| Number in AAQ NEPM review | Aspect of AAQ NEPM | Review recommendation | Included in Information Impact Statement? |
|---------------------------|--|---|--|
| 10 | Performance monitoring stations | Siting: the GRUB concept does not fit well with current population exposure approaches. There has been confusion around the definition of GRUB stations, and this has led to inconsistencies between jurisdictions. The recommendations were to discontinue the GRUB concept and to redesign the monitoring networks to represent population exposure on a pollutant-by-pollutant basis without compromising data collection for long-term trend analysis. | No. A detailed treatment of this was outside the scope of the Impact Statement. |
| | | The 'other means' of evaluating performance (such as dispersion modelling) do not appear to have been used widely by the jurisdictions. These could be especially valuable for assessing exposure reduction. | No. A detailed treatment of this was outside the scope of the Impact Statement. |
| 11 | | The population threshold and formula should be removed to enable monitoring on potential population risk basis rather than on population size. The population formula is seen as an impediment to effective monitoring and therefore to adequate protection of populations, particularly those in small regional centres that characterise populations in several jurisdictions. The procedure to determine the location and number of sites could be based on those used in Europe and the United States. | No. Being considered by inter-jurisdictional technical working groups. |
| – | Trend monitoring stations | The AAQ NEPM review did not explicitly address the topic of trend stations, but did mention that all existing monitoring stations should be used to inform long-term trends in air quality. | No. Being considered by inter-jurisdictional technical working groups. |
| 12 | Monitoring methods – PM ₁₀ | The development of Australian standards for monitoring air pollution takes several years, but instrumentation for the measurement of particles (both PM ₁₀ and PM _{2.5}) is continually evolving. The requirement for an Australian standard monitoring method therefore results in a significant time lag in terms of the introduction of new and potentially superior methods for measuring particles. The review concluded that some flexibility needs to be built into the AAQ NEPM framework to enable a faster response to technological advances in instrumentation. It was recommended that the AAQ NEPM should allow the use of any methods that have been tested and approved by the USEPA or the EU as reference or equivalence methods for monitoring ambient air quality. | Not addressed in detail. Being considered by inter-jurisdictional technical working groups. |
| 13 | Monitoring methods – PM _{2.5} | According to the AAQ NEPM review, one of the difficulties arising from the PM _{2.5} equivalence program was the lack of shared understanding about what it was trying to achieve; whether equivalency means generating the same number on two instruments, or whether it means that the instrumentation measures the same physical characteristics of the particles. The latter is referring to the fact that as instruments used to monitor particles (e.g. gravimetric versus optical and light scattering instruments) measure particles differently, determining equivalency is not straightforward and may be impossible in some cases. The review recommended that the findings of the PM _{2.5} equivalence program should also be taken into account in any variation of the AAQ NEPM. The AAQ NEPM review also recommended the removal of Schedule 5 (equivalence program) from the AAQ NEPM. | Not addressed in detail. Being considered by inter-jurisdictional technical working groups. |

| Number in AAQ NEPM review | Aspect of AAQ NEPM | Review recommendation | Included in Information Impact Statement? |
|---------------------------|--|--|--|
| – | Evaluation of performance against standards and goal | The AAQ NEPM review concluded that the protocols for evaluating and reporting performance should be tightened. In particular, the general approach to date has been to report performance in terms of the number of exceedances of the standards, referenced against the goals for the respective pollutants (i.e. the number of allowed exceedances). The review considered that the number of exceedances alone is of little real value. This number may incorporate events where concentrations are just over the numerical standard, or where concentrations are considerably higher than the standard, and therefore says little about the impacts on communities, or about the effectiveness of air quality management programs. | Not addressed in detail. Some analysis Section 8.2 |
| 15 | Severity of exceedances | Clause 17 of the AAQ NEPM should therefore be modified to incorporate a measure of 'severity of exceedance'. The review also recommended that the requirement to express performance as 'met', 'not met', or 'not demonstrated' should be removed from the AAQ NEPM, as no guidance is provided on what factors need to be considered. | No. Considered to be outside the scope of Impact Statement. |
| 16 | Reporting | In relation to reporting the AAQ NEPM review focused largely on the clear interpretation of air quality data (rather than just reporting compliance) and the communication of air quality data to the community. Revise guidance documents and templates associated with assessment and reporting to accommodate presentation of clear messages, to allow for better communication and more accessible air quality reports. | No. Considered to be outside the scope of Impact Statement. |
| 18 | | Require timely reporting of all exceedances, with jurisdictions publicly releasing the analysis of these events on their respective websites within 3 months of the event | No. Considered to be outside the scope of Impact Statement. |
| – | Accountability | The issue was raised as to whether jurisdictions should be made more accountable for implementation of the AAQ NEPM and compliance with the standards. Increased accountability and transparency could be achieved by jurisdictions through improvements in the reporting protocol. Reports should attribute all exceedances and provide information on management actions being undertaken to deal with non-compliance with the standards. The latter should include trend analysis to demonstrate the effectiveness of management strategies over time. Exceedances are only of limited utility in describing impacts of air pollution on population health, so further descriptors of the underlying distribution of air quality data need to be developed and included in reports. | No. Considered to be outside the scope of Impact Statement. |
| 17 | Form of standards | The review considered that inclusion of a natural events rule would enable identification of issues that impact on air quality to be separated into 'natural' events that are not easily managed and 'anthropogenic' impacts that are manageable through the implementation of air quality management strategies. Strict guidance would need to be provided to identify what constitutes a 'natural' event (similar to the guidance developed by the USEPA). The justification and analysis would need to be included in the annual reporting to NEPC. | Yes. Sections 7.5.2 and 8.2.5. |

| Number in AAQ NEPM review | Aspect of AAQ NEPM | Review recommendation | Included in Information Impact Statement? |
|---------------------------|--------------------------------|---|--|
| 19 | PRC | Disband the existing PRC and replace with a specialist working group or groups with a broader range of expertise to assist with scientific and technical matters. | No. Not relevant to PM standard-setting. |
| 20 | Secondary pollutant precursors | Evaluate the options to assess ozone and secondary particle precursors. | No. Considered to be outside the scope of Impact Statement. |
| 21 | Future work | Initiate research into the composition of particles in Australia and associated health impacts. | No. Considered to be outside the scope of Impact Statement. |
| 22 | | Initiate health research on the impact of air pollution (in particular, particles) in regional areas. | No. Considered to be outside the scope of Impact Statement. |
| 23 | | Monitor and report coarse particle fraction. | No. Considered to be outside the scope of Impact Statement. |

Appendix B MONITORING METHODS FOR PM₁₀ AND PM_{2.5}

B.1 REFERENCE METHODS

The reference method for monitoring PM₁₀ and PM_{2.5} in Australia is the manual gravimetric method. The method is a non-continuous (batch), one-day-in-three technique in which PM is sampled by drawing air at ambient temperature and pressure through a filter. The filter is weighed before and after sampling to determine the PM mass. The Australian/New Zealand Standards for measuring PM₁₀ and PM_{2.5} are:

AS/NZS 3580.9.6-2003: Methods for sampling and analysis of ambient air - Determination of suspended particulate matter - PM₁₀ high volume sampler with size selective inlet - Gravimetric method.

AS/NZS 3580.9.10-2006: Reference method for the determination of fine particulate matter as PM_{2.5} in the atmosphere.

These reference methods are similar to those employed in the United States and Europe. It has long been known that the reference methods are subject to sampling artefacts, including particle bounce on heavily-loaded filters and the loss of semi-volatile components of PM (**USEPA, 2009**).

B.2 ALTERNATIVE METHODS

For a variety of practical reasons, the reference methods have not been widely adopted in Australia and elsewhere (e.g. the UK). The operation of a gravimetric sampler and the manual weighing of filters is labour-intensive, and only provides 24-hour mean PM concentrations. The manual nature of the reference method also introduces a significant time delay in data acquisition, rendering it unsuitable for real-time data production. Where data are not collected every day the concentration-response relationship in air pollution health studies cannot be fully evaluated in terms of lags between ambient concentration and health outcomes (**USEPA, 2009**).

Fortunately, some automated and continuous methods can be used as alternatives to the reference methods, but not all these methods are recognised as being equivalent to the reference methods for AAQ NEPM purposes. Automated methods can be less expensive for routine air quality monitoring, and can provide data over much shorter time intervals (e.g. hourly). However, because of the different measurement techniques employed the data from the various alternative methods are not directly comparable. The main alternative methods used in Australia are summarised below.

B.2.1 TEOM

The Tapered Element Oscillating Microbalance (TEOM) is the most common automatic method for measuring and reporting PM₁₀ and PM_{2.5} concentrations in Australia; TEOM samplers have almost universally been adopted by the Australian jurisdictions to measure PM₁₀. The TEOM draws air through a hollow, tapered glass tube (the element). The wide end of the tube is fixed, whereas the narrow end can oscillate in response to an applied electric field. Particles are collected on the filter attached to the narrow end of the tube. The frequency of oscillation is proportional to the accumulated mass, and therefore small changes in PM mass can be quantified by accurately measuring the tube's resonant frequency. To minimise the contribution of liquid water to the measured PM mass, the TEOM conditions the incoming sample aerosol to 50°C prior to and during its measurement. The main advantage of the TEOM is that concentrations are reported on a continuous basis. However, it is known that the operational temperature of the TEOM results in the loss of semi-volatile SOA and ammonium nitrate (**Grover et al., 2005**). It was shown by **Charron et al. (2004)** that most of the PM₁₀ mass not measured by the TEOM belongs to the PM_{2.5} fraction. The TEOM therefore has therefore been shown to produce PM concentrations that are significantly different from those data produced by the reference method, in particular when the ambient temperature is low during autumn and winter. The TEOM appears to provide a good measurement of PM₁₀ during the warmer spring and summer months, or when the aerosol is less volatile (**PRC, 2001c**).

In Australia there are two ways in which the TEOM data are adjusted:

Firstly, in the case of PM₁₀ there is an internal manufacturer's correction. This correction was introduced to account for the measurement differences between the TEOM sampler and the high-volume reference method in

the United States. This internal factor is incorporated into all TEOM PM₁₀ analysers sold in Australia³⁶, and is given by $TEOM_{raw} * 1.03 + 3 \mu\text{g}/\text{m}^3$. However, there are some concerns that the empirical factors developed for conditions in the United States may not apply to Australian conditions.

Secondly, AAQ NEPM PRC Technical Paper No. 10 provides a basis for the removal of bias due to the loss of volatile components in TEOM PM₁₀ measurements (**PRC, 2001c**). Under this protocol the PM₁₀ daily average data are multiplied by a factor which varies linearly from 1.4 at daily mean temperatures less than or equal to 5°C, to 1.0 at temperatures equal to or greater than 15°C. The protocol resulted from a study by CSIRO, and was intended as a first step towards a nationally-consistent means for removing the TEOM bias.

PRC (2001c) recommend that, wherever possible, TEOM PM₁₀ data should be adjusted through the application of a site-specific method based on co-located TEOM and reference measurements. When a site-specific adjustment is not available, and the TEOM site is known to experience a significant contribution from volatiles, the TEOM data should be adjusted using the CSIRO temperature method. The national temperature adjustment is not required in regions where volatiles do not contribute significantly to the particle measurements. It is worth noting that the CSIRO method is not applied consistently across jurisdictions. For example, it is applied to the PM₁₀ data from TEOMs in Victoria, but not in NSW.

B.2.2 Filter Dynamic Measurement System (FDMS)

The FDMS is a refinement of the TEOM that retains the semi-volatile PM component that is not measured by earlier TEOM models. It is now widely deployed in the UK to measure both PM₁₀ and PM_{2.5} concentrations (**Laxen et al., 2010**), but is used in few Australian jurisdictions at present.

The FDMS calculates the total PM mass concentration based upon independent measurements of the non-volatile and volatile components. The air that is drawn into the analyser passes through a drier to remove water, before entering the sensor unit where the PM is collected and weighed on a filter held at 30°C (compared with the TEOM, which operates at 50°C). The analyser samples in this 'base cycle' mode (measuring non-volatile particles) for six minutes, during which time there will be loss of volatile particles. The sample flow is then switched so that it passes through a chamber cooled to 4°C, and then through a filter³⁷ which removes all the PM in the airstream. This cooled, scrubbed air is then returned to the sensor unit, where it is sampled normally. This 'reference' or 'purge' cycle (which also runs for six minutes) provides an estimate of the volatile PM component that is being lost, which can then be added to the base component to give an overall PM mass concentration.

The loss of volatile particles occurs relatively slowly, and so the loss during a particular cycle will include volatile material collected during previous cycles. This is apparent as a time shift of a few hours in the purge concentration. This can affect the interpretation of PM changes happening over a timescale of a few hours, although daily average concentrations will not be significantly affected.

B.2.3 Beta-Attenuation Monitor (BAM)

The Beta-Attenuation Monitor can be used for continuous automatic measurement of PM₁₀ or PM_{2.5}. The instrument determines the extent to which PM absorbs beta particles emitted by a weak beta-source (typically ¹⁴C). Air is drawn at a constant flow rate through a section of paper tape, on which particles are collected. The tape is mechanically advanced past the sampling inlet, and the transmission of beta particles through the tape is measured at the beginning and at the end of the sampling period (one to 24 hours). The increase in the amount of PM collected on the tape causes a lower beta particle measurement. The difference between the two measurements is used to determine the PM concentration. BAMs are available with both heated and non-heated sample inlets, and this has implications for equivalence and adjustment.

A common example of this type of sampler is the Met One Instruments Model BAM-1020, which is designed for continuous operation at a fixed site. The instrument has a heated inlet, and when an internal sensor detects an inlet relative humidity content of more than 55%, the inlet heater will activate. Heat is applied to maintain the inlet

³⁶ In Western Australia, this adjustment has also historically (and incorrectly) been applied to the PM_{2.5} data as well as the PM₁₀ data.

³⁷ The purge filter can also provide a time-integrated particulate matter sample that can be used for subsequent chemical analysis.

temperature around 3-5°C above the ambient air temperature, thus preventing the condensation of water on the filter tape. Evidence from the UK shows that the BAM measures significantly higher PM₁₀ concentrations than the reference sampler or the TEOM³⁸ (AQEG, 2005).

B.2.4 Partisol

The Partisol is a non-reference gravimetric sampler that is used in some Australian jurisdictions. The Partisol 2025 system employs a sequential system of filters that enables several 24-hour period samples to be collected automatically. The Partisol has a lower sampling flow than the reference method, but requires the same pre- and post-exposure conditioning and weighing of filters (AQEG, 2012).

B.2.5 Optical monitors

Optical monitors are employed by some jurisdictions to assess the impacts of airborne particles on visibility. One type of optical instrument - the nephelometer - measures the scattering of an incident beam of light by airborne particles. Australian studies have shown that nephelometers (especially those with appropriate humidity control) provide good correlations with PM_{2.5} concentrations, as determined by gravimetric methods (Wendt & Walsh 2007). More advanced nephelometers also exist, including tri-band systems (which use three different wavelengths of light), giving even better correlations. There are also other types of optical instruments which use lasers to count particles and estimate their size – these instruments can provide useful information on PM₁₀, PM_{2.5} and PM₁, but they rely on assumptions about particle density and other characteristics. Co-location of optical instruments and gravimetric methods can allow ‘calibration’ of optical methods for many applications (AQEG, 2005).

B.3 EQUIVALENCE AND ADJUSTMENT

All of the alternative instruments give different results from the reference method to varying degrees under differing circumstances, and have many variants. Considerable emphasis is therefore placed on establishing equivalence between the alternative methods and the reference method (NEPC, 2011a).

