Health Risk Assessment – Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants

Report prepared for EPA Victoria

Bin Jalaludin

 Christine Cowie

Respiratory and Environmental Epidemiology

Woolcock Institute of Medical Research

30 June 2012

**Background**

EPA Victoria wishes to identify health endpoints and relevant concentration-response functions (CRFs) associated with exposure to particulate matter less than 10*µ*g (PM10) and 2.5*µ*g (PM2.5) in diameter, nitrogen dioxide(NO2), ozone (O3) and sulphur dioxide (SO2) in ambient air. This preliminary work is expected to form the basis of an exposure assessment and risk characterisation for a broader health risk assessment (HRA) project for the review of the National Environment Protection (Ambient Air Quality) Measure.

**Scope of the project**

The scope of the consultancy was as follows:

1. All relevant health endpoints for PM10, PM2.5,NO2, O3 and SO2 to be identified.
2. For each health endpoint, the relevant associated CRF will be identified. In the first instance, CRFs from Australian studies will be identified. If Australian studies are either not available or not appropriate, then CRFs from international studies will be identified.
3. Health endpoints and associated CRFs to be identified solely from published reports, systematic reviews and meta-analyses. The grey literature from the United Kingdom (for example, Department of Health), United States (for example, US EPA), the European Union, World Health Organization and Australia, and electronic databases (for example, Medline, PubMed) will be searched for any published systematic reviews and meta-analyses. Literature reviews, systematic reviews or meta-analyses of primary studies will not be conducted.
4. Weight of evidence (WoE) assessments of primary studies will not be conducted. WoE requires interpretation of findings from all epidemiological and toxicological studies (of air pollutants in this instance) to form a considered opinion on the relevance and the significance of the findings overall. It involves evaluating the quality of measurement methods, size and power of study design, consistency of results across studies, and biological plausibility of CRFs and statistical associations. Such WoE assessments are beyond the scope of this consultancy. WoE outlined in reviews and reports identified under point 3 above will be assessed.
5. Information on the availability of routinely collected baseline health data at the state or national level where available will be provided.

**Health effects of air pollution**

Exposure to ambient air pollution has been linked to various health outcomes ranging from small transient changes in the respiratory tract and impaired lung function, restricted activity/reduced performance, emergency department visits and hospital admissions to mortality. There is also now strong evidence that there are important effects on the cardiovascular system. The most severe effects in terms of the overall health burden include a significant reduction in life expectancy of the average population which is linked to long-term exposure to high levels of particulate matter (PM). Documented health effects associated with air pollution exposures are shown in the table below ([WHO Europe 2000](#_ENREF_127); [WHO Europe 2004](#_ENREF_130)).

Table: Health effects of ambient air pollution

|  |  |  |
| --- | --- | --- |
| **Air pollutant** | **Effects related to short-term exposure** | **Effects related to long-term exposure** |
| *Particulate matter* | * Lung inflammatory reactions
 | * Increase in lower respiratory symptoms
 |
|  | * Respiratory symptoms
 | * Reductions in lung function in children
 |
|  | * Adverse effects on the cardiovascular system
 | * Increase in chronic obstructive pulmonary disease
 |
|  | * Increased medication use
 | * Reductions in lung function in adults
 |
|  | * Increased hospitalisations
 | * Reduction in life expectancy, mainly due to cardiopulmonary mortality and probably to lung cancer
 |
|  | * Increased mortality
 |  |
|  |  |  |
| *Ozone* | * Adverse effects on pulmonary function
 | * Reductions in lung function development
 |
|  | * Lung inflammatory reactions
 |  |
|  | * Adverse effects on the respiratory system
 |  |
|  | * Increased medication use
 |  |
|  | * Increased hospitalisations
 |  |
|  | * Increased mortality
 |  |
|  |  |  |
| *Nitrogen dioxide* (an indicator of traffic-related air pollution) | * Effects on pulmonary function, especially in asthmatics
 | * Reduction in lung function
 |
|  | * Increase in airway allergic inflammatory reactions
 | * Increased probability of respiratory symptoms
 |
|  | * Increased hospitalisations
 |  |
|  | * Increased mortality
 |  |
| *Sulphur dioxide* | * Effects on pulmonary function, especially in asthmatics
 | * Probable reduction in life expectancy
 |
|  | * Increased hospitalisations
 |  |
|  | * Increased mortality
 |  |

**Brief overview of published health risk assessments and cost-benefit analyses**

Health risk assessments (HRAs) are often undertaken to provide data for cost-benefit analyses (CBAs).

The World Health Organisation has suggested that health outcomes that are potentially relevant and should be considered in a HRA include the following ([WHO Europe 2001](#_ENREF_128)):

**Acute (short-term) outcomes**

* Daily mortality
* Respiratory hospital admissions
* Cardiovascular hospital admissions
* Emergency room visits for respiratory and cardiac problems
* Primary care visits for respiratory and cardiac conditions
* Use of respiratory and cardiovascular medications
* Days of restricted activity
* Work absenteeism
* School days missed
* Self-medication
* Avoidance behaviour
* Acute symptoms
* Physiologic changes, for example, in lung function

**Chronic (long-term) disease outcomes**

* Mortality (in infants and adults) from cardiopulmonary disease
* Chronic respiratory disease incidence and prevalence (including asthma, chronic obstructive pulmonary disease (COPD))
* Chronic change in physiologic function
* Lung cancer
* Chronic cardiovascular disease

**Reproductive outcomes**

* Pregnancy complications (including foetal death)
* Low birth weight
* Pre-term delivery

However, in reviewing existing guideline documents it is clear that evidence for some of these outcomes is either inadequate or inconsistent, leading to difficulty in setting CRFs. Where data are adequate, CRFs have been established. Often these have been location specific with European agencies using data from European studies and the United States Environmental Protection Agency (USEPA) using data from US studies. Occasionally, CRFs have been chosen based on the results of one epidemiological study only. Reports of CBAs of air pollutants provide a good source of information on CRFs and these have been reviewed for this project.

A recent report summarised eight major CBAs ([Jalaludin, Salkeld et al. 2009](#_ENREF_59)) from the USA ([US EPA 1999](#_ENREF_112); [US EPA 2004](#_ENREF_113)), Europe ([Seethaler 1999](#_ENREF_100); [AEA Technology Environment 2005](#_ENREF_7); [DEFRA 2006](#_ENREF_28)), New Zealand ([Fisher, Kjellstrom et al. 2005](#_ENREF_39)) and Australia ([BTRE 2005](#_ENREF_15); [DEC 2005](#_ENREF_26)). The pollutants commonly evaluated in CBAs include PM10, PM2.5,O3, SO2, NO2 and carbon monoxide (CO). There is good evidence and a broad epidemiological literature to obtain CRFs for PM. While all of the eight CBAs assessed the effects of PM, four of them ([Seethaler 1999](#_ENREF_100); [BTRE 2005](#_ENREF_15); [DEC 2005](#_ENREF_26); [Fisher, Kjellstrom et al. 2005](#_ENREF_39)) used PM as the only indicator of ambient air pollution for cost-benefit purposes. However, a concern is that selecting only one ambient air pollutant as the main pollutant may underestimate the magnitude of the health effects. Adding the health effect estimates of another air pollutant not correlated with PM (for example, O3) can minimise the extent of this underestimation. Some of the reviewed CBAs have used this approach.

However, other CBAs also quantified the health effects of other air pollutants, for example, SO2, NO2 and CO, in addition to PM either in the main analysis or in sensitivity analyses. An issue here is that ambient concentration of some of these air pollutants are highly correlated making it difficult to separate out the effects of the individual pollutants. This is particularly the case for PM and NO2, PM and SO2 (overseas) and also sometimes for NO2 and O3. It is therefore thought that NO2 and SO2 might be markers or surrogates of the effects of PM pollution and that they do not exert independent adverse effects on health. Therefore, simply summing the health effects associated with each of the specific pollutants can lead to an overestimation of the total health effects.

Some studies have used multi-pollutant models in their analyses in an attempt to distinguish the independent effects of each pollutant. In general, they have found that the estimates for the effects of PM pollution are robust and change minimally when pollutants such as NO2 and SO2 are added to the model. This implies that the majority of effects seen are likely to be due to exposure to PM in ambient air rather than to the other pollutants. In Australian studies, the effects of exposure to O3 have been similarly robust and independent of the effects of other pollutants.

Therefore, in HRAs and CBAs, use is often made of a single index pollutant (or surrogate pollutant) or alternatively two pollutants. This approach encompasses the majority of effects of all other correlated pollutants, and avoids the issue of overestimation of effects. Currently, the USEPA ([US EPA 2011](#_ENREF_121)) and the European Commission ([European Commission 2005](#_ENREF_38)) focus only on PM and O3 in their HRAs, for these reasons. The recent CBA from the United States ([US EPA 2011](#_ENREF_121)) quantified and monetised health endpoints only for PM and O3 as follows:

1. PM
	1. Premature mortality (long-term exposure)
	2. Chronic and acute bronchitis
	3. Hospital admissions for cardiovascular disease and respiratory disease
	4. Emergency department visits for asthma
	5. Non-fatal heart attacks
	6. Lower respiratory symptoms
	7. Minor restricted activity days
	8. Work loss days
	9. Asthma exacerbations (asthmatic population)
	10. Upper respiratory symptoms (asthmatic population)
	11. Infant mortality
2. O3
	1. Premature mortality (short-term exposure)
	2. Hospital admissions for respiratory disease
	3. Emergency department visits for asthma
	4. Minor restricted activity days
	5. School loss days
	6. Outdoor worker productivity

Health effects associated with ambient air pollution are divided into two broad categories - premature mortality and morbidity. For PM (PM10, PM2.5), there is an established association with both long-term and short-term premature mortality. Only one CBA ([DEFRA 2006](#_ENREF_28)) quantified both the long-term and short-term premature mortality. The other CBAs only quantified long-term premature mortality as any short-term mortality effects would be captured in the long-term mortality effects. The other two key health effects quantified for PM by all the CBAs were respiratory and cardiovascular hospital admissions.