Various equivalence programs have been undertaken in the United States and Europe, involving an assessment of the accuracy and precision of each type of instrument. For example, in the United States the comparability of alternative particle monitoring methods is measured relative to the reference method using high-volume samplers, and a set of criteria is prescribed for determining equivalence. The USEPA also publishes a list of designated reference and equivalent methods³⁹ for PM₁₀ and PM_{2.5}. The TEOM 1400A/B is a United States equivalent method for PM₁₀, but not for PM_{2.5}. The Partisol 2025 and the Met One BAM-1020 are equivalent methods for both PM₁₀ and PM_{2.5}.

In the UK Defra carried out extensive equivalence trials between 2004 and 2006. These trials found that measurements made using Partisol, FDMS and BAM instruments were shown to be equivalent to the PM₁₀ reference method. However, correction factors needed to be applied to measurements from the BAM. The TEOM was demonstrated as not being equivalent to the reference method due to the loss of volatile PM. A so-called Volatile Correction Model (VCM) was developed to allow measurements of PM₁₀ from TEOM instruments to be converted to reference equivalent; it uses the measurements of volatile PM made using nearby FDMS instruments to correct the measurements made by the TEOM. It passed the equivalence testing and became the recommended method for correcting TEOM measurements (Defra 2009). The VCM does not appear to have been tested in Australia.

B.4 IMPLICATIONS FOR AUSTRALIA

In the UK, AQEG (2012) recently challenged the robustness of the evidence for making future policy decisions concerning PM_{2.5}. Policy decisions rely upon the ability to measure PM_{2.5} in an accurate, reproducible and reliable way, with the establishment of long-term and consistent records. Currently there are significant

³⁸ This includes the 1.3 correction factor that was used in the UK prior to the widespread adoption of the FDMS.

³⁹ <http://www.epa.gov/ttnamti1/files/ambient/criteria/reference-equivalent-methods-list.pdf>

challenges associated with the reliable and reproducible measurement of PM_{2.5} and measurement methods are still evolving. In Europe the reference method is currently being revised. The measurement uncertainty is currently at the limit of being meaningful for interpretation by models and vice versa. A similar situation exists in Australia, and measurement issues will be even more important because of the lower PM concentrations involved. There is currently some inconsistency in the ways in which PM₁₀ and PM_{2.5} are measured in the different jurisdictions. This needs to be addressed, and a more consistent national approach to monitoring should be developed. Consideration should be given to developments in other countries. For example, in the UK there has been a large-scale switch from TEOM analysers to FDMS analysers, and the UK experience could valuably inform the Australian approach. In the UK the long-term reliability of the FDMS instrument has not yet been determined. The costs of establishing a consistent national monitoring network should be determined.

The model of exposure reduction has been based upon the assumption that no safe lower concentration threshold exists for particulate matter, and any reduction in concentration would lead to public health benefits. This model has understandably been designed in the context of reducing ambient concentrations in densely populated urban areas. However, there is a threshold below which data become unreliable for use in a policy setting framework because effects cannot be clearly distinguished.

Another critical requirement identified by AQEG, and one which again applies to Australia, concerns the availability and quality of chemically-speciated PM measurements. These are essential to the development of effective mitigation policy via source apportionment, as they allow the delineation of source–receptor relationships. Speciated measurements could also be used in epidemiological studies to strengthen the knowledge of health impacts.

Appendix C ENHEALTHRECOMMENDATIONS

Mr Barry Buffier
Chair
Air Thematic Oversight Group
COAG Standing Committee on Environment and Water
GPO Box 787
Canberra ACT 260

Dear Mr Buffier

Thank you for the opportunity to provide comment on the particulate matter (PM) standards to be considered in the Information Report to Enable the National Environment Protection Council Decision on Whether to Vary the Ambient Air Quality NEPM Particle Standards. The Environmental Health Standing Committee of the Australian Health Protection Principal Committee (enHealth) understands some of the key proposals under consideration to be:

- The 24hr average and annual average PM_{2.5} advisory reporting standards should become compliance standards
- The compliance standard for 24hr average PM₁₀ concentration should remain unchanged at 50µg/m³, with consideration given to reducing it to 40µg/m³
- The *status quo* (no standard) should be maintained for annual average PM₁₀ concentration, with consideration given to the introduction of a compliance standard of 20µg/m³.

Since the introduction of the Air NEPM in 1998, there have been significant advancements in our understanding of the health effects of exposure to ambient PM. A recent report by the World Health Organization (WHO), *Review of evidence on health aspects of air pollution – REVIHAAP Project*, provides a succinct account of these advancements. Particularly relevant to the Australian standard setting process are:

1. The substantial body of evidence that now exists to support the conclusions that long-term and short-term exposure to PM_{2.5} are:
 - a. causally associated with mortality and cardiovascular disease
 - b. likely to be causally associated with respiratory disease.
2. Increasing evidence that short-term exposure to coarse particles (PM_{10-2.5}) has adverse health effects.
3. Some evidence, albeit weaker, that long-term exposure to PM₁₀ is independently associated with adverse health effects.

4. Increasing evidence that long-term and short-term exposure to PM at levels below current standards is associated with adverse health effects. In fact, a recent Canadian study provides evidence of an association between long-term exposure to PM_{2.5} and mortality at levels below those generally experienced in Australia.
5. Empirical evidence that reductions in ambient PM_{2.5} concentrations are associated with an increase in life-expectancy

Given the clear evidence that long-term and short-term exposure to PM_{2.5} causes adverse health effects, enHealth strongly supports the proposal to introduce compliance standards for annual average and 24hr average PM_{2.5} concentrations. In light of the increasing evidence that short-term exposure to PM₁₀ is independently associated with health effects, enHealth also supports a 24hr compliance standard for PM₁₀.

While there is less certainty around the independent health effects of long-term exposure to PM₁₀, enHealth considers that introduction of a long-term PM₁₀ standard is prudent, given a) the increasing evidence in this area, b) the uncertainty that all health effects would be eliminated by controlling PM_{2.5} only, and c) the somewhat limited coverage of the PM_{2.5} monitoring network in Australia.

In regard to the numerical values of the proposed standards, as discussed above, there is new evidence that health effects occur at levels of exposure currently experienced in Australia. Indeed, there is evidence that health improvements will be achieved by reducing exposure below these levels. It is clear, therefore, that no standard could be completely protective of health. Because of this, it is enHealth's position that the numeric values should be set as low as reasonably achievable, taking into account social and economic factors. It is noted that the *Economic Analysis to Inform the National Plan for Clean Air (Particles)* concludes that the following:

| Standard | Numeric value (µg/m ³) | Net economic benefit | Achievable |
|----------------------------------|------------------------------------|----------------------|------------|
| Annual average PM _{2.5} | 8 | Yes | Yes |
| 24hr average PM _{2.5} | 25 | Yes | Possible |
| Annual average PM ₁₀ | 20 | Yes | Yes |
| 24hr average PM ₁₀ | 40 | Yes | Yes |

Based on this, enHealth recommends that these values are used for updating the Ambient Air Quality NEPM Particle Standards.

enHealth notes that Review of the Ambient Air Quality NEPM recommends the introduction of an exposure reduction framework for priority pollutants. Given that no threshold has been identified below which exposure to PM is not associated with health effects, enHealth supports in principle the introduction an exposure reduction framework for particles.

Should you require any further information, please contact Professor Wayne Smith, Director of Environmental Health Branch, Health Protection NSW on (02) 9424 5925

Yours sincerely

A handwritten signature in blue ink, appearing to read 'Jim Dodds', with a large loop on the left and several smaller loops on the right.

Mr Jim Dodds

4 October 2013

Appendix D PM₁₀ AND PM_{2.5} MONITORING SITES IN AUSTRALIA

The monitoring stations included in the analysis were those for which data were supplied by the jurisdictions. The sites are summarised in **Tables D.1 to D.8**. It should be noted that a range of site types were included in the datasets, and not all of these sites were designed for AAQ NEPM compliance. Nevertheless, most of the sites included were representative of urban background exposure.

Trend stations represent long-term monitoring trends, and are located at a nominated site for at least a decade. Trend sites are generally representative of regional population exposure and generally approximate the GRUB definition⁴⁰. Performance stations are located at a site for at least five years and used to evaluate air quality against the AAQ NEPM. Campaign monitoring is conducted to determine whether longer-term monitoring is necessary elsewhere. Monitoring is conducted at various types of site, although the majority of sites are in residential areas of cities and towns.

There are currently more sites measuring PM₁₀ than PM_{2.5}. The monitoring stations operated by NSW EPA predominantly use TEOMs to measure PM₁₀ and PM_{2.5}, with a small number of BAMs for PM_{2.5} near mines. In addition, the Australian Nuclear Science and Technology Organisation (ANSTO) measures PM_{2.5} (with compositional analysis) using a gravimetric filter method at seven sites in NSW. Monthly data from these sites for the years 2005–2011 were obtained from the ANSTO web site⁴¹. The PM₁₀ monitoring by EPA Victoria is mostly undertaken using TEOMs; gravimetric filter measurements – high-volume air samplers (HVASs) are also deployed at two locations. Monitoring of PM_{2.5} is only conducted at Alphington and Footscray, using a combination of low-volume samplers (Partisol) and nephelometers to provide a continuous dataset. In Queensland, measurements have historically been made using TEOMs, but in 2009 several sites were upgraded and now use FDMS analysers. South Australia and Western Australia use TEOMs to measure PM₁₀ and PM_{2.5}. Routine measurements of PM_{2.5} are only made at one site in South Australia. At the sites in Tasmania, PM is measured using a gravimetric filter method (typically low-volume samplers), with TEOMs being used at some locations.

⁴⁰ www.environment.nsw.gov.au/air/nepm/summary.htm

⁴¹ www.ansto.gov.au/Resources/Localenvironment/Atmosphericmonitoring/Fineparticlepollution/index.htm

Table D.1: NSW monitoring sites (shaded cells = sites not included in state-average calculations and less than 8 years of data)

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|---------------|--------------|-------------------------|-------------------|------|------------------|-------------------|---------------|
| NSW_E01 | NSW EPA | Bargo | Sydney | Residential, rural | | | ✓ | ✗ | TEOM |
| NSW_E02 | NSW EPA | Blacktown | Sydney | Residential, urban | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E03 | NSW EPA | Bringelly | Sydney | Residential, semi-rural | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E06 | NSW EPA | Chullora | Sydney | Residential/commercial | Trend | Yes | ✓ | ✓ | TEOM/BAM |
| NSW_E07 | NSW EPA | Earlwood | Sydney | Residential | Campaign | Yes | ✓ | ✓ | TEOM/BAM |
| NSW_E08 | NSW EPA | Lindfield | Sydney | Residential | | | ✓ | ✗ | TEOM |
| NSW_E09 | NSW EPA | Liverpool | Sydney | Residential/commercial | Campaign | Yes | ✓ | ✓ | TEOM/BAM |
| NSW_E10 | NSW EPA | Macarthur | Sydney | Residential, semi-rural | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E11 | NSW EPA | Oakdale | Sydney | Rural | Performance | Yes | ✓ | ✗ | TEOM |
| NSW_E12 | NSW EPA | Prospect | Sydney | Residential | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E13 | NSW EPA | Randwick | Sydney | Residential | | | ✓ | ✗ | TEOM |
| NSW_E14 | NSW EPA | Richmond | Sydney | Residential | Trend | Yes | ✓ | ✓ | TEOM/BAM |
| NSW_E15 | NSW EPA | Rozelle | Sydney | Residential | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E16 | NSW EPA | St Marys | Sydney | Semi-rural | | Yes | ✓ | ✗ | TEOM |
| NSW_E17 | NSW EPA | Vineyard | Sydney | Residential, semi-rural | | Yes | ✓ | ✗ | TEOM |
| NSW_E18 | NSW EPA | Westmead | Sydney | Residential, urban | | | ✓ | ✓ | TEOM |
| NSW_E19 | NSW EPA | Woolooware | Sydney | Residential | | | ✓ | ✓ | TEOM |
| NSW_E20 | NSW EPA | Beresfield | Lower Hunter | Residential, semi-rural | Campaign | Yes | ✓ | ✓ | TEOM |
| NSW_E21 | NSW EPA | Newcastle | Lower Hunter | CBD | Trend | Yes | ✓ | ✗ | TEOM |
| NSW_E22 | NSW EPA | Wallsend | Lower Hunter | Residential | | Yes | ✓ | ✓ | TEOM |
| NSW_E23 | NSW EPA | Aberdeen | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E24 | NSW EPA | Bulga | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E25 | NSW EPA | Camberwell | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✓ | TEOM/BAM |
| NSW_E26 | NSW EPA | Jerrys Plains | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E27 | NSW EPA | Maison Dieu | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E28 | NSW EPA | Merriwa | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|-------------------|--------------|------------------------|--------------------------|------|------------------|-------------------|---------------|
| NSW_E29 | NSW EPA | Mt Thorley | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E30 | NSW EPA | Muswellbrook | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✓ | TEOM/BAM |
| NSW_E31 | NSW EPA | Muswellbrook NW | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E32 | NSW EPA | Singleton | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✓ | TEOM/BAM |
| NSW_E33 | NSW EPA | Singleton NW | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E34 | NSW EPA | Singleton South | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E35 | NSW EPA | Warkworth | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E36 | NSW EPA | Wybong | Upper Hunter | Rural – coal mining | Campaign – UHAQMN | | ✓ | ✗ | TEOM |
| NSW_E37 | NSW EPA | Albion Park | Illawarra | Semi-rural | Performance | Yes | ✓ | ✗ | TEOM |
| NSW_E38 | NSW EPA | Albion Park South | Illawarra | Semi-rural | Performance | Yes | ✓ | ✗ | TEOM |
| NSW_E39 | NSW EPA | Kembla Grange | Illawarra | Residential | Performance | Yes | ✓ | ✗ | TEOM |
| NSW_E40 | NSW EPA | Warrawong | Illawarra | Residential/industrial | | | ✓ | ✓ | TEOM |
| NSW_E41 | NSW EPA | Wollongong | Illawarra | CBD | Trend | Yes | ✓ | ✓ | TEOM/BAM |
| NSW_E42 | NSW EPA | Albury | Regional NSW | Rural | Campaign – Pop. exposure | | ✓ | ✗ | TEOM |
| NSW_E43 | NSW EPA | Bathurst | Regional NSW | Rural | Campaign – Pop. Exposure | | ✓ | ✗ | TEOM |
| NSW_E46 | NSW EPA | Tamworth | Regional NSW | Rural | Campaign – Pop. Exposure | | ✓ | ✗ | TEOM |
| NSW_E47 | NSW EPA | Wagga Wagga | Regional NSW | Rural | | | ✓ | ✓ | TEOM |
| NSW_E48 | NSW EPA | Wagga Wagga N | Regional NSW | Rural | Campaign – Pop. exposure | | ✓ | ✗ | TEOM/BAM |
| NSW_A01 | ANSTO | Liverpool | Sydney | Urban/industrial | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A02 | ANSTO | Lucas Heights | Sydney | Rural | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A03 | ANSTO | Mascot | Sydney | Urban | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A04 | ANSTO | Mayfield | Lower Hunter | Urban | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A05 | ANSTO | Muswellbrook | Upper Hunter | Urban periphery | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A06 | ANSTO | Richmond | Sydney | Mixed urban/rural | Campaign – Research | | ✗ | ✓ | Grav. filter |
| NSW_A07 | ANSTO | Warrawong | Illawarra | Urban/industrial | Campaign – Research | | ✗ | ✓ | Grav. filter |

Table D.2: VIC monitoring sites (shaded cells = sites not included in state-average calculations and less than 8 years of data)

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|---------------|----------------|--------------------------------------|---------------------------|------|------------------|-------------------|--|
| VIC_E01 | EPA Victoria | Alphington | Port Phillip | Inner suburb, residential | Trend | Yes | ✓ | ✓ | Gravimetric reference method/Partisol/TEOM |
| VIC_E03 | EPA Victoria | Box Hill | Port Phillip | Inner suburb, residential | Trend | | ✓ | ✗ | TEOM |
| VIC_E04 | EPA Victoria | Brighton | Port Phillip | Inner suburb, residential | Performance: pop. average | | ✓ | ✗ | TEOM |
| VIC_E06 | EPA Victoria | Dandenong | Port Phillip | Outer suburb, industrial/residential | Performance: pop. average | | ✓ | ✗ | TEOM |
| VIC_E07 | EPA Victoria | Deer Park | Port Phillip | Outer suburb, residential | Trend | | ✓ | ✗ | TEOM |
| VIC_E08 | EPA Victoria | Footscray | Port Phillip | Inner suburb, industrial/residential | Trend | Yes | ✓ | ✓ | Gravimetric reference method/Partisol/TEOM |
| VIC_E09 | EPA Victoria | Geelong South | Port Phillip | Suburb, residential | Trend | Yes | ✓ | ✗ | Gravimetric reference method/TEOM |
| VIC_E10 | EPA Victoria | Mooroolbark | Port Phillip | Outer suburb, residential | Performance: pop. average | | ✓ | ✗ | TEOM |
| VIC_E12 | EPA Victoria | Richmond | Port Phillip | Inner suburb, residential | Performance | Yes | ✓ | ✗ | Gravimetric reference method/TEOM |
| VIC_E13 | EPA Victoria | RMIT | Port Phillip | CBD (elevated: 3rd floor) | Trend | Yes | ✓ | ✗ | Gravimetric reference method/TEOM |
| VIC_E14 | EPA Victoria | Moe | Latrobe Valley | Residential near power station | Performance | Yes | ✓ | ✗ | TEOM |
| VIC_E15 | EPA Victoria | Traralgon | Latrobe Valley | Residential near power station | Trend | Yes | ✓ | ✗ | TEOM |

Table D.3: QLD monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|-----------------|--------|--|-------------|------|------------------|-------------------|---|
| QLD_D02 | DSITIA | Brisbane CBD | SEQ | CBD | | | ✓ | ✗ | TEOM |
| QLD_D05 | DSITIA | Flinders View | SEQ | Industry/residential, major roads, industry (coal fired power station) | Trend | Yes | ✓ | ✗ | TEOM |
| QLD_D07 | DSITIA | Mountain Creek | SEQ | Residential, major roads, forestry/agriculture and burning | Performance | Yes | ✓ | ✗ | TEOM |
| QLD_D08 | DSITIA | North Toowoomba | SEQ | Commercial/residential, major roads, solid fuel heaters | Campaign | Yes | ✓ | ✓ | TEOM |
| QLD_D09 | DSITIA | Pinkenba | SEQ | Industrial, BP refineries | | | ✓ | ✗ | Gravimetric reference method/TEOM |
| QLD_D10 | DSITIA | Rocklea | SEQ | Light industrial/residential, major roads | Trend | Yes | ✓ | ✓ | Gravimetric reference method/Partisol/TEOM/FDMS |

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|---------------|----------------------|------------|---|---------------------------------|------|------------------|-------------------|--|
| QLD_D11 | DSITIA | South Brisbane | SEQ | Roadside | | | ✓ | ✓ | TEOM/FDMS |
| QLD_D12 | DSITIA | Springwood | SEQ | Residential, major roads | Performance: population average | | ✓ | ✓ | Gravimetric reference method/Partisol/TEOM |
| QLD_D14 | DSITIA | Woolloongabba | SEQ | Roadside | Trend-peak | | ✓ | ✓ | Gravimetric reference method/TEOM/FDMS |
| QLD_D15 | DSITIA/Caltex | Wynnum N | SEQ | Industry/residential, Caltex refineries | | | ✓ | ✓ | TEOM |
| QLD_D16 | DSITIA | The Gap | Mt Isa | Residential | Population average | | ✓ | ✗ | TEOM |
| QLD_D20 | DSITIA | Pimlico | Townsville | Residential, major roads, industry (port operations, metals processing) | Campaign: population average | | ✓ | ✗ | TEOM |
| QLD_D22 | DSITIA | West Mackay | Mackay | Light industry/residential, agricultural burning | | Yes | ✓ | ✗ | TEOM |
| QLD_D26 | DSITIA | South Gladstone | Gladstone | Industry/residential, major roads, industry (power generation, metals processing) | Trend | Yes | ✓ | ✓ | TEOM/FDMS |
| QLD_D27 | DSITIA | Clinton | Gladstone | Airport/residential | | | ✓ | ✓ | Gravimetric reference method/TEOM/FDMS |
| QLD_D28 | DSITIA | Targinie (Swans Rd) | Gladstone | Rural/residential | | | ✓ | ✓ | FDMS |
| QLD_D29 | DSITIA | Targinie (Stupkin L) | Gladstone | Rural/residential | | | ✓ | ✗ | TEOM |
| QLD_D30 | DSITIA | Boat Creek | Gladstone | Rural/residential | | | ✓ | ✓ | FDMS |
| QLD_D31 | DSITIA | Boyne Island | Gladstone | Residential | | | ✓ | ✓ | FDMS |

Table D.4: SA monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|----------------------------|----------|--|-------------|------|------------------|-------------------|---------------|
| SA_E01 | EPA SA | Birkenhead | Adelaide | Residential/light industrial | | | ✓ | ✗ | TEOM |
| SA_E02 | EPA SA | Christie Downs | Adelaide | Residential, urban | Trend | Yes | ✓ | ✗ | TEOM |
| SA_E03 | EPA SA | Elizabeth Downs | Adelaide | Residential, urban | Performance | Yes | ✓ | ✗ | TEOM |
| SA_E04 | EPA SA | Kensington Gardens | Adelaide | Residential, urban | Trend | Yes | ✓ | ✗ | TEOM |
| SA_E05 | EPA SA | Netley | Adelaide | Residential/light industrial area, traffic | Trend | Yes | ✓ | ✓ | TEOM |
| SA_E06 | EPA SA | Pt Pirie, Frank Green Park | Spencer | Residential/industrial | Trend | Yes | ✓ | ✗ | TEOM |
| SA_E07 | EPA SA | Pt Pirie, Oliver Street | Spencer | Residential/industrial | Trend | Yes | ✓ | ✗ | TEOM |
| SA_E09 | EPA SA | Whyalla, Schulz Park | Spencer | Residential/industrial | Trend | Yes | ✓ | ✗ | TEOM |
| SA_E10 | EPA SA | Whyalla, Walls St | Spencer | Industrial (steelworks) | | | ✓ | ✗ | TEOM |

Table D.5: WA monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|--------------------|-----------|--------------------------------|------------------------------|------|------------------|-------------------|---------------|
| WA_D01 | DER | Perth: Caversham | Perth | Metropolitan area | Performance | Yes | ✓ | ✓ | TEOM |
| WA_D02 | DER | Perth: Duncraig | Perth | Metropolitan area | Trend | Yes | ✓ | ✓ | TEOM |
| WA_D03 | DER | Perth: Quinns Rock | Perth | Metropolitan area | Trend | Yes | ✗ | ✓ | TEOM |
| WA_D04 | DER | Perth: South Lake | Perth | Residential, metropolitan area | Performance | Yes | ✓ | ✓ | TEOM |
| WA_D05 | DER | Albany | Albany | Regional area | Campaign: pop. average | | ✓ | ✗ | TEOM |
| WA_D06 | DER | Bunbury | Bunbury | Regional area | Campaign/trend: pop. average | | ✓ | ✓ | TEOM |
| WA_D07 | DER | Busselton | Busselton | Regional area | Trend: population average | | ✗ | ✓ | TEOM |
| WA_D08 | DER | Collie | Collie | Regional area | DER | | ✓ | ✗ | TEOM |
| WA_D09 | DER | Geraldton | Geraldton | Regional area | Campaign | | ✓ | ✗ | TEOM |

Table D.6: TAS monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|--------------|--------------|-------------|------------------|--------------------|------|------------------|-------------------|-------------------|
| TAS_E01 | EPA | Ti Tree Bend | Launceston | Light Industry | Trend | Yes | ✓ | ✓ | Grav. filter/TEOM |
| TAS_E02 | EPA | New Town | Hobart | Residential | Trend | Yes | ✓ | ✓ | Grav. filter/TEOM |
| TAS_E03 | EPA | George Town | George Town | Industry | | | ✓ | ✓ | Grav. filter |
| TAS_A01 | ANSTO | Cape Grim | Cape Grim | Rural | Campaign: research | No | ✗ | ✓ | Grav. filter |

Table D.7: NT monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|---------------------|------------|--------|------------------------------|---------------------------------|------|------------------|-------------------|---------------|
| NT_E01 | Charles Darwin Uni. | Casuarina | Darwin | Residential/light industrial | Performance: population average | | ✓ | ✓ | Partisol/TEOM |
| NT_E02 | NT Government | Palmerston | Darwin | | Population average | | ✓ | ✓ | TEOM |

Table D.8: ACT monitoring sites

| Site code | Organisation | Site name | Region | Site description | Purpose | GRUB | PM ₁₀ | PM _{2.5} | Instrument(s) |
|-----------|----------------|-----------|----------|------------------|-------------|------|------------------|-------------------|----------------------------------|
| ACT_E01 | ACT Government | Civic | Canberra | CBD | Performance | Yes | ✓ | ✘ | Gravimetric reference method/BAM |
| ACT_E02 | ACT Government | Monash | Canberra | Residential | Performance | Yes | ✓ | ✓ | Partisol/TEOM/BAM |

Appendix E ANALYSIS OF PM₁₀ AND PM_{2.5} MONITORING DATA

E.1 DATA COLLECTION

This analysis focuses primarily on the measurements from state government monitoring sites, although it is recognised that some other datasets are available (such as from NSW Roads and Maritime Services, and from coal mine sites). Some comments on the data are made in relation to the current AAQ NEPM standards.

Monitoring data were obtained from the state authorities as 24-hour average concentrations between 2003 and 2012 inclusive. The data were used in the form provided by the jurisdictions without adjustment. The only exceptions to this were the following:

removal of the data for the extreme dust storm that affected NSW and Queensland on 23 September 2009, as the inclusion of the very high concentrations on this day would have resulted in an inaccurate picture of underlying trends

removal of the internal manufacturer's correction in the TEOM PM_{2.5} data for WA (see **Section B2.1**).

For each monitoring site, the annual mean concentration of PM₁₀ and/or PM_{2.5} was determined for the years with sufficient data. A year was taken to have sufficient data for a given year where the data capture rate was greater than 75%⁴².

The following aspects were considered in this part of the analysis: inter-

annual trends, based on annual average concentrations

seasonal patterns, based on monthly average concentrations over several years

daily patterns, based on average concentrations for each day of the week over several years

geographical variations

exceedances of air quality standards.

Clearly PM concentrations are affected by meteorology, site type, location, etc. For example, a site might be 'industrial', 'residential', 'roadside', etc. All these factors have implications in terms of the measured concentrations; however, a more detailed analysis to take them into account would require a large amount of work and could not be included in this Impact Statement.

E.2 INTER-ANNUAL TRENDS

The trends in the annual mean PM₁₀ and PM_{2.5} concentrations at each monitoring site included in the analysis are shown in **Figure E.1** and **Figure E.2** respectively.

The overall mean concentration across all sites in a given state was then calculated. In NSW and Victoria there are several sites with long-term records of PM₁₀ and (in the case of NSW) PM_{2.5}. For these cases an extra criterion was applied in the data analysis: only sites with more than seven years of data between 2003 and 2012 were included in the calculation of the means.

The overall results for the annual mean PM₁₀ concentrations in each jurisdiction are shown in **Figure E.3**. The shading around the line in each graph represents the 95% confidence interval⁴³ around the mean, and the data for NT reflect a change from one site (Casuarina) to another (Palmerston). In most jurisdictions there has been a general reduction in the overall annual mean PM₁₀ concentrations between 2003 and 2012. The main exceptions are SA and WA, where concentrations have remained relatively steady, and NT, where concentrations have increased in recent years (although there are few monitoring sites in NT, and full data sets are not available for all

⁴² Clause 18 (5) of the AAQ NEPM specifies that the annual report for a pollutant must include the percentage of data available in the reporting period. An average concentration can be valid only if it is based on at least 75% of the expected samples in the averaging period. The 75% data availability criterion is specified as an absolute minimum requirement for data completeness (**PRC 2001b**).

⁴³ The confidence interval indicates the reliability of an estimate. A 95% confidence interval shows the range of values within which the real value can be said to fall with a 95% level of confidence. Given that the confidence level is based on the data, it does not take into account any systematic errors or bias in the sampling.

years). There is currently no annual mean standard for PM₁₀ in the AAQ NEPM against which these trends can be evaluated. In some jurisdictions there is a peak in 2009. This is associated with the unusually warm, dry weather during the year, and the occurrence of several major dust storms.

It should be noted that these trends can be affected significantly by changes in instrumentation at a site (e.g. one type of instrument can give results that are systematically lower or higher than another), the relocation of a monitoring site, or a change in the number/distribution of sites. Some caution is therefore needed when interpreting the trends. Nevertheless, it could be argued with some degree of confidence that the data for NSW and Victoria provide good indications of the underlying trend in PM₁₀, as the data are generally more consistent than in the other jurisdictions. Where there is no shading (as in the case of NT and ACT), it is because only one value (site) was available and therefore the confidence interval could not be calculated.

The trends for annual mean PM_{2.5} are shown in **Figure E.4**. The data for Tasmania exclude the ANSTO Cape Grim site. The general trends for PM_{2.5} were similar to those for PM₁₀. The data for Queensland can effectively be separated into two periods (2003–2008 and 2009–2012) on account of the introduction of several new monitoring sites in 2009 and the switch from TEOM to FDMS instruments at several sites. With the exception of NT, the overall average annual mean PM_{2.5} concentration in 2012 was below the advisory reporting standard of 8 µg/m³ in the AAQ NEPM. In WA the PM_{2.5} concentration appears to have stabilised at around 5 µg/m³, and in NT the concentration appears to be increasing (based on a limited data set).

The trends in the ratio of PM_{2.5} to PM₁₀, for the sites where these metrics were measured concurrently, are shown in **Figure E.5**. The ratio appears to be quite stable with time in most jurisdictions, but there are some differences in the value. For example, the ratio is higher in SA and Tasmania than in NSW, Victoria, Queensland and WA. It should be noted that different types of instrument were used to measure PM₁₀ and PM_{2.5} in the ACT, and the ratios cannot be considered to be very reliable.

For both PM₁₀ and PM_{2.5} in each jurisdiction, **Table E.1** shows the average annual change in concentration and the significance of the trend between 2003 and 2012 (or the shorter periods mentioned above for PM_{2.5} in Queensland). The Mann–Kendall nonparametric test was used to determine the significance of trends at the 95% confidence level. This showed that there was a significant downward trend in PM₁₀ concentrations in three jurisdictions: NSW (–0.45 µg/m³ per year), Tasmania (–0.65 µg/m³ per year) and the ACT (–0.56 µg/m³ per year). There were no significant trends in annual mean PM₁₀ concentrations in the other jurisdictions.