Of the eight CBAs reviewed, four quantified the health effects associated with O3 ([US EPA 1999](#_ENREF_112); [US EPA 2004](#_ENREF_113); [AEA Technology Environment 2005](#_ENREF_7); [DEFRA 2006](#_ENREF_28)). The most common health effect quantified was respiratory hospital admissions. Two CBAs also quantified the short-term effect of ozone on premature mortality ([AEA Technology Environment 2005](#_ENREF_7); [DEFRA 2006](#_ENREF_28)). Other health endpoints reported in at least two CBAs were emergency department visits for asthma and minor restricted activity days, although at least for the latter health outcome, quantification is based primarily on one study only.

Two CBAs quantified the effects of NO2 ([US EPA 1999](#_ENREF_112); [DEFRA 2006](#_ENREF_28)) and SO2 ([US EPA 1999](#_ENREF_112); [DEFRA 2006](#_ENREF_28)) and only one report quantified the effect of CO ([US EPA 1999](#_ENREF_112)). For NO2, the health effects that were quantified included respiratory and cardiovascular disease hospital admissions and respiratory illness; for SO2 they included short-term mortality, cardiovascular disease hospital admissions and respiratory illness; and, for CO they included only respiratory and cardiovascular disease hospital admissions.

**Brief overview of hazard assessment in Australia**

In 2011, the National Environment Protection Council (NEPC) ([National Environment Protection Council 2011](#_ENREF_77)) recommended the following approach to hazard assessment::

* Human-based studies are preferred.
* Epidemiological studies, especially those representative of the general population (including sensitive groups), should be used, if available. Controlled human exposure studies should only be used for short-term health outcomes, when appropriate epidemiological studies are not available. Toxicological studies should be used as supporting evidence of biological plausibility and coherence of effect. When no epidemiological human data are available, toxicological evidence can be used for standard setting, with the appropriate application of uncertainty factors.
* Any clinically significant effect of air pollution should be considered adverse.
* Mortality should be considered as a critical health outcome.
* More sensitive health outcomes (for example, hospital admissions, emergency department visits, exacerbation of asthma and other respiratory or cardiovascular diseases and reversible decrements in lung function) should also be used where CRFs are available. Particular attention should be paid to people with asthma, given the high prevalence of asthma in the Australian population.
* Broader quality-of-life issues, such as work loss days and school absenteeism, should be considered as health outcomes where data are available.
* Sensitive subpopulations within the general population should be taken into consideration; they include children, older adults, people with existing respiratory and cardiovascular disease, asthmatics, diabetics, and low socioeconomic groups.
* A non-threshold approach should be taken for the current criteria pollutants.
* CRFs obtained from meta-analyses or multi-city studies should be used, provided the primary data are homogeneous. If significant heterogeneity is present, then CRFs for single cities should be used, and risk assessed for the relevant cities for which data are available.
* CRFs from well-conducted Australian studies are preferred. If high-quality Australian data for a particular health outcome are not available, then CRFs from overseas studies should be used provided the nature of the exposure and demographics of the population are similar. If overseas data are used, then the uncertainties associated with the use of the data need to be well documented.

When individual epidemiological studies are used to derive CRFs, the National Health and Medical Research Council ([National Health and Medical Research Council 2006](#_ENREF_78)) recommends the following steps to assess the validity and usefulness of such studies:

* *Step 1—Evaluate studies for internal validity*: that is, the adequacy of study design and the extent to which it has validly measured what it intends or purports to measure.
* *Step 2 —Evaluate studies for external validity*: that is, determine whether the results can be validly generalised, extrapolated or transferred to other settings (for example, climatic, demographic, pollution sources and levels).
* *Step 3 —Evaluate corroboration, contradiction and plausibility:* that is, consider whether the Bradford-Hill criteria may be useful here.
* *Step 4 —Make a choice*: that is, select the study or studies that best represent the endpoint of most relevance for setting an air quality standard.

**Methods used in this report**

For this report, we have broadly followed the approach recommended by the NEPC ([National Environment Protection Council 2011](#_ENREF_77)). However, in view of the very short timeframe for the completion of this report, we have adopted the following approach:

1. Only human epidemiological studies were considered. We have not considered controlled human exposure studies and toxicological studies.
2. CRFs representative of the general population were selected where available.
3. Identification of relevant health endpoints and associated CRFs from published reports, systematic reviews and meta-analyses from:
* United Kingdom ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19); [Committee on the Medical Effects of Air Pollutants 2007](#_ENREF_22); [Committee on the Medical Effects of Air Pollutants 2009](#_ENREF_23); [Committee on the Medical Effects of Air Pollutants 2010](#_ENREF_24));
* United States ([US EPA 2006](#_ENREF_114); [US EPA 2008](#_ENREF_115); [US EPA 2010](#_ENREF_118); [US EPA 2010](#_ENREF_119); [US EPA 2010](#_ENREF_120); [US EPA 2011](#_ENREF_121));
* European Commission ([AEA Technology Environment 2005](#_ENREF_7); [European Commission 2005](#_ENREF_38));
* World Health Organization ([WHO Europe 2000](#_ENREF_127); [WHO Europe 2003](#_ENREF_129); [WHO Europe 2004](#_ENREF_131)); and,
* Australia ([Curtin University of Technology 2009](#_ENREF_25); [Jalaludin, Salkeld et al. 2009](#_ENREF_59)).
1. Identification of relevant health endpoints and associated CRFs from individual Australian studies if systematic reviews and meta-analyses of Australian studies were not available.
2. Recommended CRFs from well-conducted Australian meta-analyses in the first instance. If CRFs from well-conducted Australian meta-analyses are not available, then CRFs from international reports are recommended. If CRFs from Australian meta-analyses and international reports are not available, then CRFs from individual Australian studies are recommended if appropriate.

For each of the air pollutants, we have tabulated the available health endpoints and associated CRFs. We have also provided references of the source reports and original publications from where the health endpoints and CRFs were derived. Finally, we have recommended CRFs that could be used for HRAs in the Australian context.

There may be assumptions and uncertainties associated with each of the health endpoints and CRFs. We therefore recommend that those who wish to use the health endpoints and associated CRFs also seek out the original reports and publications. CRFs derived from single studies (not meta-analyses or multi-city studies) or single locations should be used with caution as they may not be representative of the larger population.

CRFs for the five air pollutants are presented in Tables 1-5.

**Availability of health outcome data**

We have reported on the availability of relevant Australian health outcome data deemed useful for HRAs and CBAs (presented in Table 6). Relevant morbidity data will need to be accessed via each state health agency. While the Australian Institute of Health & Welfare does collate state data for some health outcomes, in most cases they will not be available to external users in the format required. Mortality data are available from the Australian Bureau of Statistics. Application to all agencies is necessary and for state agencies the timeframe for receipt of data may vary from a few weeks to a few months.

**REFERENCES**

AEA Technology Environment (2005). Methodology for the cost-benefit analysis for CAFE: Volume 2: Health impact assessment. Oxon, UK, AEA Technology Environment.

BTRE (2005). Health impacts of transport emissions in Australia: economic costs. Working Paper 63. Canberra, Bureau of Transport and Regional Economics, Department of Transport and Regional Services, Commonwealth of Australia.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2007). The effects of long-term exposure to ozone. London, Department of Health, UK.

Committee on the Medical Effects of Air Pollutants (2009). Long-term exposure to air pollution: effect on mortality. London, Department of Health, UK.

Committee on the Medical Effects of Air Pollutants (2010). The mortality effects of long-term exposure to pariculate air pollution in the United Kingdom. London, Department of Health, UK.

Curtin University of Technology (2009). Review of the health effects of specific air pollutants Canberra, Report Commissioned by the Australian Government Department of Health and Ageing.

DEC (2005). Air Pollution Economics: Health Costs of Air Pollution in the Greater Sydney Metropolitan Region. Sydney, Department of Environment and Conservation, NSW.

DEFRA (2006). An Economic Analysis to Inform the Air Quality Strategy Review Consultation. London, UK, Department for Environment, Food and Rural Affair.

European Commission (2005). ExternE. Externalities of Energy: Methodology 2005 Update. P. Bickel and R. Friedrich, Luxemburg, European Commission.

Fisher, G., T. Kjellstrom, et al. (2005). Health and Air Pollution in New Zealand: Christchurch Pilot Study, Health Research Council, Ministry for the Environment, Ministry of Transport, New Zealand.

Jalaludin, B., G. Salkeld, et al. (2009). A methodology for cost-benefit analysis of ambient air pollution health impacts. Canberra, Australian Government Department of the Environment, Water, Heritage and the Arts, Commonwealth of Australia**:** 314.

National Environment Protection Council (2011). Methodology for setting air quality standards in Australia. Part A. Adelaide, Commonwealth of Australia.

National Health and Medical Research Council (2006). Ambient air quality standards setting. An approach to health-based hazard assessment. Canberra, Australian Government.

Seethaler, R. (1999). Health Costs due to Road Traffic-related Air Pollution. Bern, Federal Department of Environment, Transport, Energy and Communications; Bureau for Transport Studies, Switzerland.

US EPA (1999). The Benefits and Costs of the Clean Air Act 1990 to 2010. Washington, DC, United States Environmental Protection Agency.

US EPA (2004). Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. Washington, DC, United States Environmental Protection Agency.

US EPA (2006). Regulatory impact analysis. National Ambient Air Quality Standards for particle pollution, Research Triangle Park, North Carolina.

US EPA (2008). Final ozone National Ambient Air Quality Standards regulatory impact analysis, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina**:** 558.

US EPA (2010). Final Regulatory Impact Analysis (RIA) for the NO2 National Ambient Air Quality Standards (NAAQS), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, North Carolina, USA**:** 155.

US EPA (2010). Final Regulatory Impact Analysis (RIA) for the SO2 National Ambient Air Quality Standards (NAAQS), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA**:** 189.

US EPA (2010). Quantitative Health Risk Assessment for Particulate Matter, Health and Environmental Impacts Division, US Environmental Protection Agency, NC, USA**:** 596.

US EPA (2011). The benefits and costs of the Clean Air act from 1990 to 2020, U.S. Environmental Protection agency, USA.

WHO Europe (2000). Air quality guidelines for Europe: second edition. Copenhagen, WHO Regional Office for Europe.

WHO Europe (2001). Quantification of the heatlh effects of exposure to air pollution: report of a WHO working group Bilthoven, Netherlands 20-22 November 2000. Copenhagen, WHO Regional Office for Europe.

WHO Europe (2003). Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide: report on a WHO working group. Bonn, Germany, WHO**:** 98.

WHO Europe (2004). Health aspects of air pollution. Results from the WHO project "Systematic review of health aspects of air pollution in Europe". Copenhagen, World Health Organization.

WHO Europe (2004). Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3). Report of a WHO task group. Copenhagen, World Health Organization.