In the case of PM_{2.5} there was a significant downward trend in concentrations in NSW (–0.15 µg/m³ per year), Victoria (–0.20 µg/m³ per year), Queensland (2003–2008 period only; –0.21 µg/m³ per year), SA (–0.19 µg/m³ per year), and Tasmania (–0.55 µg/m³ per year). For the PM_{2.5}:PM₁₀ ratio, there was a significant downward trend in NSW and in Queensland (though only during 2003–2008 in the case of the latter). These trends may be due in part to the increase in coal mining activity (a source of coarse particles) during this period.

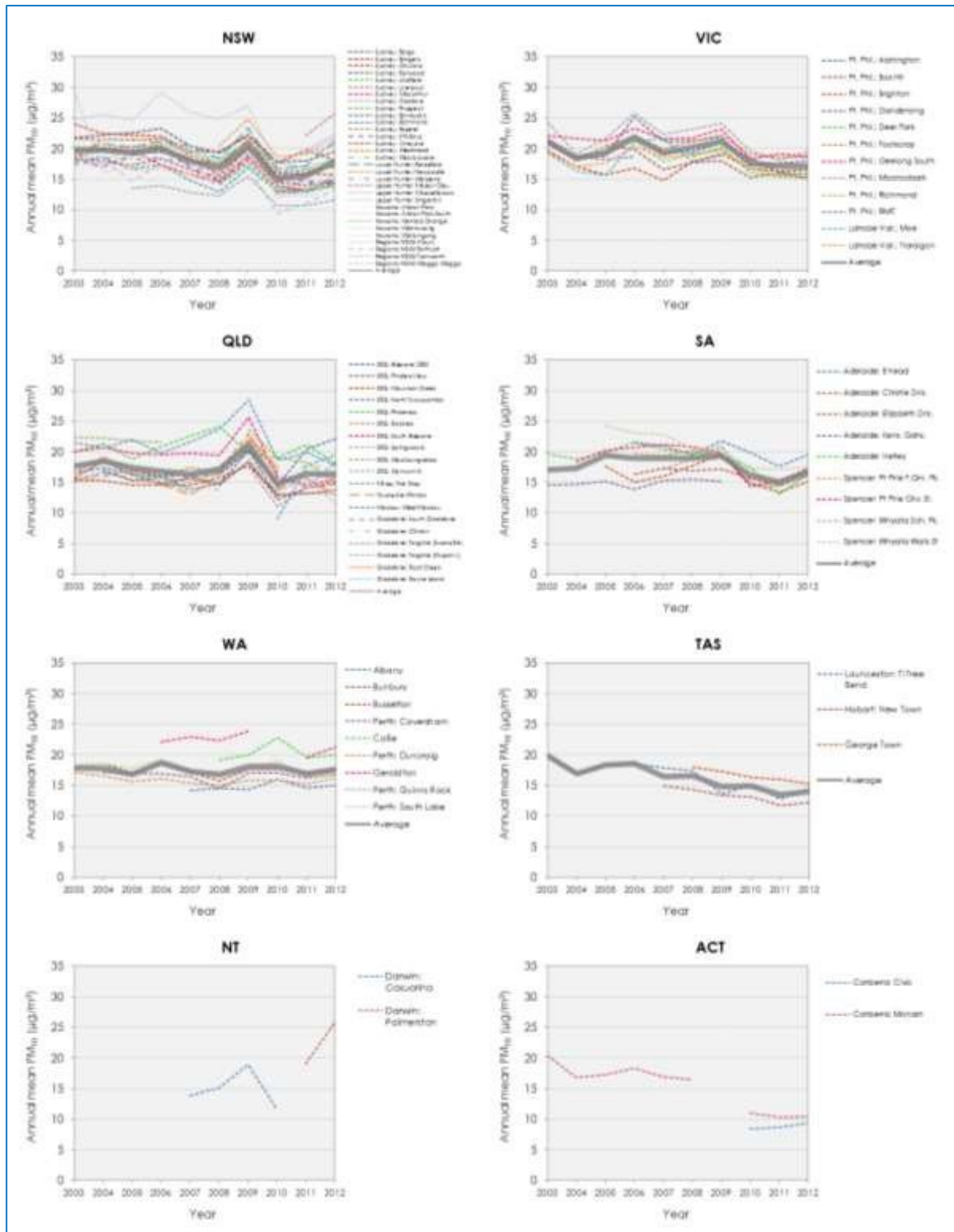


Figure E.1: Annual mean PM₁₀ concentrations by monitoring site

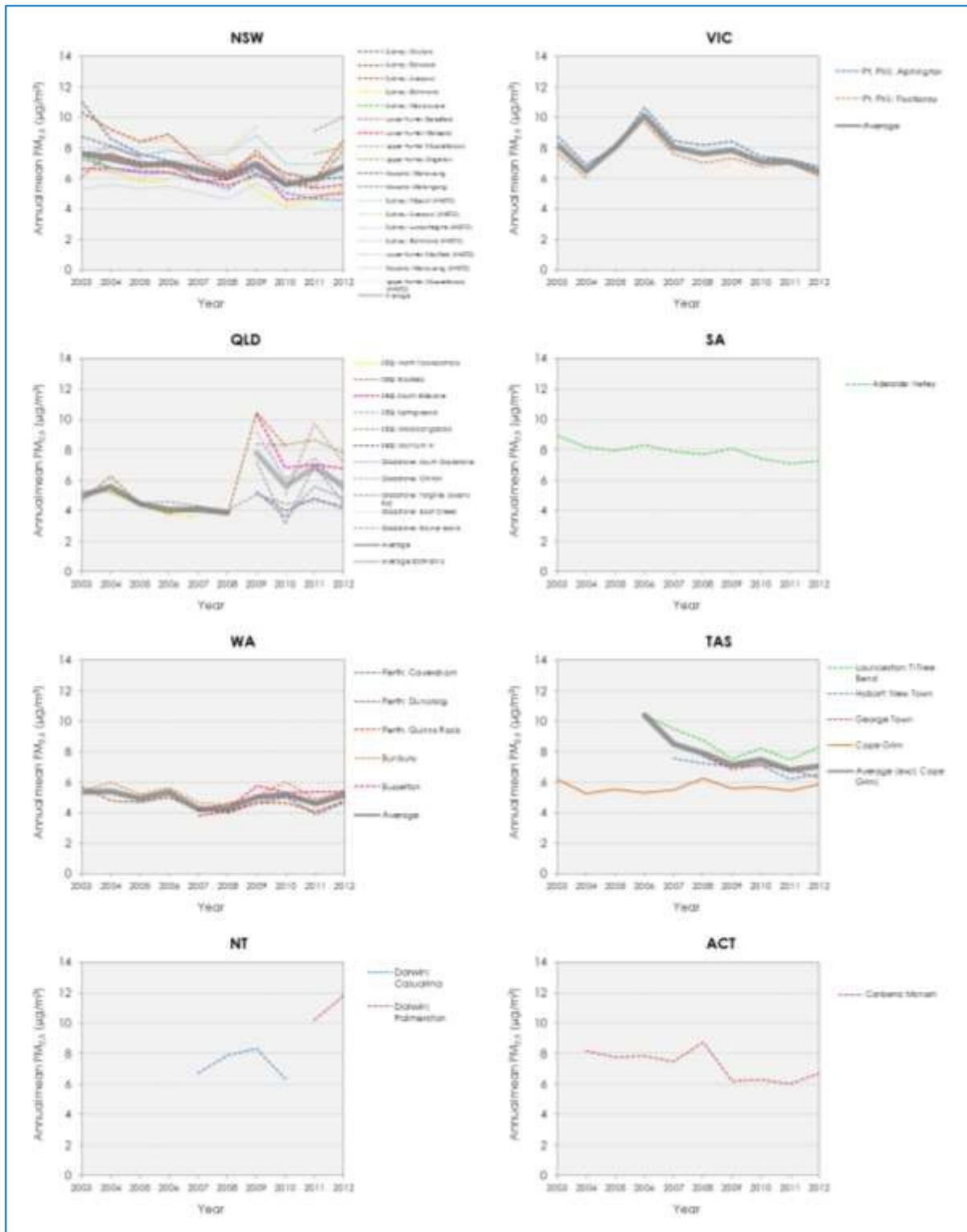


Figure E.2: Annual mean PM_{2.5} concentrations by monitoring site

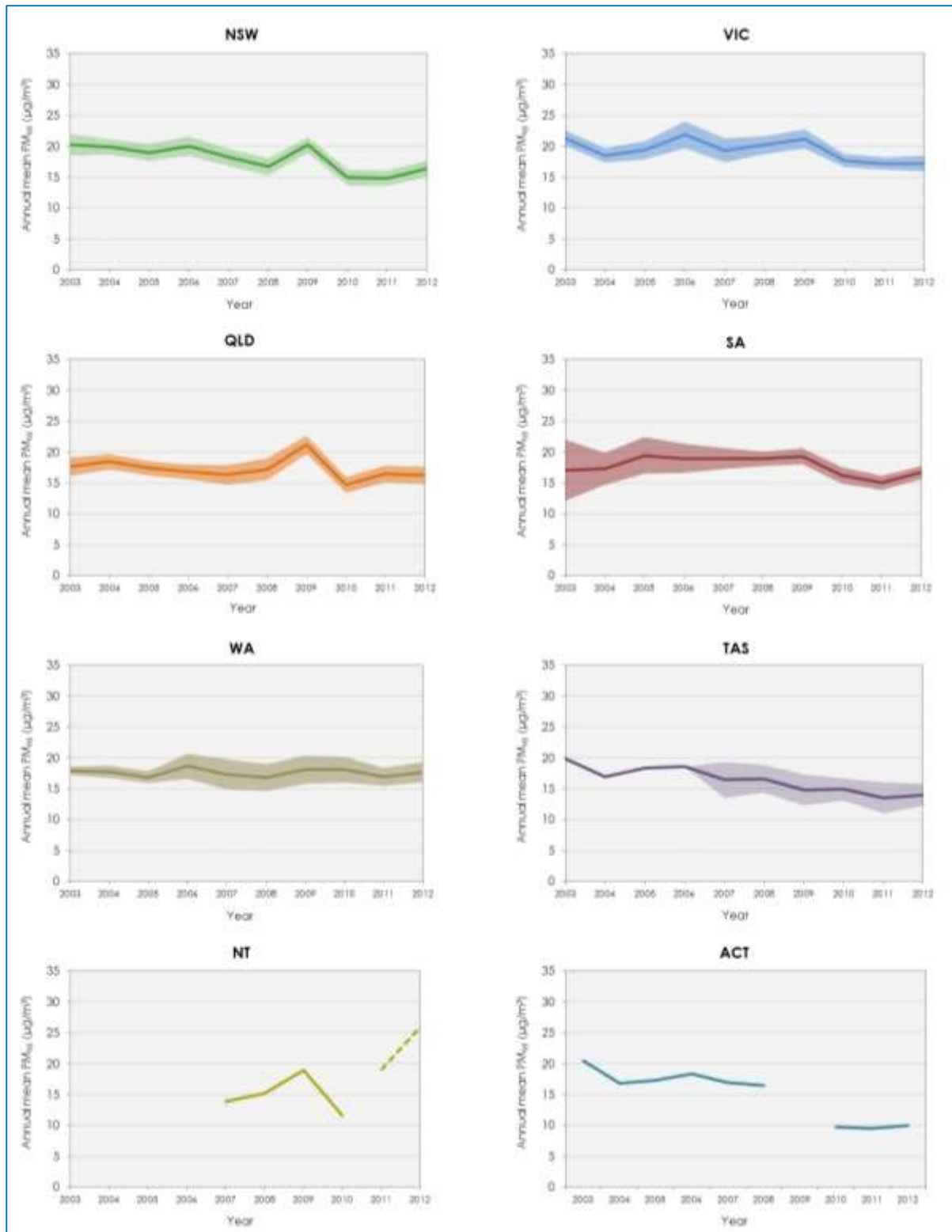


Figure E.3: Trend in annual mean PM₁₀ concentration by jurisdiction (shading shows 95% confidence interval; no shading indicates data were only available for one site)

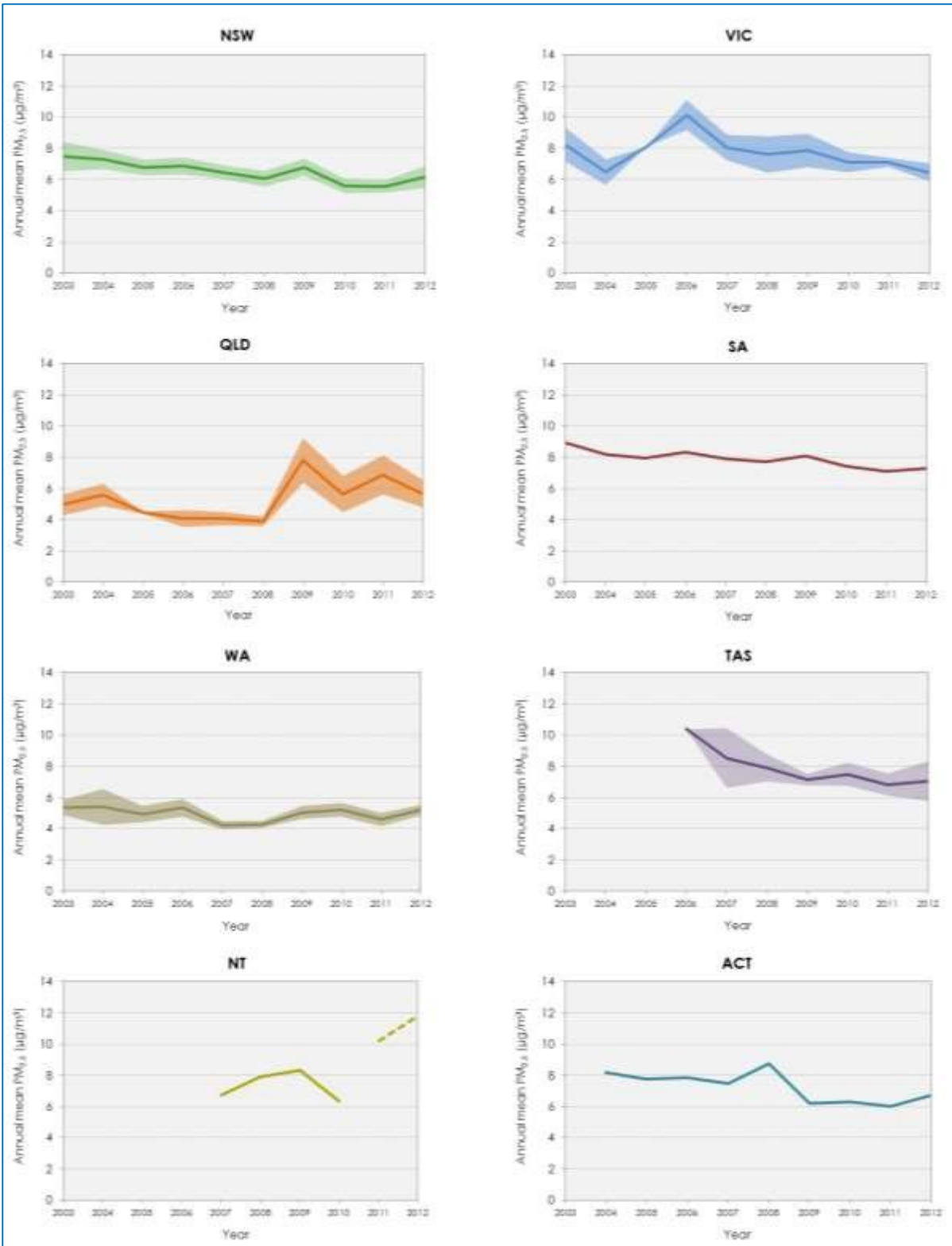


Figure E.4: Trend in annual mean PM_{2.5} concentration by jurisdiction (shading shows 95% confidence interval; no shading indicates data were only available for one site)