Table 1: PM2.5 health endpoints and associated concentration-response functions

|  | **Concentration-response function (95%CI)** |
| --- | --- |
| **Health outcomes** | **Australian** | **UK** | **Europe** | **US EPA** | **WHO** | **Recommended** |
| ***Long-term outcomes (annual average concentration)*** |
| **Mortality** |
| All cause  | n/a1 | 1.06 (1.04-1.11) per 10 µg/m31.06 (1.00-1.15) per 10 µg/m3 to be used in a sensitivity analysis.([Pope, Burnett et al. 2002](#_ENREF_88))([Committee on the Medical Effects of Air Pollutants 2009](#_ENREF_23))Age: 30+ years. | 1.05 per 10 µg/m3(95%CI not provided)Pooled estimate from ([Pope, Burnett et al. 2002](#_ENREF_88))([European Commission 2005](#_ENREF_38))Age: 30+years. | 1.06 (1.04-1.08) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120))All ICD9Age: 30+years. | 1.14 (1.04-1.24) per 10 µg/m3([Dockery, Pope et al. 1993](#_ENREF_31))([WHO Europe 2000](#_ENREF_127))Age: 30+ years1.07 (1.04-1.11) per 10 µg/m3([Pope, Thun et al. 1995](#_ENREF_90))([WHO Europe 2000](#_ENREF_127))Age: 30+years. | Recommended CRF: 1.06 (1.04-1.08) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120)) |
| Cardiopulmonary  | n/a | 1.09 (1.03-1.16)per 10 µg/m3([Pope, Burnett et al. 2002](#_ENREF_88))([Committee on the Medical Effects of Air Pollutants 2009](#_ENREF_23))Age: 30+ years. | n/a | 1.14 (1.11-1.17 per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120))ICD9: 401-440, 460-519Age: 30+ years. | n/a | Recommended CRF: 1.14 (1.11-1.17 per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120)) |
| Ischaemic heart disease | n/a | n/a | n/a | 1.24 (1.19-1.28) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120))ICD9: 410-414Age: 30+ years. | n/a | Recommended CRF: 1.24 (1.19-1.28) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120)) |
| Lung cancer | n/a | 1.08 (1.01-1.16)per 10 µg/m3([Pope, Burnett et al. 2002](#_ENREF_88))([Committee on the Medical Effects of Air Pollutants 2009](#_ENREF_23))Age: 30+ years. | n/a | 1.14 (1.06-1.123) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120))ICD9: 162Age: 30+ years. | n/a | Recommended CRF: 1.14 (1.06-1.123) per 10 µg/m3([Krewski, Jerrett et al. 2009](#_ENREF_64))([US EPA 2010](#_ENREF_120)) |
| Infant (<12 months of age) | n/a | n/a | n/a | 1.07 (0.93-1.24) for 10 µg/m3([Woodruff, Parker et al. 2006](#_ENREF_136))([US EPA 2006](#_ENREF_114))All ICD9Age: <12 months | n/a | Recommended CRF: 1.07 (0.93-1.24) for 10 µg/m3([Woodruff, Parker et al. 2006](#_ENREF_136))([US EPA 2006](#_ENREF_114)) |
| Life expectancy lost (years of life lost; YOLL) | n/a | 6 months of life expectancy lost in the UK at current levels of anthropogenic PM2.5 (~9 µg/m3)([Committee on the Medical Effects of Air Pollutants 2010](#_ENREF_24)) | 6.02E-04 YOLL/ (person/year/µg/m3) ([Leksell and Rabl 2001](#_ENREF_67)) ([European Commission 2005](#_ENREF_38)) | n/a | n/a | Recommended CRF: 6.02E-04 YOLL/ (person/year/µg/m3) ([Leksell and Rabl 2001](#_ENREF_67)) ([European Commission 2005](#_ENREF_38)) |
| **Morbidity** |
| Incidence of chronic obstructive pulmonary disease (COPD) or chronic bronchitis | n/a | n/a | Chronic bronchitis:1.181 (0.98-3.25) per 45 µg/m3OR1.141 (0.996-1.30) per 10 µg/m3([Abbey, Lebowitz et al. 1995](#_ENREF_2)) ([European Commission 2005](#_ENREF_38)) Adults (27+ years) with cough or sputum on most days for at least three months of the year for at least two years. | COPD:1.81 (0.98-3.25) per 10 µg/m3([Abbey, Hwang et al. 1995](#_ENREF_1))([US EPA 2006](#_ENREF_114))Age: >26 years | Chronic bronchitis:1.34 (0.94-1.99) per 10 µg/m3([Dockery, Cunningham et al. 1996](#_ENREF_30))([WHO Europe 2000](#_ENREF_127))?Age | Recommended CRF for COPD: 1.81 (0.98-3.25) per 10 µg/m3([Abbey, Hwang et al. 1995](#_ENREF_1))([US EPA 2006](#_ENREF_114))Age: >26 yearsChronic bronchitis:No CRF recommended. |
| Incidence of asthma | Ever had wheezing:No effect.Ever had asthma:No effect.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly. PM2.5 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Recent symptoms (in last 12 months) | No effect for asthma exacerbation, wheeze, cough or shortness of breath. ([Bennett, Simpson et al. 2007](#_ENREF_14))MelbourneN=1,446Mean age: 37 years. 12-month average.No effect for wheeze, wheeze after exercise, current asthma, use of bronchodilators, cough, visit to doctor/hospital, rhinitis and itchy rash in single pollutant models.Increased risk for rhinitis in 2-pollutant model with O3: 1.26 (1.04-1.53) per 2.16 µg/m3([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly. PM2.5 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRF only for rhinitis ([Williams, Marks et al. 2012](#_ENREF_132)).No effect for other symptoms in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Lung function growth  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly. PM2.5 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in forced vital capacity (FVC; litres) | No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly. PM2.5 over lifetime. Age: mean age10.0 years. 2,860 children. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Airway inflammation | No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly. PM2.5 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Birth outcomes** |
| Birth defects | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Prematurity | 1.09 (0.97–1.23) per 10 Mm-1 bsp in first trimester0.95 (0.85–1.06) per 8.2 Mm-1 bsp in last 90 days before birth([Hansen, Neller et al. 2006](#_ENREF_44))Preterm: <37 weeks gestation.Brisbane1.426 (1.264–1.608) per 1 µg/m3([Jalaludin, Mannes et al. 2007](#_ENREF_56))SydneyPreterm: <37 weeks gestation.First trimester.Winter season. | n/a | n/a | n/a | n/a | No CRF recommended.Inconsistent results from 2 Australian studies. |
| Low birth weight | No effect of bsp on birth weight or small for gestational age (<10th centile for age and gender)([Hansen, Neller et al. 2007](#_ENREF_45))Brisbane1.03 (1.01-1.05) for small for gestational age (<2 standard deviations for age and gender) per 1 µg/m3Second trimester-4.10 grams (-6.79 to -1.41 grams) per 1 µg/m3Second trimester([Mannes, Jalaludin et al. 2005](#_ENREF_70))Sydney | n/a | n/a | n/a | n/a | No CRF recommended.Inconsistent results from 2 Australian studies. |
| ***Short-term outcomes (dailyaverageconcentration)*** |
| **Mortality** |
| Non-trauma | No effect.([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 3 cities (Sydney, Perth, Melbourne)ICD9: <800; ICD10: A-R, Z35.5, Z35.8Age: All0.9% (0.2-1.6%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Age: All ages.All year.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: <800; ICD10: A-R, Z35.5, Z35.8 | n/a | n/a | 0.98% (0.75 to 1.22%) per 10 µg/m3([Zanobetti and Schwartz 2009](#_ENREF_138))([US EPA 2010](#_ENREF_120))ICD10: A00-R99All ages | 1.00339 (0.99150-1.01542) per 10 µg/m3([Anderson, Bremner et al. 2001](#_ENREF_9))([WHO Europe 2004](#_ENREF_131))1 study onlyICD9: <800All ages1.015 (1.011-1.019) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?ICD codes?All ages | Recommended CRF: 0.9% (0.2-1.6%) per 3.78 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cardiovascular | 1.0439 (1.0090-1.0800) increase per 1 unit bsp (10-4.m-1)([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 cities (Sydney, Perth, Melbourne, Brisbane)ICD9: 390-459ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58Age: All ages.Lag 1 24-hour bsp.1.5% (0.7-2.3%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Age: All ages.All year.No heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 1.4% (0.7-2.2%) per 10 µg/m3([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))9 studies ICD9: 390-459All ages. | n/a | 0.85% (0.46 to 1.25%) per 10 µg/m3([Zanobetti and Schwartz 2009](#_ENREF_138))([US EPA 2010](#_ENREF_120)) ICD10: I01-I59Ages: All ages. | 1.00507 (0.98808- 1.02236) per 10 µg/m3([Anderson, Bremner et al. 2001](#_ENREF_9))([WHO Europe 2004](#_ENREF_131))1 study onlyICD9: 390-459Age: All ages. | Recommended CRF: 1.5% (0.7-2.3%) per 3.78 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory  | 1.0948 (1.0174-1.1781) increase per 1 unit bsp (10-4.m-1)([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 cities (Sydney, Perth, Melbourne, Brisbane)ICD9: 460-519ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8Age: All ages.Lag 1 24-hour bsp.No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Age: All ages.All year.No heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | n/a | n/a | 1.68% (1.04 to 2.33%) per 10 µg/m3([Zanobetti and Schwartz 2009](#_ENREF_138))([US EPA 2010](#_ENREF_120))ICD10: J00-J99Age: All ages. | 0.99943 ( 0.96912- 1.03069) per 10 µg/m3([Anderson, Bremner et al. 2001](#_ENREF_9))([WHO Europe 2004](#_ENREF_131))1 study onlyICD9: 460-519Age: All ages.  | No CRF recommended.No effect in Australian 4- cities studies ([Environment Protection and Heritage Council 2005](#_ENREF_35))May use CRF from Zanobetti et al ([Zanobetti and Schwartz 2009](#_ENREF_138))In a sensitivity analysis. |
| **Hospitalisation** |
| Cardiovascular | 15-64 years: No effect65+ years: 1.3% (0.6-2.0) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 65+ years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459; ICD10: I00–I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0),G45 (excluding G45.3), G46, M30, M31, R58 | n/a | n/a | 0.80% (0.59-1.10%) per 10 µg/m3([Bell, Ebisu et al. 2008](#_ENREF_13))([US EPA 2010](#_ENREF_120))ICD9: 426-428, 430-438,410-414, 429, 440-449Age: 65-99 years | n/a | Recommended CRF: 65+ years: 1.3% (0.6-2.0) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cardiac | 5.1% (3.5-6.7% per 10 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 3 cities - Sydney, Melbourne, Perth. lCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1Age: All ages.1-hour maximum.15-64 years: No effect65+ years: 1.9% (1.0-2.7%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 65+ years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 1.9% (1.0-2.7%) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) in a sensitivity analysis. |
| Cardiac failure | 15-64 years: No effect65+ years: 3.6% (1.8-5.4%) per 3.78 µg/m324-hour average.Lag 01.Moderate heterogeneity for 65+ years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 428; ICD10: I50 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 3.6% (1.8-5.4%) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cerebrovascular  | Stroke:15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 430-438; ICD10: I60-I66, I67 (excluding I67.0, I67.3), I68 (excluding I68.0), I69, G45 (excluding G45.3), G46 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Ischaemic heart disease  | 15-64 years: No effect65+ years: 1.6% (0.7-2.4%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 410-413; ICD10: 120-122, 124, 125.2 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 1.6% (0.7-2.4%) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Arrhythmia | 15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 437; ICD10: I46-I49 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Myocardial infarction | 15-64 years: No effect.65+ years: 2.7% (1.3-4.2%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity for 65+ years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 410; ICDI0: I21, I22 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 2.7% (1.3-4.2%) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory | 1.0401 (1.0045-1.0770) increase per 1 unit bsp (10-4.m-1)([Simpson, Williams et al. 2005](#_ENREF_103))Pooled CRF from 4 cities - Sydney, Perth, Melbourne, Brisbane.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8Age: 65+ years.24-hour bsp.Lag 1.0 year: 2.4% (1.0-3.8%) increase per 3.78 µg/m31-4 years: 1.7% (0.7-2.7%) increase per 3.78 µg/m35-14 years: No effect15-64 years: 1.1% (0.0-2.1%) increase per 3.78 µg/m365+ years: 1.6% (0.9-2.3%) increase per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9),R09.1, R09.8 | n/a | n/a | No effect.([Bell, Ebisu et al. 2008](#_ENREF_13))([US EPA 2010](#_ENREF_120))ICD9: 490-492, 463-466, 480-487Age: 65-99 years.2.07% (1.2-2.95%) per 10 µg/m3([Zanobetti and Schwartz 2009](#_ENREF_138))([Abt Associates Inc 2011](#_ENREF_3))ICD9: 460-519Age: 65-99 years.2-day average | 0-14 years: No effect.15-64 years:No effect.65+ years:No effect.([Anderson, Bremner et al. 2001](#_ENREF_9))([WHO Europe 2004](#_ENREF_131))1 study onlyICD9: 460-519.Age: All ages. | Recommend CRF: CRFs from Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Asthma | 1.0893 (1.0240-1.1587) increase per 1 unit bsp (10-4.m-1)([Simpson, Williams et al. 2005](#_ENREF_103))Pooled CRF from 4 cities (Sydney, Perth, Melbourne, Brisbane)ICD9: 493; ICD10: J45, J46, J44.8Age: 15-64 years.Lag 3 24-hour bsp.0 year: not calculated due to uncertain diagnosis.1-4 years: No effect.5-14 years: No effect.15-64 years: 2.2% (0.7-3.6%) per 3.78 µg/m3.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 15-64 years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 493; ICD10: J45, J46, J44.8 | n/a | n/a | 1.04 (1.01-1.06) per 11.8 µg/m3([Sheppard 2003](#_ENREF_101))([Abt Associates Inc 2011](#_ENREF_3))Age: 0-64 yearsICD9 493 | n/a | Recommend CRF: CRFs from Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Chronic obstructive pulmonary disease (COPD) | 15-64 years: No effect65+ years: 1.6% (0.6-2.7%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 15-64 years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 490-492, 494-496; ICDI0: J40-J44, J47, J67  | n/a | n/a | n/a | n/a | Recommend CRF: CRF for 65+ years from Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Pneumonia and acute bronchitis | 0 years: 1.0% (0.0-3.4%) per 3.78 µg/m31-4 years: 2.4% (0.1-4.7%) per 3.78 µg/m315-64 years: No effect65+ years: 2.0% (0.8-3.2%) per 3.78 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 15-64 years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 466, 480-486; ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J21 | n/a | n/a | n/a | n/a | Recommend CRF: CRFs from Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| **Emergency department visits** |
| Asthma  | 1.4% (0.9-1.8%) increase per 9.4 µg/m3([Jalaludin, Khalaj et al. 2008](#_ENREF_55))Sydney.ICD9: 493.Age: 1-14 years.  | n/a | n/a | 1.0045 (1.0029-1.0062) per 1 µg/m3([Ito, Thurston et al. 2007](#_ENREF_52))([US EPA 2010](#_ENREF_120))ICD9: 493Age: All ages.24-hour average.New York. | n/a | Recommended CRF: 1.4% (0.9-1.8%) increase per 9.4 µg/m3([Jalaludin, Khalaj et al. 2008](#_ENREF_55))May use CRF from Ito et al ([Ito, Thurston et al. 2007](#_ENREF_52)) in a sensitivity analysis. |
| Respiratory disease  | n/a | n/a | n/a | 1.00046 (0.99954-1.00136) per 1 µg/m3([Tolbert, Klein et al. 2007](#_ENREF_110))([US EPA 2010](#_ENREF_120))Age: All ages.24-hour average.Atlanta.ICD9: 491-493, 786.07, 786.09, 496, 460-465, 460.0, 477, 480-486, 466.1, 466.11, 466.19 | n/a | No CRF recommended.May use CRF from Tolbert ([Tolbert, Klein et al. 2007](#_ENREF_110))in a sensitivity analysis as the CRF is close to being statistically significant. Note that respiratory disease ICD codes include asthma. |
| Cardiovascular disease  | n/a | n/a | n/a | 1.00046 (0.99936-1.00154) per 1 µg/m3([Tolbert, Klein et al. 2007](#_ENREF_110))([US EPA 2010](#_ENREF_120))All ages.24-hour average.Atlanta.ICD9: 410-414, 427-428, 433-437, 440, 443-445, 451-453 | n/a | No CRF recommended.May use CRF from Tolbert ([Tolbert, Klein et al. 2007](#_ENREF_110))in a sensitivity analysis as the CRF is close to being statistically significant.  |
| **Incidence of myocardial infarction (heart attacks)** |
| Non-fatal heart attacks(24-hr PM)  | n/a  | n/a | n/a | 1.62 (1.13-2.34) per 20 µg/m3([Peters, Dockery et al. 2001](#_ENREF_86))([US EPA 2006](#_ENREF_114))Age: 18+ yearsICD9: 410 | n/a | Recommended CRF: 1.62 (1.13-2.34) per 20 µg/m3([Peters, Dockery et al. 2001](#_ENREF_86)) |
| **Lung function** |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect ([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean age 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | -1.9% (-3.1 to -0.6%) per 10 µg/m3([Raizenne, Neas et al. 1996](#_ENREF_91))Children | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in peak expiratory flow rate (PEF; litres per minute) | No effect of bsp.([Rutherford, Simpson et al. 2000](#_ENREF_94))Brisbane and IpswichMixed-modelsAge: All(n=53)History of allergy to pollen or fungi on skin prick testingNo effect. ([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean age 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Minor morbidity** |
| Asthma exacerbation  | n/a | n/a | n/a | n/a (not reported in Abt Associates 2011or in USEPA 2006)Pooled estimate from Vedal 1998 and Ostro 2001([US EPA 2006](#_ENREF_114))Age: 6-18 years | n/a | No CRF recommended. |
| Increased airway hyper-responsiveness | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Restricted activity days (RAD)2 | n/a | n/a | 0.475% (0.417-0.533%) per 1 μg/m3 ([Ostro 1987](#_ENREF_82))([European Commission 2005](#_ENREF_38))Age: 15-64 years.In a sensitivity analysis, all ages used. | n/a | n/a | Recommended CRF: 0.475% (0.417-0.533%) per 1 μg/m3 PM2.5([Ostro 1987](#_ENREF_82))([European Commission 2005](#_ENREF_38)) |
| Minor restricted activity days (MRAD)3  | n/a | n/a | 0.74% (0.60-0.88%) per 1 μg/m3 ([Ostro and Rothschild 1989](#_ENREF_83))([European Commission 2005](#_ENREF_38))Age: 18-64 years. | 1.0769 (1.0622-1.0918) per 10 μg/m3 ([Ostro and Rothschild 1989](#_ENREF_83))([US EPA 2006](#_ENREF_114))Age: 18-64 years. | n/a | Recommended CRF: 1.0769 (1.0622-1.0918) per 10 μg/m3 ([Ostro and Rothschild 1989](#_ENREF_83))([US EPA 2006](#_ENREF_114)) |
| Work lost days (WLD)2  | n/a | n/a | 0.46% (0.39-0.53%) per 1 μg/m3 ([Ostro 1987](#_ENREF_82))([European Commission 2005](#_ENREF_38))CAFE CBA 2005Age: 15-64 years. | 1.0471 (1.0397-1.0545) per 10 μg/m3 ([Ostro 1987](#_ENREF_82))([US EPA 2006](#_ENREF_114))Age: 18-64 years. | n/a | Recommended CRF: 1.0471 (1.0397-1.0545) per 10 μg/m3 ([Ostro 1987](#_ENREF_82))([US EPA 2006](#_ENREF_114)) |
| Acute bronchitis (incidence, 8-12 years) | n/a | n/a | n/a | 1.5 (0.91-2.47) per 14.9 µg/m3([Dockery, Cunningham et al. 1996](#_ENREF_30))([US EPA 2006](#_ENREF_114))Annual average.  | n/a | Recommended CRF: 1.5 (0.91-2.47) per 14.9 µg/m3([Dockery, Cunningham et al. 1996](#_ENREF_30))([US EPA 2006](#_ENREF_114)) |
| Lower respiratory symptoms  | n/a | n/a | n/a | 1.33 (1.11-1.58) per 15 µg/m3([Schwartz and Neas 2000](#_ENREF_98))([US EPA 2006](#_ENREF_114))Age: 7-14 years.  | n/a | Recommended CRF: 1.33 (1.11-1.58) per 15 µg/m3([Schwartz and Neas 2000](#_ENREF_98))([US EPA 2006](#_ENREF_114)) |
| Acute respiratory symptoms | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Wheeze | No effect.Rodriguez 2007Age: 0-5 years.Perth.1-hour maximum.No effect.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | Only for African-American children([Ostro, Lipsett et al. 2001](#_ENREF_81))([Abt Associates Inc 2011](#_ENREF_3)) | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Cough | 1.006 (1.000-1.012) per ?1µg/m3([Rodriguez, Tonkin et al. 2007](#_ENREF_92))Age: 0-5 years.Perth.1-hour maximum.No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | Only for African-American children.([Ostro, Lipsett et al. 2001](#_ENREF_81))([Abt Associates Inc 2011](#_ENREF_3)) | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Shortness of breath | No effect.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | Only for African-American children.([Ostro, Lipsett et al. 2001](#_ENREF_81))([Abt Associates Inc 2011](#_ENREF_3)) | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Bronchodilator use | No effect.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Upper respiratory symptoms  | Runny/blocked nose: No effect.([Rodriguez, Tonkin et al. 2007](#_ENREF_92))Age: 0-5 years.Perth.1-hour maximum. | n/a | n/a | Only for African-American children.([Ostro, Lipsett et al. 2001](#_ENREF_81))([Abt Associates Inc 2011](#_ENREF_3)) | n/a | No CRF recommended.Only Australian study did not show any adverse effects. |
| Increased respiratory symptoms | Any day symptoms: No effect on any day symptoms - cough, wheeze, shortness of breath, runny nose, eye irritation, fever.Any night symptoms: No effect on any night symptoms - cough, wheeze, shortness of breath.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| General practitioner consultation for asthma | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| General practitioner consultation for upper respiratory disease | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |

1n/a=not available

2A restricted activity days is defined as a day when a person is forced to alter his/her normal activity. A severe restriction include days when it necessary to stay in bed. For employed adults, restricted activity days include Work Loss Days; for children, it would include days off school (whether or not the child is confined to bed) (ExternE 1995).

3Minor restricted activity days do not involve work loss or bed disability but do include some noticeable limitation on ‘normal’ activity (ExternE 1995).

**REFERENCES**

Abbey, D. E., B. L. Hwang, et al. (1995). "Estimated long-term ambient concentrations of PM10 and development of respiratory symptoms in a nonsmoking population." Archives of Environmental Health **50**(2): 139-152.

Abbey, D. E., M. D. Lebowitz, et al. (1995). "Long-term ambient concentrations of particulates and oxidants and development of chronic disease in a cohort of nonsmoking California residents " Inhalation Toxicology **7**: 19-34.

Abt Associates Inc (2011). BENMAP. User's manual appendices, Office of Air Quality Planning and Standards, Research Triangle Park, NC, USA. .

Abt Associates Inc. (2005). BENMAP: Technical appendices, Prepared by Abt Associates Inc. for the Office of Air Quality Planning and Standards, US EPA, Research Triangle Park, North Carolina.

ACAM (2011). Asthma in Australia 2011 Canberra, AIHW Asthma Series no 4. Cat. No. ACM. Australian Centre for Asthma Monitoring, AIHW.

Ackermann-Liebrich, U., P. Leuenberger, et al. (1997). "Lung function and long term exposure to air pollutants in Switzerland. Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team." American Journal of Respiratory and Critical Care Medicine **155**(1): 122-129.

AEA Technology Environment (2005). Methodology for the cost-benefit analysis for CAFE: Volume 2: Health impact assessment. Oxon, UK, AEA Technology Environment.

Anderson, H. R., R. W. Atkinson, et al. (2004). Meta-Analysis of Time-Series Studies and Panel Studies of Particulate Matter (PM) and Ozone (O3). Copenhagen, World Health Organization Regional Office for Europe**:** 80.

Anderson, H. R., S. A. Bremner, et al. (2001). "Particulate matter and daily mortality and hospital admissions in the west midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke and sulphate." Occupational & Environmental Medicine **58**(8): 504-510.

Anderson, H. R., C. Spix, et al. (1997). "Air pollution and daily admissions for chronic obstructive pulmonary disease in 6 European cities: results from the APHEA project [see comments]." European Respiratory Journal **10**(5): 1064-1071.

Australian Institute of Health and Welfare (2005). Chronic respiratory diseases in Australia. Their prevalence, consequences and prevention AIHW Cat. No. PHE 63. Canberra: AIHW.

Barnett, A. G., G. M. Williams, et al. (2005). "Air pollution and child respiratory health. A case-crossover study in Australia and New Zealand." American Journal of Respiratory and Critical Care Medicine **171**(11): 1272-1278.

Bell, M. L., K. Ebisu, et al. (2008). "Seasonal and regional short-term effects of fine particles on hospital admissions in 202 US counties, 1999-2005." American Journal of Epidemiology **168**(11): 1301-1310.

Bennett, C. M., P. Simpson, et al. (2007). "Associations between ambient PM2.5 concentrations and respiratory symptoms in Melbourne, 1998–2005." Journal of Toxicology and Environmental Health, Part A **70**(19): 1613-1618.

BTRE (2005). Health impacts of transport emissions in Australia: economic costs. Working Paper 63. Canberra, Bureau of Transport and Regional Economics, Department of Transport and Regional Services, Commonwealth of Australia.

Buist, A. S., W. M. McBurnie, et al. (2007). "International variation in the prevalence of COPD (The BOLD Study): a population-based prevalence study." The Lancet **370**: 741-750.

Burnett, R. T., D. Stieb, et al. (2004). "Associations between short-term changes in nitrogen dioxide and mortality in Canadian cities." Archives of Environment Health **59**: 228-236.

Chen, L., K. Mengersen, et al. (2007). "Spatiotemporal relationship between particle air pollution and respiratory emergency hospital admissions in Brisbane, Australia." Science of the Total Environment **373**(1): 57-67.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2002). Is there a threshold for the effect of ozone on health? 1. Is there an effect on mortality and respiratory or circulatory admissions? London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2006). Cardiovascular disease and air pollution. London, Department of Health, UK.

Committee on the Medical Effects of Air Pollutants (2007). The effects of long-term exposure to ozone. London, Department of Health, UK.

Committee on the Medical Effects of Air Pollutants (2009). Long-term exposure to air pollution: effect on mortality. London, Department of Health, UK.

Committee on the Medical Effects of Air Pollutants (2010). The mortality effects of long-term exposure to pariculate air pollution in the United Kingdom. London, Department of Health, UK.

Curtin University of Technology (2009). Review of the health effects of specific air pollutants Canberra, Report Commissioned by the Australian Government Department of Health and Ageing.

DEC (2005). Air Pollution Economics: Health Costs of Air Pollution in the Greater Sydney Metropolitan Region. Sydney, Department of Environment and Conservation, NSW.

Declerq, C. and V. Macquet (2000). "Short-term Effects of Ozone on Respiratory Health of Children in Armentieres, North of France." Rev Epidemiol Sante Publique **48**(Suppl 2): S37-43.

DEFRA (2006). An Economic Analysis to Inform the Air Quality Strategy Review Consultation. London, UK, Department for Environment, Food and Rural Affair.

Delfino, R. J., R. S. Zeiger, et al. (2002). "Association of asthma symptoms with peak particulate air pollution and effect modification by anti-inflammatory medication use." Environmental Health Perspectives **110**(10): A607-A617.

Dockery, D. W., J. Cunningham, et al. (1996). "Health effects of acid aerosols on North American children: Respiratory symptoms." Environmental Health Perspectives **104**(5): 500-505.

Dockery, D. W., A. C. Pope, III, et al. (1993). "An association between air pollution and mortality in six U.S. cities [see comments]." New England Journal of Medicine **329**(24): 1753-1759.

Dockery, D. W. and C. A. Pope, III (1994). "Acute respiratory effects of particulate air pollution." Annual Review of Public Health **15**: 107-132.

Dusseldorp, A., H. Kruize, et al. (1995). "Associations of PM10 and airborne iron with respiratory health of adults living near a steel factory." American Journal of Respiratory and Critical Care Medicine **152**(6): 1932-1939.

ECRHS (1996). "European Community Respiratory Health Survey: Variations in the prevalence of respiratory symptoms, self-reported asthma attacks, and use of asthma medication in the European Community Respiratory Health Survey (ECRHS). ." Eur Respir J **9**: 687-695.

Environment Protection and Heritage Council (2005). Expansion of the multi-city mortality and morbidity study. Final report. Volume 3. Tabulated results, Environment Protection and Heritage Council.

Erbas, B., A.-M. Kelly, et al. (2005). "Air pollution and childhood asthma emergency hospital admissions: estimating intra-city regional variations." International Journal of Environmental Health Research **15**(1): 11-20.

European Commission (1995). Externalities of Energy "ExternE" Project, Volume 2, Methodology. Method for estimation of physical impacts and monetary valuation for priority impact pathways. Oxfordshire, UK, Prepared by ETSU and others**:** 408.

European Commission (2005). ExternE. Externalities of Energy: Methodology 2005 Update. P. Bickel and R. Friedrich, Luxemburg, European Commission.

Fisher, G., T. Kjellstrom, et al. (2005). Health and Air Pollution in New Zealand: Christchurch Pilot Study, Health Research Council, Ministry for the Environment, Ministry of Transport, New Zealand.

Gielen, M. H., S. C. van der Zee, et al. (1997). "Acute effects of summer air pollution on respiratory health of asthmatic children." American Journal of Respiratory and Critical Care Medicine **155**(6): 2105-2108.

Hajat, S., H. R. Anderson, et al. (2002). "Effects of air pollution on general practitioner consultations for upper respiratory diseases in London." Occupational & Environmental Medicine **59**(5): 294-299.

Hajat, S., A. Haines, et al. (2001). "Association between air pollution and daily consultations with general practitioners for allergic rhinitis in London, United Kingdom." American Journal of Epidemiology **153**(7): 704-714.

Hajat, S., A. Haines, et al. (1999). "Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London." Thorax **54**(7): 597-605.

Hansen, C., A. Neller, et al. (2006). "Maternal exposure to low levels of ambient air pollution and preterm birth in Brisbane, Australia." BJOG: An International Journal of Obstetrics & Gynaecology **113**(8): 935-941.

Hansen, C., A. Neller, et al. (2007). "Low levels of ambient air pollution during pregnancy and fetal growth among term neonates in Brisbane, Australia." Environmental Research **103**(3): 383-389.

Hansen, C. A., A. G. Barnett, et al. (2009). "Ambient Air Pollution and Birth Defects in Brisbane, Australia." Plos One **4**(4).

Hiltermann, T. J., J. Stolk, et al. (1998). "Asthma severity and susceptibility to air pollution." European Respiratory Journal **11**(3): 686-693.

Hinwood, A., N. De Klerk, et al. (2006). "The relationship between changes in daily air pollution and hospitalizations in Perth, Australia 1992 - 1998: A case-crossover study." International Journal of Environmental Health Research **16**(1): 27-46.

Hoek, G. and B. Brunekreef (1995). "Effect of photochemical air pollution on acute respiratory symptoms in children." American Journal of Respiratory and Critical Care Medicine **151**(1): 27-32.

Hu, W., K. Mengersen, et al. (2008). "Temperature, air pollution and total mortality during summers in Sydney, 1994–2004." International Journal of Biometeorology **52**(7): 689-696.

Hurley, F., A. Hunt, et al. (2005). Methodology Paper (Volume 2) for Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, In Particular in the Clean Air for Europe (CAFE) Programme. Oxon, UK, AEA Technology Environment.

Ito, K., G. Thurston, et al. (2007). "Characterization of PM2.5 gaseous pollutants and meteorological interactions in the context of time-series health effects models." Journal of Exposure Science and Environmental Epidemiology **17**(S2): S45-S60.

Jalaludin, B., T. Chey, et al. (2000). "Acute effects of low levels of ambient ozone on peak expiratory flow rate in a cohort of Australian children." International Journal of Epidemiology **29**(3): 549-557.

Jalaludin, B., B. Khalaj, et al. (2008). "Acute effects of ambient air pollutants on ED visits for asthma in children, Sydney, Australia: a case-crossover analysis." International Archives of Occupational & Environmental Health **81**(8): 967-974.

Jalaludin, B., B. Khalaj, et al. (2008). "Air pollution and ED visits for asthma in Australian children: a case-crossover analysis." International Archives of Occupational and Environmental Health **81**(8): 967-974.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**: 16.

Jalaludin, B., B. O'Toole, et al. (2004). "Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children." Environmental Research **95**(1): 32-42.

Jalaludin, B., G. Salkeld, et al. (2009). A methodology for cost-benefit analysis of ambient air pollution health impacts. Canberra, Australian Government Department of the Environment, Water, Heritage and the Arts, Commonwealth of Australia**:** 314.

Jalaludin, B., M. Smith, et al. (2000). "Acute effects of bushfires on peak expiratory flow rates in children with wheeze: a time series analysis." Australian & New Zealand Journal of Public Health **24**(2): 174-177.

Jalaludin, B. B., B. I. O'Toole, et al. (2004). "Acute effects of bushfires on respiratory symptoms and medication use in children with wheeze in Sydney, Australia." Environmental Health **4**(2): 20-29.

Jerrett, M., R. T. Burnett, et al. (2009). "Long-term ozone exposure and mortality." New England Journal of Medicine **360**(11): 1085-1095.

Just, J., C. Segala, et al. (2002). "Short-term health effects of particulate and photochemical air pollution in asthmatic children." European Respiratory Journal **20**(4): 899-906.

Krewski, D., M. Jerrett, et al. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality Boston, MA, HEI Research Report 140: Health Effects Institute.

Krupnick, A., W. Harrington, et al. (1990). "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." Journal of Environmental Economics and Management **18**(1): 1-18.

Lebowitz, M. D. (1996). "Epidemiological studies of the respiratory effects of air pollution." The European Respiratory Journal **9**: 1029-1054.

Leksell, I. and A. Rabl (2001). "Air Pollution and Mortality: Quantification and Valuation of Years of Life Lost." Risk Analysis **21**(5): 843-857.

Lewis, P. R., M. J. Hensley, et al. (1998). "Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales [see comments]." Medical Journal of Australia **169**(9): 459-463.