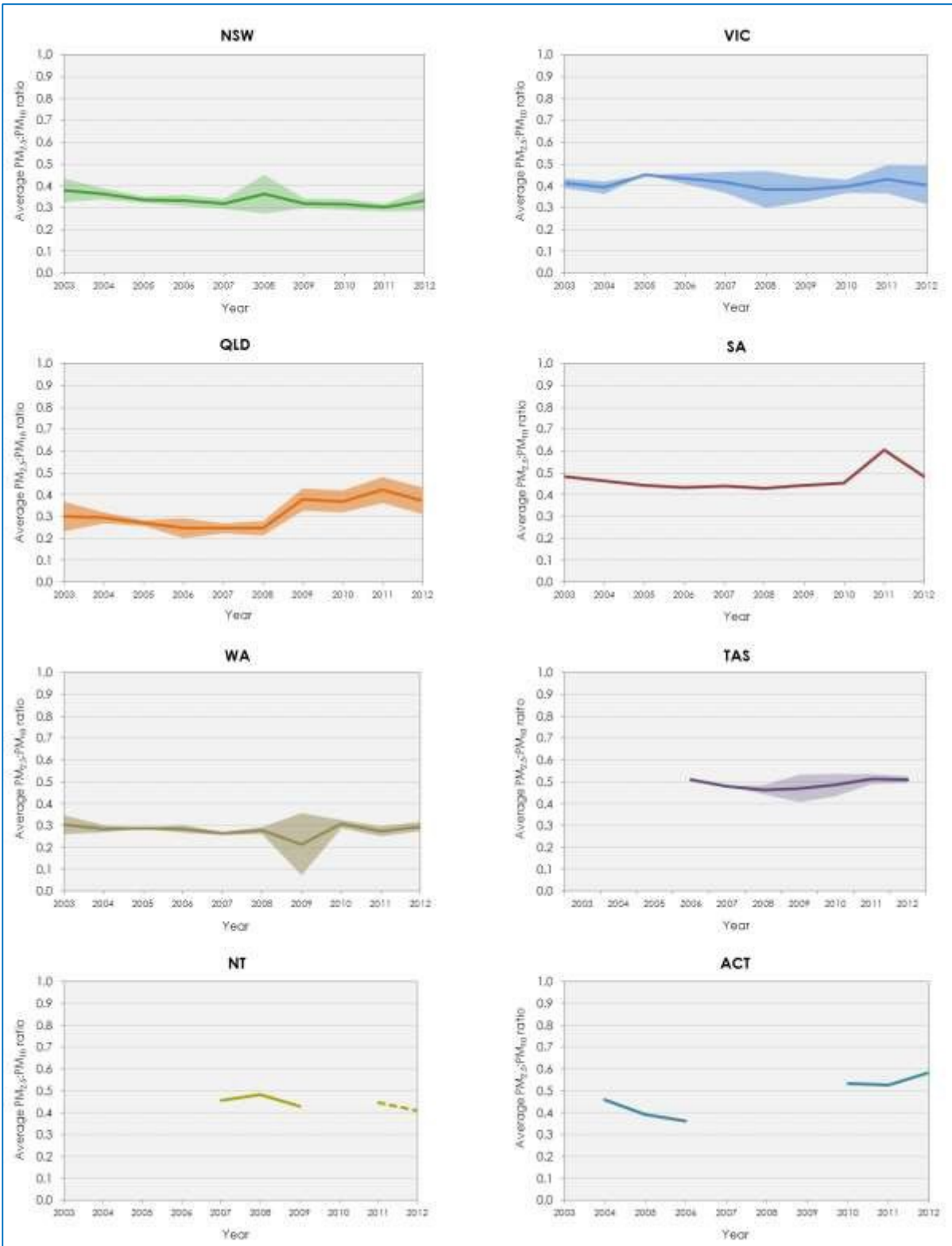


Figure E.5: Trend in annual mean PM_{2.5}:PM₁₀ ratio (shading shows 95% confidence interval; no shading indicates data were only available for one site)

Table E.1: Annual changes in concentration and significance of trends

| Jurisdiction | PM ₁₀ | | PM _{2.5} | | PM _{2.5} :PM ₁₀ ratio |
|-----------------|---|---|---|---|---|
| | Average annual change in concentration (µg/m ³ per year) | Significant trend at 95% confidence level | Average annual change in concentration (µg/m ³ per year) | Significant trend at 95% confidence level | Significant trend at 95% confidence level |
| NSW | -0.45 | Yes | -0.15 | Yes | Yes |
| VIC | -0.46 | No | -0.20 | Yes | No |
| QLD (2003–2008) | -0.16 | No | -0.21 | Yes | Yes |
| QLD (2009–2012) | | | -0.71 | No | No |
| SA | -0.05 | No | -0.19 | Yes | No |
| WA | -0.02 | No | -0.02 | No | No |
| TAS | -0.65 | Yes | -0.55 | Yes | No |
| NT | 2.40 | No | 1.02 | No | No |
| ACT | -0.56 | Yes | -0.19 | No | No |

E.3 SEASONAL PATTERNS

The seasonal (monthly average) PM₁₀ and PM_{2.5} concentrations at each monitoring site are presented in **Figure E.6** and **Figure E.7** respectively.

The average seasonal patterns in PM₁₀ in the jurisdictions are presented in **Figure E.8**. Broadly similar patterns were apparent in NSW, Victoria, South Australia and Western Australia. Concentrations are highest during the summer months. In summer, bush fires and dust storms associated with occasional extreme weather can lead to high levels of particle pollution (**SEC 2011**). Concentrations generally decreased from a high in January, reaching a minimum value during the winter months. The minimum concentration occurred in different months, being earlier in the winter (June) in NSW than in SA and WA (July), and Victoria (August). Concentrations then increased in the spring and summer. The monthly PM₁₀ profile for Queensland also shows a reduction between summer and autumn, but is unusual in that the peak concentration (for the whole year) occurs in September. In areas with a high dependence on solid fuel burning for domestic heating, the seasonal peak in particle levels usually occurs in winter (**SEC 2011**). This can be exacerbated where local topography leads to a layer of cold polluted air being trapped near the ground by an overlying layer of warmer air (a situation referred to as a temperature inversion). The retention of semi-volatile PM components will also play a role during winter. This wintertime peak is evident in the PM₁₀ data for Tasmania. The range of PM₁₀ concentrations during the year is highest for NT, where there is a strong peak in winter and spring. In the ACT the PM₁₀ concentrations are relatively stable throughout the year.

Figure E.9 shows the overall seasonal patterns for PM_{2.5}. There was no strong overall seasonal trend in NSW, SA and WA. In NSW some monitoring sites (notably those in the Upper Hunter Valley) had a wintertime peak, whereas others (e.g. in the Illawarra) had a summertime peak. In Sydney, where most of the monitoring sites are located, the monthly profile was similar to the overall average profile. In Victoria (only two sites in Melbourne monitor PM_{2.5}) the peak monthly average PM_{2.5} concentration occurs in the autumn, whereas in Queensland it occurs in the spring, as it does for PM₁₀. In Tasmania, NT and the ACT there is a strong wintertime peak in PM_{2.5}.

The monthly average PM_{2.5}:PM₁₀ ratios are shown in **Figure E.10**. In all jurisdictions there is a trend towards a maximum value for the ratio in winter and a minimum in summer.