Linn, W. S., Y. Szlachcic, et al. (2000). "Air pollution and daily hospital admissions in metropolitan Los Angeles." Environmental Health Perspectives **108**(5): 427-434.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occup Environ Med **62**: 524-530.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occupational and Environmental Medicine **62**(8): 524-530.

McDonnell, W. F., D. E. Abbey, et al. (1999). "Long-term ambient ozone concentration and the incidence of asthma in nonsmoking adults: the AHSMOG Study." Environmental Research **80**(Section A): 110-121.

Moolgavkar, S. H. (2003). Air pollution and daily deaths and hospital admissions in Los Angeles and Cook counties. Revised analyses of time-series studies of air pollution and health. Special report. Boston, MA, Health Effects Institute**:** 183-198.

Morgan, G., S. Corbett, et al. (1998). "Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994." American Journal of Public Health **88**(12): 1761-1766.

Morgan, G., V. Sheppeard, et al. (2010). "Effects of bushfire smoke on daily mortality and hospital admissions in Sydney, Australia." Epidemiology **21**(1): 47-55.

Mortimer, K. M., L. M. Neas, et al. (2002). "The effect of air pollution on inner-city children with asthma." European Respiratory Journal **19**(4): 699-705.

National Environment Protection Council (2011). Methodology for setting air quality standards in Australia. Part A. Adelaide, Commonwealth of Australia.

National Health and Medical Research Council (2006). Ambient air quality standards setting. An approach to health-based hazard assessment. Canberra, Australian Government.

NYDOH (2006). A study of ambient air contaminants and asthma in New York City, New

York State Department of Health Center for Environmental Health.

O'Connor, G. T., L. Neas, et al. (2008). "Acute respiratory health effects of air pollution on children with asthma in US inner cities." Journal of Allergy & Clinical Immunology **121**(5): 1133-1139.

Ostro, B., M. Lipsett, et al. (2001). "Air pollution and exacerbation of asthma in African-American children in Los Angeles." Epidemiology **12**(2): 200-208.

Ostro, B. D. (1987). "Air pollution and morbidity revisited: A specification test." Journal of Environmental Economics and Management **14**(1): 87-98.

Ostro, B. D. and S. Rothschild (1989). "Air pollution and acute respiratory morbidity: an observational study of multiple pollutants." Environmental Research **50**(2): 238-247.

Peel, J. L., P. E. Tolbert, et al. (2005). "Ambient air pollution and respiratory emergency department visits." Epidemiology **16**(2): 164-174.

Pereira, G., A. Cook, et al. (2010). "A case-crossover analysis of traffic-related air pollution and emergency department presentations for asthma in Perth, Western Australia." Medical Journal of Australia **193**(9): 511-514.

Peters, A., D. W. Dockery, et al. (2001). "Increased particulate air pollution and the triggering of myocardial infarction." Circulation **103**(23): 2810-2815.

Petroeschevsky, A., R. W. Simpson, et al. (2001). "Associations between outdoor air pollution and hospital admissions in Brisbane, Australia." Archives of Environmental Health **56**(1): 37-52.

Pope, C. A., III, R. T. Burnett, et al. (2002). "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution." JAMA **287**(9): 1132-1141.

Pope, C. A., III, D. W. Dockery, et al. (1991). "Respiratory health and PM10 pollution. A daily time series analysis." American Review of Respiratory Disease **144**(3 Pt 1): 668-674.

Pope, C. A., III, M. J. Thun, et al. (1995). "Particulate air pollution as a predictor of mortality in a prospective study of US adults." American Journal of Respiratory and Critical Care Medicine **151**(3): 669-674.

Raizenne, M., L. M. Neas, et al. (1996). "Health effects of acid aerosols on North American children: Pulmonary function." Environmental Health Perspectives **104**(5): 506-514.

Rodriguez, C., R. Tonkin, et al. (2007). "The relationship between outdoor air quality and respiratory symptoms in young children." International Journal of Environmental Health Research **17**(5): 351-360.

Roemer, W., G. Hoek, et al. (1993). "Effect of ambient winter air pollution on respiratory health of children with chronic respiratory symptoms." American Review of Respiratory Disease **147**(1): 118-124.

Rutherford, S., R. Simpson, et al. (2000). "Relationships between environmental factors and lung function of asthmatic subjects in south east Queensland, Australia." Journal of Occupational & Environmental Medicine **42**(9): 882-891.

Schildcrout, J. S., L. Sheppard, et al. (2006). "Ambient air pollution and asthma exacerbations in children: an eight-city analysis." American Journal of Epidemiology **164**(6): 505-517.

Schwartz, J. (1993). "Air pollution and daily mortality in Birmingham, Alabama." American Journal of Epidemiology **137**(10): 1136-1147.

Schwartz, J., D. W. Dockery, et al. (1994). "Acute effects of summer air pollution on respiratory symptom reporting in children." American Journal of Respiratory and Critical Care Medicine **150**(5): 1234-1242.

Schwartz, J. and L. M. Neas (2000). "Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren." Epidemiology **11**(1): 6-10.

Schwartz, J., D. Slater, et al. (1993). "Particulate air pollution and hospital emergency room visits for asthma in Seattle." American Review of Respiratory Disease **147**(4): 826-831.

Seethaler, R. (1999). Health Costs due to Road Traffic-related Air Pollution. Bern, Federal Department of Environment, Transport, Energy and Communications; Bureau for Transport Studies, Switzerland.

Sheppard, L. (2003). Ambient air pollution and nonelderly asthma hospital admissions in Seattle, Washington, 1987-1994. Revised analyses of time-series studies of air pollution and health. Special report. Boston, MA, Health Effects Institute**:** 227-230.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on daily mortality in four Australian cities." Australian & New Zealand Journal of Public Health **29**(3): 205-212.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on hospital admissions in four Australian cities " Australian & New Zealand Journal of Public Health **29**(3): 213-221.

Spix, C., H. R. Anderson, et al. (1998). "Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe: a quantitative summary of APHEA study results. Air Pollution and Health: a European Approach." Archives of Environmental Health **53**(1): 54-64.

Streeton, J. (1997). A review of existing health data on six pollutants. National environment protection (ambient air quality) measure. Adelaide, National Environment Protection Council**:** 278.

Sunyer, J., J. Castellsague, et al. (1996). "Air pollution and mortality in Barcelona." Journal of Epidemiology & Community Health **50**(Suppl 1): s76-s80.

Sunyer, J., M. Saez, et al. (1993). "Air pollution and emergency room admissions for chronic obstructive pulmonary disease: a 5-year study." American Journal of Epidemiology **137**(7): 701-705.

Sunyer, J., C. Spix, et al. (1997). "Urban air pollution and emergency admissions for asthma in four European cities: the APHEA Project." Thorax **52**(9): 760-765.

Toelle, B. (2012). Airflow obstruction, respiratory symptoms and respiratory illnesses in Australians aged 40 years and older: the Burden of Obstructive Lung Disease (BOLD) study in Australia (personal communication; manuscript currently under review with the Medical Journal of Australia).

Tolbert, P. E., M. Klein, et al. (2007). "Multipollutant modeling issues in a study of ambient air quality and emergency department visits in Atlanta." Journal of Exposure Science and Environmental Epidemiology **17**(S2): S29-S35.

Touloumi, G., K. Katsouyanni, et al. (1997). "Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Air Pollution and Health: a European Approach." American Journal of Epidemiology **146**(2): 177-185.

US EPA (1999). The Benefits and Costs of the Clean Air Act 1990 to 2010. Washington, DC, United States Environmental Protection Agency.

US EPA (2004). Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. Washington, DC, United States Environmental Protection Agency.

US EPA (2006). Regulatory impact analysis. National Ambient Air Quality Standards for particle pollution, Research Triangle Park, North Carolina.

US EPA (2008). Final ozone National Ambient Air Quality Standards regulatory impact analysis, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina**:** 558.

US EPA (2008). Integrated science assessment for oxides of nitrogen-health criteria, EPA/600/R-08/071. US Enviromental Protection Agency.

US EPA (2008). Integrated science assessment for sulfur oxides-health criteria, ISA: EPA/600/R-08/047F US Environmental Protection Agency

US EPA (2010). Final Regulatory Impact Analysis (RIA) for the NO2 National Ambient Air Quality Standards (NAAQS), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, North Carolina, USA**:** 155.

US EPA (2010). Final Regulatory Impact Analysis (RIA) for the SO2 National Ambient Air Quality Standards (NAAQS), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA**:** 189.

US EPA (2010). Quantitative Health Risk Assessment for Particulate Matter, Health and Environmental Impacts Division, US Environmental Protection Agency, NC, USA**:** 596.

US EPA (2011). The benefits and costs of the Clean Air act from 1990 to 2020, U.S. Environmental Protection agency, USA.

Vedal, S., J. Petkau, et al. (1998). "Acute effects of ambient inhalable particles in asthmatic and nonasthmatic children." American Journal of Respiratory and Critical Care Medicine **157**(4): 1034-1043.

Ward, D. J. and J. G. Ayres (2004). "Particulate air pollution and panel studies in children: a systematic review." Occupational & Environmental Medicine **61**(4): e13.

Whittemore, A. S. and E. L. Korn (1980). "Asthma and air pollution in the Los Angeles area." American Journal of Public Health **70**(7): 687-696.