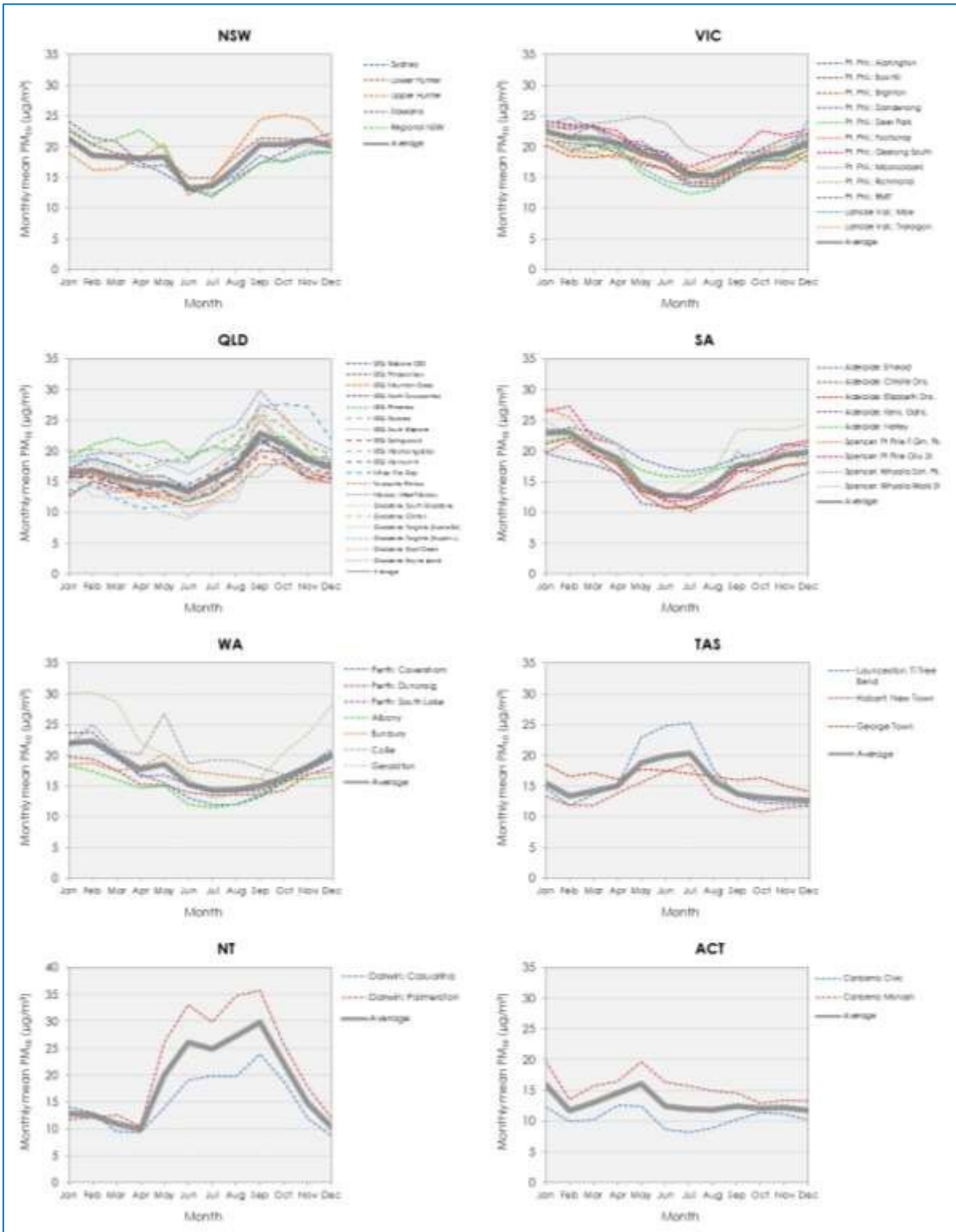


Figure E.6: Monthly mean PM₁₀ concentrations by monitoring site

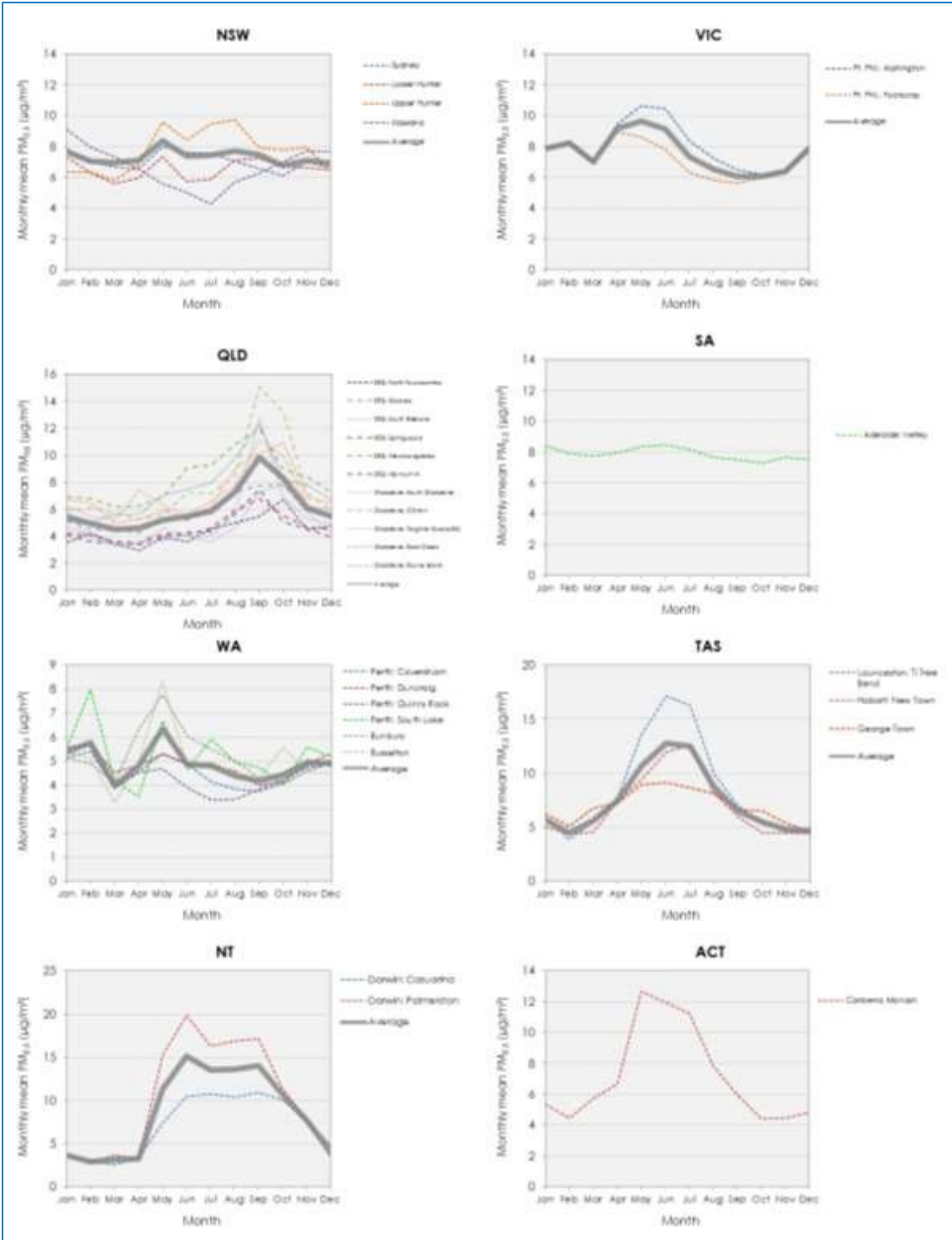


Figure E.7: Monthly mean $PM_{2.5}$ concentrations by monitoring site

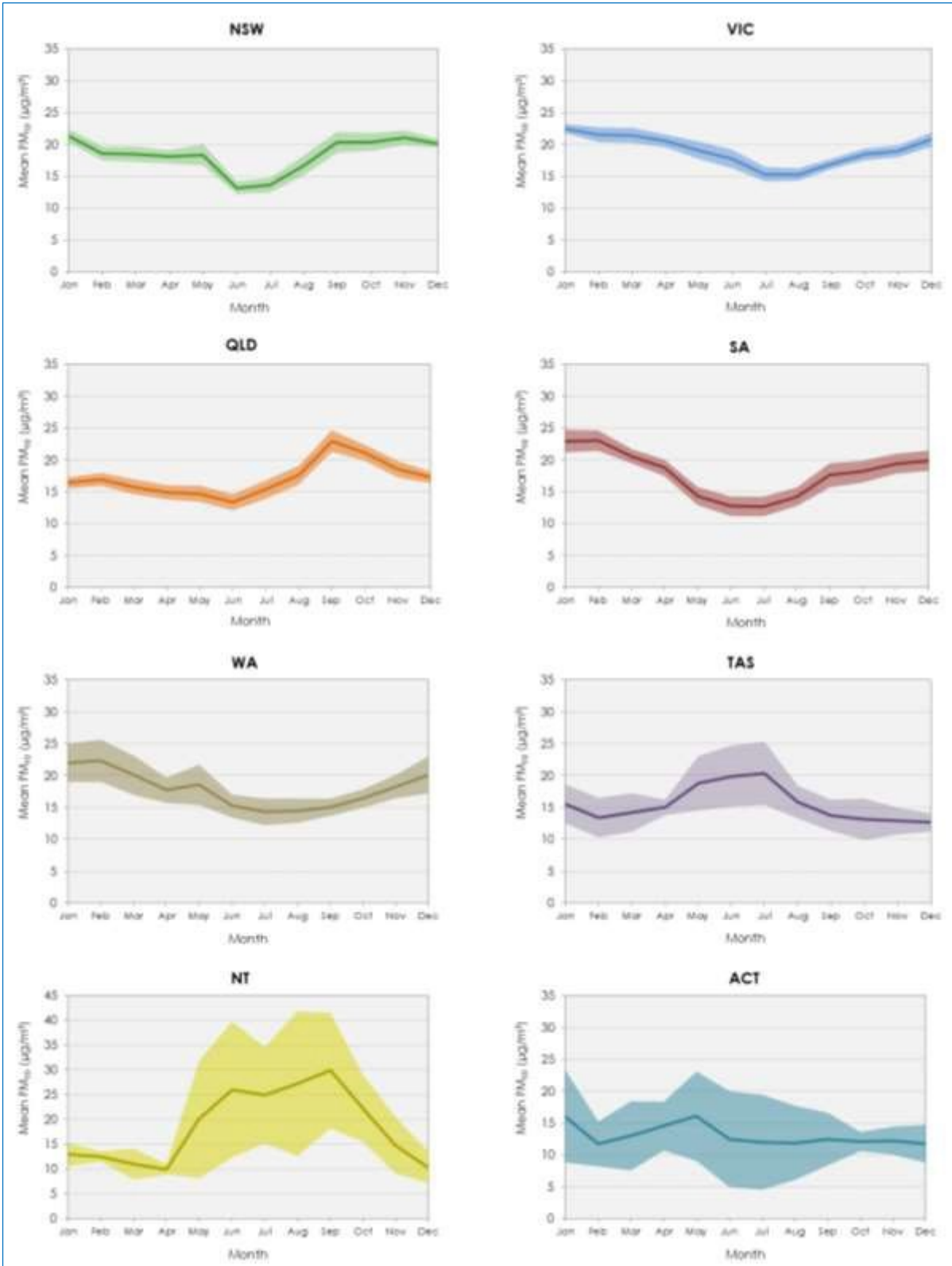


Figure E.8: Monthly mean PM₁₀ concentration by jurisdiction (shading shows 95% confidence interval; no shading indicates data were only available for one site)

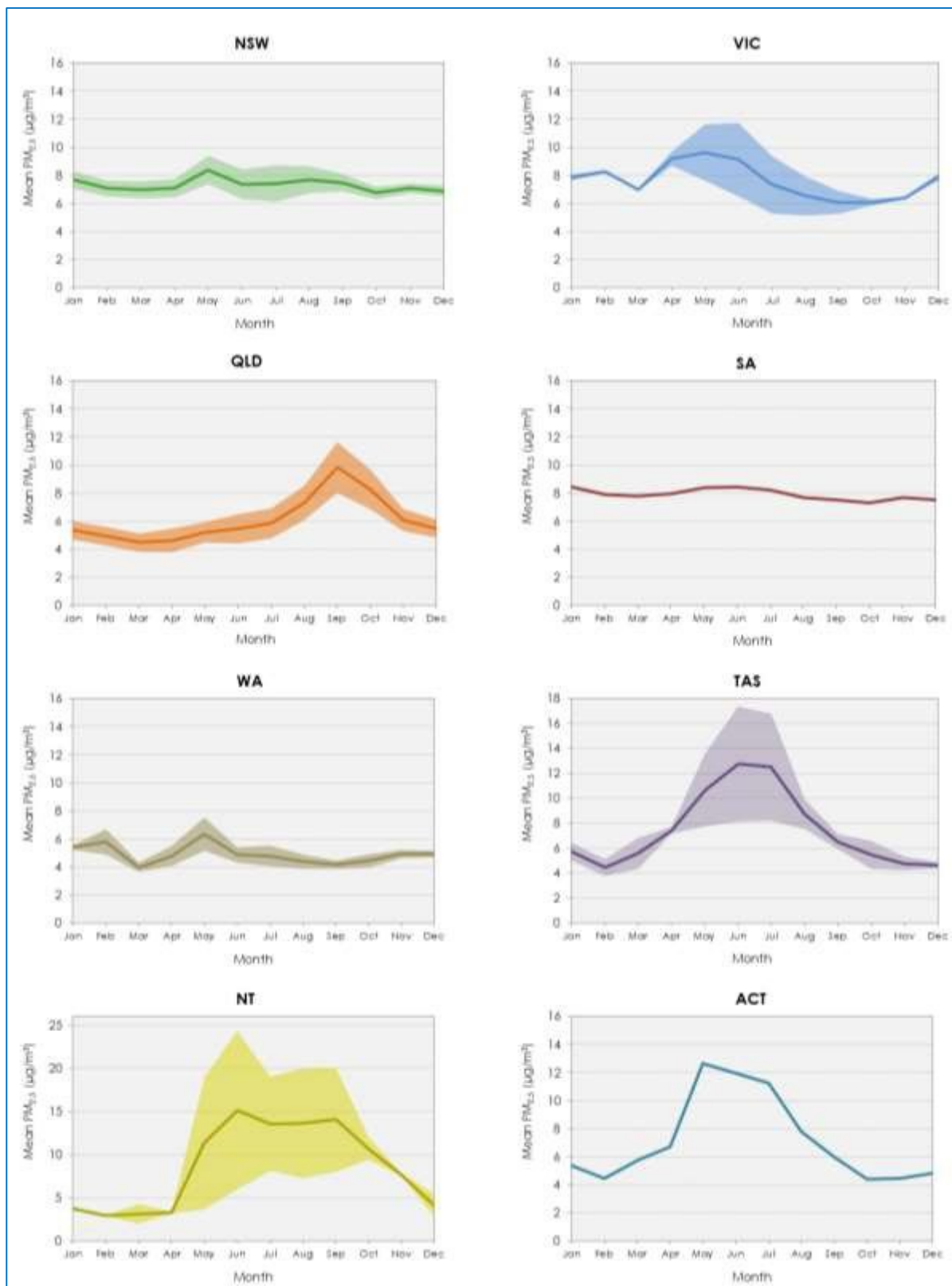


Figure E.9: Monthly mean PM_{2.5} concentration by jurisdiction (shading shows 95% confidence interval; no shading indicates data were only available for one site)

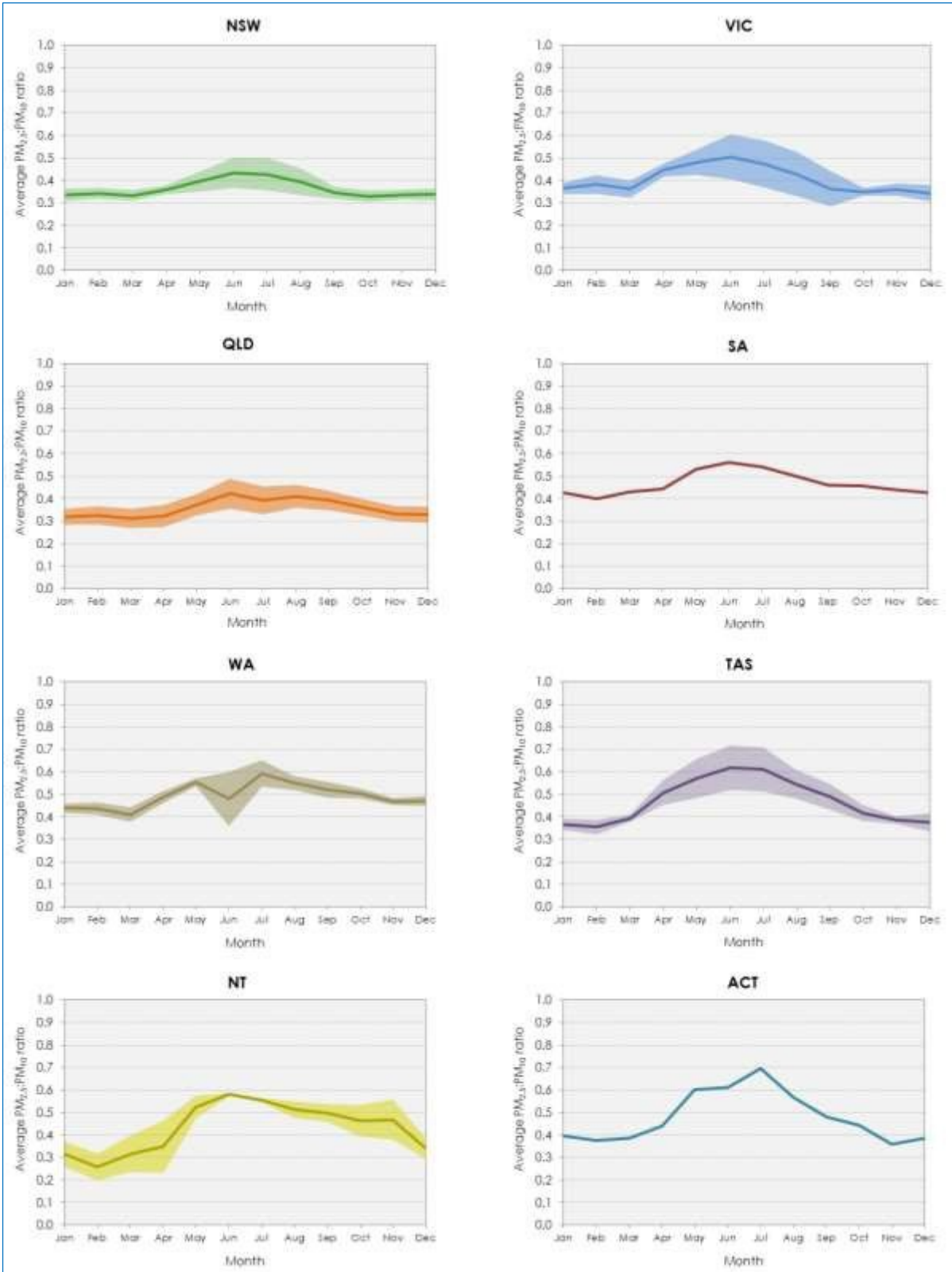


Figure E.10: Monthly mean $PM_{2.5}:PM_{10}$ ratio by jurisdiction (shading shows 95% confidence interval; no shading indicates data were only available for one site)

E.4 DAILY TRENDS

The average concentrations of PM₁₀ and PM_{2.5} for each day of the week were also determined, and some examples (for NSW) are shown in **Figure E.11**. The patterns in the other jurisdictions were broadly similar to those shown below. The day of the week tended to have relatively little influence on the concentration, although the highest concentrations were generally observed in the middle of the week.

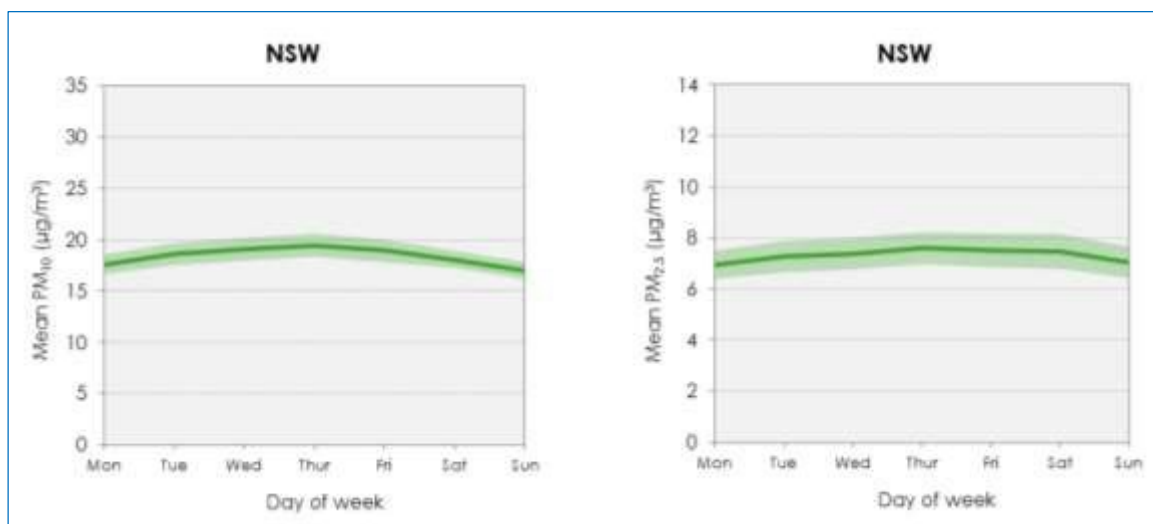


Figure E.11: Mean PM₁₀ and PM_{2.5} concentration by day of the week – NSW (shading shows 95% confidence interval)

E.5 GEOGRAPHICAL VARIATIONS

Overall annual mean PM₁₀ and PM_{2.5} concentrations were calculated for different regions and urban areas. The results are shown in **Figure E.12** and **Figure E.13**. It should be noted that these values have been calculated for the available data over the period 2003–2012, and the number of years of valid data per site varies considerably. The number of monitoring sites for each data point varies from one per year (e.g. Hobart) to around 12 per year (e.g. Sydney), and different monitoring instruments are used in different jurisdictions. Nevertheless, there is a level of consistency from jurisdiction to jurisdiction; no single state or territory stands out as having very high or very low concentrations. It was observed by **DSEWPC (2011)** that PM levels tend to be slightly higher in regional cities in south-eastern Australia than in the capital cities, and to some extent this is reflected in the data presented here for NSW. DSEWPC credit this to the effects of bush fires, dust storms, planned burning and the use of wood for domestic heating.

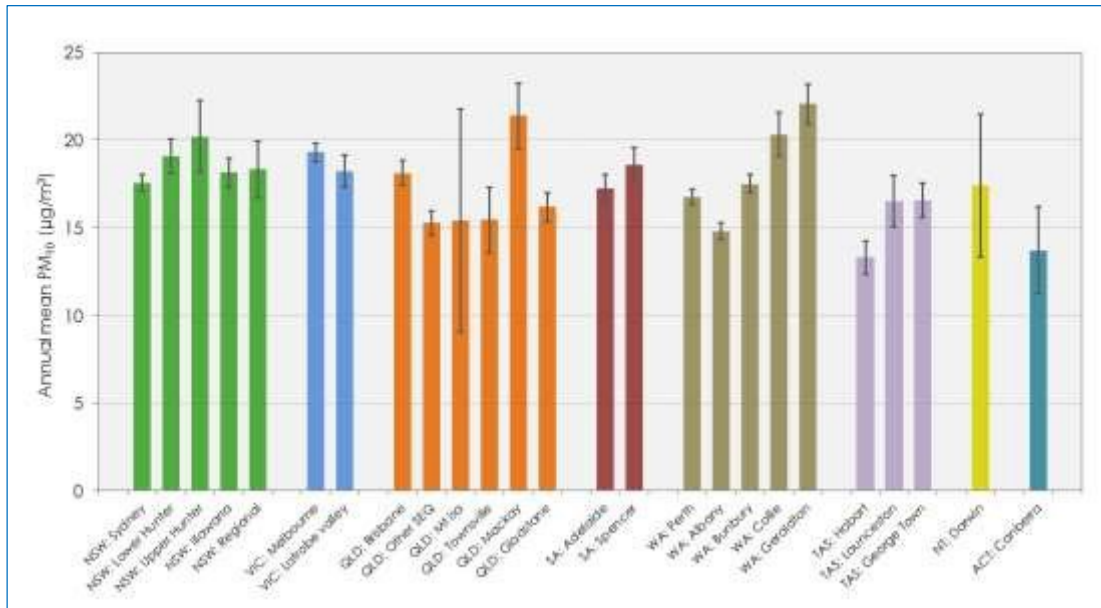


Figure E.12: Annual mean PM₁₀ concentration by location (average for 2003–2012)

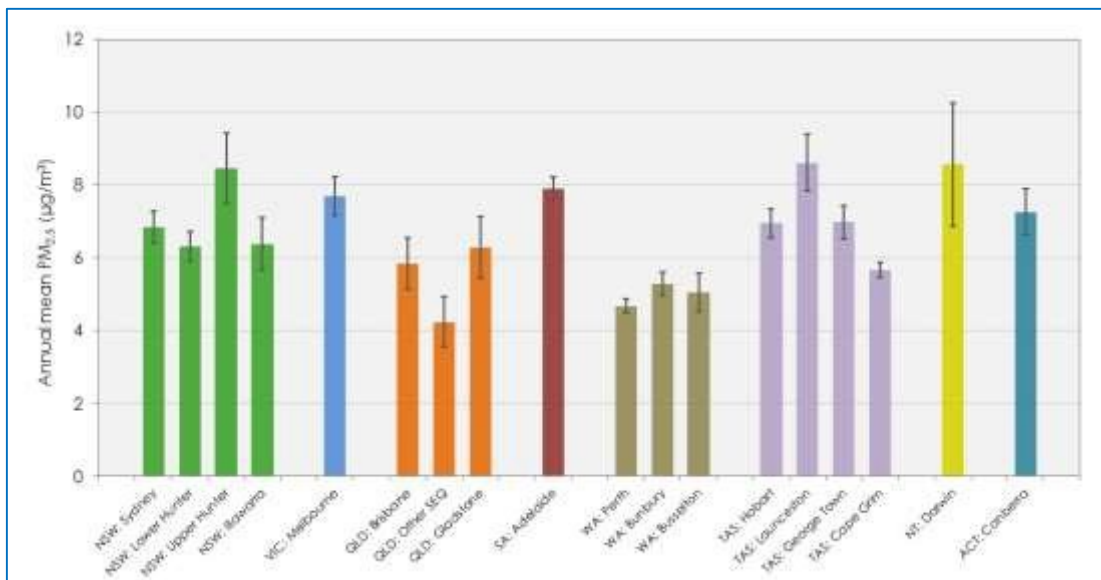


Figure E.13: Annual mean PM_{2.5} concentration by location (average for 2003–2012)

E.6 EXCEEDANCES OF AIR QUALITY STANDARDS

The exceedances of the current standards and goals⁴⁴ for PM₁₀ and PM_{2.5} between 2003 and 2012 are shown in **Tables E.2 to E.25**. The following observations apply to the data:

For the 24-hour mean PM₁₀ standard (50 µg/m³, with five exceedances allowed per year):

- Weather, climate and natural events are major factors affecting exceedances. Many monitoring sites had more than five exceedances in 2009. This was mainly due to warm, dry conditions, combined with an extreme dust event in September. Conversely, there were relatively few exceedances in the cool, wet *La Niña* years of 2010 and 2011.
- The state and territory reports on AAQ NEPM implementation reveal that in the capital cities exceedances are generally limited in number and mainly related to extreme events, on which government air quality improvement programs have very limited effect. However, if anthropogenic emissions were reduced the likelihood of an exceedance when there are extreme events would be reduced.
- Notwithstanding the above, there are no strong inter-annual trends in the patterns of exceedance.
- Such trends are, however, difficult to determine given the changes in instrumentation and monitoring locations.
- Rural or small urban sites in NSW tend to have more exceedances than urban sites.
- Victoria and SA have a higher frequency of exceedances than the other jurisdictions.

For the advisory annual mean PM_{2.5} standard (8 µg/m³):

- There have been some exceedances of the standard in most jurisdictions.
- There are no strong year-on-year patterns in terms of exceedances of the standard.

For the advisory 24-hour mean PM_{2.5} standard (25 µg/m³, with no exceedances allowed):

- There have been exceedances of this standard at most of the monitoring sites.
- Several jurisdictions have exceedances at all sites and in most years (VIC, WA, TAS, NT, ACT).
- There are no strong year-on-year patterns in terms of exceedances of the standard.

⁴⁴ For PM_{2.5} it was assumed that no exceedances of the 24-hour standard would be allowed.

24-ur PM₁₀ standard and goal

Table E.2: Exceedances of 24-hour PM₁₀ standard and goal in NSW (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|------------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Sydney: Bargo | | | | | | | | 0 | 1 | 0 |
| Sydney: Blacktown | 5 | | | | | | | | | |
| Sydney: Bringelly | 6 | 2 | 2 | 3 | 1 | 1 | 5 | 0 | 2 | 0 |
| Sydney: Chullora | 11 | 3 | 1 | 3 | 2 | 0 | 8 | 0 | 7 | 1 |
| Sydney: Earlwood | 7 | 1 | 3 | 8 | 3 | 1 | 7 | 0 | 2 | 0 |
| Sydney: Lindfield | 3 | | | | | 0 | 4 | 0 | 0 | 0 |
| Sydney: Liverpool | 6 | 1 | 2 | 3 | 1 | 1 | 7 | 0 | | 0 |
| Sydney: Macarthur | | | 1 | 4 | 1 | 1 | 6 | 1 | 0 | |
| Sydney: Oakdale | | | 0 | 1 | 0 | 1 | 5 | 0 | 1 | 0 |
| Sydney: Prospect | | | | | 0 | 0 | 10 | 0 | 0 | 0 |
| Sydney: Randwick | 4 | 0 | 0 | 1 | 1 | 0 | 8 | 0 | 0 | 0 |
| Sydney: Richmond | 7 | 0 | 0 | 2 | 0 | 0 | 5 | 0 | 0 | 3 |
| Sydney: Rozelle | | 1 | 0 | 1 | 1 | 0 | 7 | 0 | 0 | 0 |
| Sydney: St Marys | 4 | 1 | 2 | 5 | 0 | 0 | 8 | 1 | 1 | 0 |
| Sydney: Vineyard | 10 | 0 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 0 |
| Sydney: Westmead | 2 | | | | | | | | | 0 |
| Sydney: Woolooware | 2 | | | | | | | | | |
| Lower Hunter: Beresfield | 5 | 1 | 1 | 2 | 5 | 5 | 14 | 0 | 0 | 1 |
| Lower Hunter: Newcastle | | | 0 | 1 | | 2 | 12 | 1 | 0 | 0 |
| Lower Hunter: Wallsend | 4 | 1 | 1 | 1 | 2 | 1 | 9 | 0 | 0 | 0 |
| Upper Hunter: Aberdeen | | | | | | | | | | 0 |
| Upper Hunter: Bulga | | | | | | | | | | 2 |
| Upper Hunter: Camberwell | | | | | | | | | | 23 |
| Upper Hunter: Jerry's Plains | | | | | | | | | | 0 |
| Upper Hunter: Maison Dieu | | | | | | | | | 8 | 20 |
| Upper Hunter: Merriwa | | | | | | | | | | 1 |
| Upper Hunter: Mt Thorley | | | | | | | | | | 28 |
| Upper Hunter: Muswellbrook | | | | | | | | | 0 | 1 |
| Upper Hunter: M'brook NW | | | | | | | | | | 1 |
| Upper Hunter: Singleton | | | | | | | | | 2 | 6 |
| Upper Hunter: Singleton NW | | | | | | | | | | 29 |
| Upper Hunter: Singleton S | | | | | | | | | | 2 |
| Upper Hunter: Warkworth | | | | | | | | | | 0 |
| Upper Hunter: Wybong | | | | | | | | | | 1 |
| Illawarra: Albion Park | 4 | 1 | | | | | | | | |
| Illawarra: Albion Park South | | | | 2 | 1 | 1 | 8 | 0 | 1 | 0 |
| Illawarra: Kembla Grange | | | 4 | 9 | 5 | 4 | 13 | 0 | 1 | 3 |
| Illawarra: Warrawong | 5 | 2 | 5 | | | | | | | |
| Illawarra: Wollongong | 8 | 0 | 1 | 4 | 3 | 1 | 5 | 0 | 0 | 0 |
| Regional NSW: Albury | 29 | 2 | 3 | 14 | 11 | 8 | 15 | 2 | 0 | 1 |
| Regional NSW: Bathurst | 12 | 4 | 0 | 3 | 2 | 1 | 11 | 0 | 0 | 2 |
| Regional NSW: Tamworth | 7 | 2 | | 0 | | 3 | 16 | 0 | 1 | 1 |
| Regional NSW: Wagga Wagga | 20 | 28 | 27 | 37 | 34 | 23 | 20 | 6 | | |

Table E.3: Exceedances of 24-hour PM₁₀ standard and goal in VIC (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|---------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Pt Phil.: Alphington | 10 | 1 | 0 | 8 | 2 | 3 | 7 | 0 | 1 | 0 |
| Pt Phil.: Box Hill | | | 10 | 7 | 2 | 4 | 6 | 0 | 1 | 0 |
| Pt Phil.: Brighton | 8 | 0 | 0 | 6 | 1 | 5 | 6 | 0 | 0 | 0 |
| Pt Phil.: Dandenong | 8 | 1 | 0 | 12 | 5 | 8 | 12 | 0 | 0 | 0 |
| Pt Phil.: Deer Park | | | | | | 7 | 12 | 1 | 0 | 1 |
| Pt Phil.: Footscray | 10 | 3 | 0 | 11 | 4 | 4 | 13 | 4 | 0 | 3 |
| Pt Phil.: Geelong South | 10 | 11 | 7 | 17 | 14 | 6 | 12 | 1 | 2 | 1 |
| Pt Phil.: Mooroolbark | 13 | 1 | 9 | 17 | 11 | 10 | 20 | 3 | 1 | 2 |
| Pt Phil.: Richmond | | | | 9 | 3 | 5 | 8 | 0 | 0 | 0 |
| Pt Phil.: RMIT | 10 | 2 | 0 | 1 | | | | | | |
| Latrobe Valley: Moe | 11 | 1 | 0 | 15 | 13 | 6 | 7 | | | |
| Latrobe Valley: Traralgon | 7 | 0 | 0 | 9 | 5 | 2 | 5 | 3 | 0 | 0 |

Table E.4: Exceedances of 24-hour PM₁₀ standard and goal in QLD (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|---------------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| SEQ: Brisbane CBD | 1 | 2 | 2 | 0 | 1 | 1 | 6 | 0 | 0 | 0 |
| SEQ: Flinders View | 1 | 3 | 3 | 0 | 0 | 2 | 7 | 0 | 2 | 2 |
| SEQ: Mountain Creek | 1 | 1 | 2 | 0 | 0 | 1 | 7 | 0 | 0 | 1 |
| SEQ: North Toowoomba | | 0 | 3 | 1 | 1 | 4 | 10 | 0 | | |
| SEQ: Pinkenba | 1 | 2 | 4 | 3 | 9 | 7 | 7 | 3 | 4 | 0 |
| SEQ: Rocklea | 2 | 0 | 2 | 0 | 1 | 1 | 8 | 0 | | |
| SEQ: South Brisbane | 1 | 2 | 2 | 0 | 1 | 1 | 14 | 0 | 2 | 0 |
| SEQ: Springwood | 0 | 0 | 2 | 0 | 0 | 1 | 9 | 0 | 2 | 0 |
| SEQ: Woolloongabba | 2 | 3 | 3 | 1 | | | 11 | 0 | 2 | 0 |
| SEQ: Wynnum N | | | 4 | 0 | 2 | 2 | 8 | 0 | 3 | 2 |
| Mt Isa: The Gap | | | | | | | | 0 | 13 | 16 |
| Townsville: Pimlico | | | 5 | 2 | 0 | 1 | 9 | 0 | 1 | 0 |
| Mackay: West Mackay | 7 | 0 | 7 | 1 | 2 | 8 | 17 | 0 | 1 | 1 |
| Gladstone: South Gladstone | 0 | 0 | 4 | 1 | 0 | 2 | 7 | 0 | 3 | 1 |
| Gladstone: Clinton | 0 | 0 | 4 | 1 | 0 | 2 | | 0 | 8 | 0 |
| Gladstone: Targinie (Swans Rd) | | | | | | | 10 | 0 | | 5 |
| Gladstone: Targinie (Stupkin L) | 0 | 1 | 5 | 1 | 0 | | | | | |
| Gladstone: Boat Creek | | | | | | | 14 | 0 | | |
| Gladstone: Boyne Island | | | | | | | 10 | 0 | 7 | 2 |

Table E.5: Exceedances of 24-hour PM₁₀ standard and goal in SA (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|----------------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Adelaide: Birkenhead | | | | 6 | 5 | 6 | 6 | 2 | 0 | 2 |
| Adelaide: Christie Downs | | | | | 3 | 3 | 2 | 5 | 0 | 0 |
| Adelaide: Elizabeth Downs | | | 6 | 4 | 3 | 3 | 12 | 1 | 0 | 2 |
| Adelaide: Kensington Gardens | 2 | 1 | 2 | 2 | 1 | 3 | 2 | | | 1 |
| Adelaide: Netley | 6 | 3 | 6 | 11 | 11 | 4 | 5 | 3 | 0 | 1 |
| Spencer: Pt Pirie Frank Green Pk | | | | 10 | 11 | 13 | 8 | 4 | 0 | 2 |
| Spencer: Pt Pirie Oliver Street | | 4 | 6 | 13 | 11 | 17 | 14 | 3 | 1 | 0 |
| Spencer: Whyalla Schultz Pk | | | | | 5 | 6 | 10 | 3 | 1 | 0 |
| Spencer: Whyalla Walls St | | | 30 | 29 | 25 | 17 | 23 | 4 | 8 | 10 |

Table E.6: Exceedances of 24-hour PM₁₀ standard and goal in WA (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|-------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Perth: Caversham | | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 4 |
| Perth: Duncraig | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| Perth: South Lake | 0 | 1 | 3 | 0 | 1 | 1 | 0 | 4 | 1 | 2 |
| Albany | | | | | 1 | 2 | 0 | 1 | 0 | 0 |
| Bunbury | 1 | 4 | 3 | 3 | 0 | 0 | 1 | 2 | 2 | 2 |
| Collie | | | | | | 7 | 3 | 16 | 4 | 6 |
| Geraldton | | | | 4 | 10 | 10 | 14 | | 3 | 3 |

Table E.7: Exceedances of 24-hour PM₁₀ standard and goal in TAS (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|--------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Launceston: Ti Tree Bend | 23 | 10 | 14 | 5 | 8 | 1 | 0 | 0 | 0 | 1 |
| Hobart: New Town | | | | | 0 | 0 | 0 | 1 | 0 | 0 |
| George Town | | | | | | 0 | 1 | 2 | 2 | 1 |

Table E.8: Exceedances of 24-hour PM₁₀ standard and goal in NT (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|--------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Darwin: Casuarina | | | | | 0 | 1 | 9 | 1 | | |
| Darwin: Palmerston | | | | | | | | | 3 | 23 |

Table E.9: Exceedances of 24-hour PM₁₀ standard and goal in ACT (sites and years with more than five exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM ₁₀ of 50 µg/m ³ per year | | | | | | | | | |
|------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Canberra: Civic | | | | | | | | | 0 | 0 |
| Canberra: Monash | 13 | 3 | 10 | 4 | 5 | 3 | | 0 | 0 | 0 |

Advisory annual mean PM_{2.5} standard

Table E.10: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in NSW (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|--------------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Sydney: Chullora | | 8.6 | 7.6 | 7.2 | 6.4 | 5.9 | 6.6 | 5.7 | 5.9 | 6.1 |
| Sydney: Earlwood | 7.8 | 7.5 | 7.1 | 6.9 | 5.9 | 5.5 | 6.2 | 5.7 | 5.4 | 5.6 |
| Sydney: Liverpool | | 9.2 | 8.4 | 8.9 | 7.2 | 6.5 | 7.5 | 6.3 | 5.9 | 8.5 |
| Sydney: Richmond | 6.6 | 6.5 | 5.8 | 5.9 | | 7.3 | 5.2 | 4.2 | 4.7 | 5.3 |
| Sydney: Westmead | 8.2 | | | | | | | | | |
| Sydney: Woollooware | 7.5 | | | | | | | | | |
| Lower Hunter: Beresfield | 6.1 | 7.7 | 6.8 | 6.8 | 6.3 | 6.0 | 7.9 | 6.0 | 5.5 | 7.9 |
| Lower Hunter: Wallsend | 6.6 | 6.7 | 6.5 | 6.4 | 5.8 | 5.9 | 6.8 | 4.6 | 4.8 | 5.1 |
| Upper Hunter: Camberwell | | | | | | | | | | 7.5 |
| Upper Hunter: Muswellbrook | | | | | | | | | 9.1 | 10.1 |
| Upper Hunter: Singleton | | | | | | | | | 7.6 | 8.0 |
| Illawarra: Warrawong | 8.8 | 8.2 | 7.4 | | | | | | | |
| Illawarra: Wollongong | 7.3 | 6.7 | 6.3 | 6.4 | 6.0 | 5.3 | 6.4 | 5.1 | 4.6 | 4.6 |
| Regional NSW: Wagga Wagga | | | | | | | | | | 8.7 |
| Sydney: Mascot (ANSTO) | 7.7 | 8.1 | 7.5 | 7.9 | 7.5 | 7.6 | 8.9 | 6.9 | 6.9 | 7.3 |
| Sydney: Liverpool (ANSTO) | | | 8.4 | 8.5 | 7.8 | 7.8 | 9.4 | | | |
| Sydney: Lucas Heights (ANSTO) | 5.3 | 5.6 | 5.3 | 5.5 | 5.1 | 4.6 | 5.7 | 4.9 | 5.0 | 4.9 |
| Sydney: Richmond (ANSTO) | | | 5.9 | 7.1 | 7.2 | 6.1 | 6.8 | | | |
| Lower Hunter: Mayfield (ANSTO) | 7.4 | 8.1 | 7.4 | 7.9 | 7.4 | 6.8 | 7.1 | 6.4 | 6.1 | 6.7 |
| Illawarra: Warrawong (ANSTO) | 6.8 | 6.4 | 6.5 | 6.4 | 7.0 | 6.0 | 6.4 | 6.2 | 6.2 | 6.2 |
| Upper Hunter: M'brook (ANSTO) | 6.8 | 6.3 | 6.1 | 6.5 | 6.4 | 5.1 | 6.7 | 5.1 | 5.6 | 5.7 |

Table E.11: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in VIC (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|----------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Pt Phil.: Alphington | 8.8 | 6.9 | 8.1 | 10.6 | 8.5 | 8.2 | 8.4 | 7.4 | 7.2 | 6.8 |
| Pt Phil.: Footscray | 7.7 | 6.1 | | 9.6 | 7.6 | 7.0 | 7.3 | 6.8 | 7.0 | 6.2 |

Table E.12: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in QLD (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|--------------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| SEQ: North Toowoomba | | 5.2 | 4.4 | 3.7 | 3.6 | | | | | |
| SEQ: Rocklea | 4.6 | 6.3 | 4.4 | 3.9 | 4.3 | 3.7 | 10.4 | 8.3 | | |
| SEQ: South Brisbane | | | | | | | 10.4 | 6.8 | 7.0 | 6.8 |
| SEQ: Springwood | 5.3 | 5.3 | 4.5 | 4.6 | 4.3 | 4.1 | 5.1 | 4.5 | 4.6 | 4.4 |
| SEQ: Woolloongabba | | | | | | | 8.4 | 8.3 | 8.7 | 7.8 |
| SEQ: Wynnum N | | | | | | | 5.2 | 4.0 | 4.8 | 4.1 |
| Gladstone: South Gladstone | | | | | | | 9.2 | 6.1 | 7.5 | 5.3 |
| Gladstone: Clinton | | | | | | | | 5.1 | 9.8 | 7.1 |
| Gladstone: Targinie (Swans Rd) | | | | | | | 5.2 | 3.6 | | 4.8 |
| Gladstone: Boat Creek | | | | | | | 9.1 | 6.7 | | |
| Gladstone: Boyne Island | | | | | | | 7.2 | 3.1 | 7.0 | 4.5 |

Table E.13: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in SA (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Adelaide: Netley | 9.0 | 8.2 | 7.9 | 8.3 | 7.9 | 7.7 | 8.1 | 7.5 | 7.1 | 7.3 |

Table E.14: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in WA (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|---------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Perth: Caversham | 4.9 | | | | 4.4 | 4.0 | 4.6 | 5.0 | 3.9 | 4.7 |
| Perth: Duncraig | 5.7 | 4.8 | 4.7 | 5.0 | 4.2 | 4.6 | 5.1 | 5.1 | 4.6 | 5.0 |
| Perth: Quinns Rocks | | | | | 3.8 | 4.1 | 4.6 | 4.6 | 4.1 | 4.8 |
| Perth: South Lake | | | | | | | | | 4.7 | 5.8 |
| Bunbury | 5.5 | 6.0 | 5.2 | 5.6 | 4.7 | 4.5 | 5.1 | 6.0 | 4.9 | 5.4 |
| Busselton | | | | | 4.2 | 4.2 | 5.8 | 5.3 | 5.4 | 5.4 |

Table E.15: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in TAS (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|--------------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Launceston: Ti Tree Bend | | | | 10.4 | 9.5 | 8.8 | 7.5 | 8.3 | 7.5 | 8.3 |
| Hobart: New Town | | | | | 7.6 | 7.3 | 7.1 | 7.1 | 6.2 | 6.5 |
| George Town | | | | | | 7.7 | 6.9 | 7.2 | | |
| Cape Grim (ANSTO) | 6.2 | 5.2 | 5.5 | 5.3 | 5.5 | 6.2 | 5.6 | 5.7 | 5.5 | 5.9 |

Table E.16: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in NT (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|--------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Darwin: Casuarina | | | | | | | 8.3 | | | |
| Darwin: Palmerston | | | | | | | | | 10.2 | 11.8 |

Table E.17: Exceedances of advisory annual mean PM_{2.5} standard of 8 µg/m³ in ACT (sites and years with values above 8 µg/m³ are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Annual average PM _{2.5} concentration (µg/m ³) | | | | | | | | | |
|------------------|---|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Canberra: Monash | | 8.2 | | 7.9 | | | | 6.3 | 6.0 | 6.7 |

Advisory 24-hour PM_{2.5} standard (assuming no exceedances allowed)

Table E.18: Exceedances of advisory 24-hour PM_{2.5} standard in NSW (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|----------------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Sydney: Chullora | | 0 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| Sydney: Earlwood | 5 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sydney: Liverpool | | 4 | 2 | 3 | 0 | 1 | 2 | 0 | 2 | 0 |
| Sydney: Richmond | 4 | 0 | 0 | 1 | | 0 | 1 | 0 | 2 | 2 |
| Sydney: Westmead | 2 | | | | | | | | | |
| Sydney: Woolooware | 3 | | | | | | | | | |
| Lower Hunter: Beresfield | 3 | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 |
| Lower Hunter: Wallsend | 2 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 0 |
| Upper Hunter: Camberwell | | | | | | | | | | 0 |
| Upper Hunter: Muswellbrook | | | | | | | | | 4 | 3 |
| Upper Hunter: Singleton | | | | | | | | | 0 | 0 |
| Illawarra: Warrawong | 4 | 0 | 0 | | | | | | | |
| Illawarra: Wollongong | 5 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| Regional NSW: Wagga Wagga | | | | | | | | | | 0 |

Table E.19: Exceedances of advisory 24-hour PM_{2.5} standard in VIC (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|----------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Pt Phil.: Alphington | 10 | 0 | 4 | 19 | 7 | 10 | 9 | 3 | 1 | 0 |
| Pt Phil.: Footscray | 7 | 0 | | 18 | 8 | 8 | 6 | 3 | 0 | 1 |

Table E.20: Exceedances of advisory 24-hour PM_{2.5} standard in QLD (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|--------------------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| SEQ: North Toowoomba | | 1 | 0 | 0 | 0 | | | | | |
| SEQ: Rocklea | 1 | 5 | 0 | 0 | 0 | 0 | 6 | 0 | | |
| SEQ: South Brisbane | | | | | | | 6 | 0 | 3 | 1 |
| SEQ: Springwood | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 3 | 0 |
| SEQ: Woolloongabba | | | | | | | 3 | 3 | 3 | 1 |
| SEQ: Wynnum N | | | | | | | 1 | 0 | 3 | 0 |
| Gladstone: South Gladstone | | | | | | | 7 | 0 | 9 | 1 |
| Gladstone: Clinton | | | | | | | | 0 | 14 | 1 |
| Gladstone: Targinie (Swans Rd) | | | | | | | 4 | 0 | | 0 |
| Gladstone: Boat Creek | | | | | | | 12 | 0 | | |
| Gladstone: Boyne Island | | | | | | | 7 | 0 | 11 | 3 |

Table E.21: Exceedances of advisory 24-hour PM_{2.5} standard in SA (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Adelaide: Netley | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |

Table E.22: Exceedances of advisory 24-hour PM_{2.5} standard in WA (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|--------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Perth: Caversham | 0 | | | | 0 | 0 | 0 | 1 | 1 | 3 |
| Perth: Duncraig | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 1 | 4 |
| Perth: Quinns Rock | | | | | 0 | 1 | 1 | 2 | 1 | 3 |
| Perth: South Lake | | | | | | | | | 1 | 3 |
| Bunbury | 1 | 5 | 3 | 6 | 2 | 0 | 3 | 4 | 2 | 3 |
| Busselton | | | | | 2 | 1 | 11 | 5 | 5 | 4 |

Table E.23: Exceedances of advisory 24-hour PM_{2.5} standard in TAS (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|--------------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Launceston: Ti Tree Bend | | | | 35 | 20 | 17 | 12 | 11 | 6 | 16 |
| Hobart: New Town | | | | | 7 | 9 | 4 | 2 | 0 | 3 |
| George Town | | | | | | 6 | 2 | 5 | | |

Table E.25: Exceedances of advisory 24-hour PM_{2.5} standard in NT (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|--------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Darwin: Casuarina | | | | | | | 5 | | | |
| Darwin: Palmerston | | | | | | | | | 15 | 24 |

Table E.25: Exceedances of advisory 24-hour PM_{2.5} standard in ACT (sites and years with any exceedances are highlighted in red; shaded cells represent no monitoring or years with <75% of data)

| Monitoring site | Number of exceedances of 24-hour mean PM _{2.5} of 25 µg/m ³ per year | | | | | | | | | |
|------------------|--|------|------|------|------|------|------|------|------|------|
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Canberra: Monash | | 15 | | 20 | | | | 2 | 4 | 3 |

Appendix F SUMMARY OF QUESTIONS FOR CONSULTATION

Chapter 2: Characteristics and measurement of airborne PM

- The characteristics of airborne PM are described in some detail. Would any further information on airborne PM characteristics assist in informing action to reduce airborne PM? If so, please provide details.
- Please provide any additional Australia-specific aspects of PM measurement that you believe are important to the actions to reduce airborne PM being considered in this Impact Statement.

Chapter 3: Health effects and monetary costs of airborne PM

- Is there any any additional Australia-specific information on the health effects or monetary costs of PM that should be included? If so, please provide details.

Chapter 4: Policy context and legislation

- Have all aspects of the current air quality management framework in Australia been adequately described? If not, please provide further details.
- Have any significant regulatory developments, local or international, been overlooked? Please provide information.
- What are your views on the feasibility of an exposure-reduction framework for PM in Australia?

Chapter 5: Airborne PM in Australia

- Do you think that any additional information on emissions and ambient PM concentrations in Australia is required to inform the actions being considered for reducing airborne PM?
- Are there other issues that have not been considered or have not been attributed sufficient weight in the discussion?

Chapter 6: The problem and the case for government intervention

- Do you agree that further government involvement is required to address the potential future health impacts and costs of airborne PM?

Chapter 7: Statement of options

- Do you agree that the AAQ NEPM framework is an important element in the management actions to address ambient air quality in Australia?
- Have any options for the metrics, averaging times, and values of the standards been overlooked?
- Do you agree that the metrics and values of PM standards selected for analysis are appropriate for Australia?
- Do you consider the options outlined for the form of the standards to be feasible for Australia? Have any options been overlooked?
- Is there any other information relating to the options for an exposure-reduction framework that should be considered?

Chapter 8 Impact analysis

- Have all health, environmental, economic and social impacts of PM in Australia been identified? If not, please provide reasons and suggestions for additional analyses.
- Have all key assumptions been correctly identified and included in the analysis? If not, please provide details.

Chapter 9: Preferred options

- Do you agree with the introduction of an annual PM₁₀ standard, given the apparent adverse health effects of coarse particles and their prevalence in some regions?
- Do you support upgrading the current AAQ NEPM advisory reporting standards for PM_{2.5} to compliance standards?
- Do you support the preferred numerical values for new/revised 24-hour and annual PM_{2.5} and PM₁₀ standards? Which value for the 24-hour PM₁₀ standard do you consider to be the most appropriate, and why?
- What is your preferred option for the form of the 24-hour PM₁₀ and PM_{2.5} standards? Should the options be trialled?
- Do you have any comments regarding the possible inclusion of PM metrics, other than PM₁₀ and PM_{2.5}, in the future?
- Do you agree with the preferred form of the exposure-reduction framework under which an exposure index based on monitoring would be used to track population exposure for major urban areas?