WHO (2006). "WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Global Update 2005. Summary of Risk Asessment.".

WHO (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global Update 2005. Summary of risk assessment. Geneva, World Health Organization.

WHO Europe (2000). Air quality guidelines for Europe: second edition. Copenhagen, WHO Regional Office for Europe.

WHO Europe (2001). Quantification of the heatlh effects of exposure to air pollution: report of a WHO working group Bilthoven, Netherlands 20-22 November 2000. Copenhagen, WHO Regional Office for Europe.

WHO Europe (2003). Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide: report on a WHO working group. Bonn, Germany, WHO**:** 98.

WHO Europe (2004). Health aspects of air pollution. Results from the WHO project "Systematic review of health aspects of air pollution in Europe". Copenhagen, World Health Organization.

WHO Europe (2004). Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3). Report of a WHO task group. Copenhagen, World Health Organization.

Williams, G., G. Marks, et al. (2012). Australian Child Health and Air Pollution Study (ACHAPS). Final report. Environment Protection and Heritage Council (in press).

Wilson, A. M., C. P. Wake, et al. (2005). "Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study." Environmental Research **97**(3): 312-321.

Wong, C. M., R. W. Atkinson, et al. (2002). "A tale of two cities: effects of air pollution on hospital admissions in Hong Kong and London compared." Environmental Health Perspectives **110**(1): 67-77.

Woodruff, T. J., J. Grillo, et al. (1997). "The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States." Environmental Health Perspectives **105**(6): 608-612.

Woodruff, T. J., J. D. Parker, et al. (2006). "Fine particle matter (PM2.5) air pollution and selected causes of postneonatal infant mortality in California." Environmental Health Perspectives **114**(5): 786-790.

Yu, O., L. Sheppard, et al. (2000). "Effects of ambient air pollution on symptoms of asthma in Seattle-area children enrolled in the CAMP study." Environmental Health Perspectives **108**(12): 1209-1214.

Zanobetti, A. and J. Schwartz (2009). "The effect of fine and coarse particulate air pollution on mortality: A National Analysis." Environmental Health Perspectives **117**(6): 898-903.

Zmirou, D., J. Schwartz, et al. (1998). "Time-series analysis of air pollution and cause-specific mortality." Epidemiology **9**(5): 495-503.

Table 2: PM10 health endpoints and concentration-response functions

|  | **Concentration-response function (95%CI)** |
| --- | --- |
| **Health outcomes** | **Australian** | **UK** | **Europe**  | **US EPA** | **WHO** | **Recommended** |
| ***Long-term outcomes (annual average concentration)*** |
| **Mortality** |
| All cause | n/a1\* | n/a | 0.386% (0.295-0.477%) per 1 µg/m3([Pope, Thun et al. 1995](#_ENREF_90))([European Commission 1995](#_ENREF_37))ICD9: AllAge: 30+ years | n/a | 1.10 (1.03-1.18) per 10 µg/m3([Dockery, Pope et al. 1993](#_ENREF_31))([WHO Europe 2000](#_ENREF_127))?ICD codes?Age | Recommended CRF: 0.386% (0.295-0.477%) per 1 µg/m3([Pope, Thun et al. 1995](#_ENREF_90)). |
| Cardiopulmonary  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Ischaemic heart disease  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lung cancer  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Infant all cause (<12 months age) | n/a | n/a | 4% (2-7%) per 10 µg/m3([Woodruff, Grillo et al. 1997](#_ENREF_135))([European Commission 2005](#_ENREF_38))ICD9: AllAge: <12 months  | n/a | n/a | Recommended CRF: 4% (2-7%) per 10 µg/m3([Woodruff, Grillo et al. 1997](#_ENREF_135)). |
| Life expectancy (Years of life lost; YOLL) | n/a | 2-6 months per death brought forward.([DEFRA 2006](#_ENREF_28)) | 2.69E-04 YOLL / (person/yr/µg/m3) ([European Commission 2005](#_ENREF_38))Applies CRF from Pope 1995 to whole population. | n/a | n/a | Recommended CRF: 2.69E-04 YOLL / (person/yr/µg/m3) ([European Commission 2005](#_ENREF_38)). |
| **Morbidity** |
| Incidence of chronic obstructive pulmonary disease (COPD) or chronic bronchitis | n/a | n/a | Chronic bronchitis:1.15 (0.99-1.33) per 20 µg/m3([Abbey, Hwang et al. 1995](#_ENREF_1))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))Adults (27+ years) with cough or sputum on most days for at least three months of the year for at least two years. | n/a | Chronic bronchitis:1.29 (0.96-1.83) per 10 µg/m3([Dockery, Cunningham et al. 1996](#_ENREF_30))([WHO Europe 2000](#_ENREF_127))?Age | No CRF recommended for chronic bronchitis.Both the reported CRFs are statistically non-significant. May be used in a sensitivity analysis. |
| Incidence of asthma | Ever had wheezing:No effectEver had asthma:No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly PM10 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Recent symptoms (in last 12 months) | Nigh cough: 1.34 (1.19-1.53) per 10 µg/m3Chest colds: 1.43 (1.12-1.82) per 10 µg/m3([Lewis, Hensley et al. 1998](#_ENREF_68))Children in school years 3-5.Illawarra/Hunter.Annual mean PM10.No effect or protective effects for wheeze, wheeze after exercise, current asthma, use of bronchodilators, cough, visit to doctor/hospital, rhinitis and itchy rash in various single pollutant and 2-pollutant models.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly PM10 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)).May use the CRFs from the study by Lewis et al ([Lewis, Hensley et al. 1998](#_ENREF_68)) in a sensitivity analysis. |
| Lung function growth  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly PM10 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in forced vital capacity (FVC; litres) | No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly PM10 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Airway inflammation | 1.04 (1.01-1.06) per 1 µg/m3 in single pollutant model. Estimates are similar in 2-pollutant models with PM2.5, NO2, SO2 and CO([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly PM10 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRF: 1.04 (1.01-1.06) per 1 µg/m3 ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Birth outcomes** |
| Birth defects | Mixed results from only Australian study ([Hansen, Barnett et al. 2009](#_ENREF_46))Brisbane | n/a | n/a | n/a | n/a | No CRF recommended.Only 1 Australian study. |
| Prematurity | 1.462 (1.267-1.688) per 1 µg/m3AutumnFirst trimester1.343 (1.190-1.516) per 1 µg/m3WinterFirst Trimester([Jalaludin, Mannes et al. 2007](#_ENREF_56))Preterm: <37 weeks gestation.Sydney1.15 (1.06–1.25) per 4.5 µg/m3First trimester([Hansen, Neller et al. 2006](#_ENREF_44))Preterm: <37 weeks gestation.Brisbane | n/a | n/a | n/a | n/a | No CRF recommended.Few Australian studies.  |
| Low birth weight | 1.01 (1.00-1.04) per 1 µg/m3 for small for gestational age (<2 standard deviations for age and gender).Second trimester-2.05 (-3.36 to -0.74) grams per 1 µg/m3 for small for gestational age (<2 standard deviations for age and gender). Second trimester([Mannes, Jalaludin et al. 2005](#_ENREF_71))SydneyNo effect on birth weight or small for gestational age (<10thcentile for age and gender).([Hansen, Neller et al. 2007](#_ENREF_45))Brisbane | n/a | n/a | n/a | n/a | No CRF recommended.Few Australian studies.  |
| ***Short-term outcomes (daily average concentration)*** |
| **Mortality** |
| Non-trauma | All ages: No effect ([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 3 cities - Brisbane, Sydney, Melbourne.ICD9: <800ICD10: A-R, Z35.5, Z35.81.3% (0.4-2.3%) per 10 µg/m3([Morgan, Sheppeard et al. 2010](#_ENREF_75))Sydney Age: All ages.24-hour averageICD9: <800; ICD10: A-R, Z35.5, Z35.8All ages: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01All yearHigh heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: <800; ICD10: A-R, Z35.5, Z35.8 | 0.074% (0.062-0.086%) per 1 µg/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))CRF is a WHO summary finding based on 17 international studies ICD: All Age: All ages. | 1.0105 (1.0025-1.0186) per 10 µg/m3([Schwartz 1993](#_ENREF_96))([European Commission 1995](#_ENREF_37))?ICD?Age | n/a | 1.0074 (1.0062-1.0086) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?ICD?Age1.006 (1.004-1.008) per 10 µg/m3([WHO Europe 2004](#_ENREF_131))33 studiesICD9: <800Age: All ages. | No CRF recommended.No effect in 2 Australian meta-analyses ([Environment Protection and Heritage Council 2005](#_ENREF_35); [Simpson, Williams et al. 2005](#_ENREF_102)). CRF from Morgan et al ([Morgan, Sheppeard et al. 2010](#_ENREF_75)) or WHO ([WHO Europe 2004](#_ENREF_131)) may be used in a sensitivity analysis. |
| Cardiovascular | 1.4 (0.0-2.9%) per 10 µg/m3([Morgan, Sheppeard et al. 2010](#_ENREF_75))Sydney Age: All24-hour averageICD9: 390-459; ICD10: I00-I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R581.8% (0.6-3.0%) per 7.53 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Age: All ages.All year.No heterogeneityMeta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 0.9% (0.7-1.2%) per 10 µg/m3([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))CRF not intended for health risk assessment purposes.40 studies ICD9: 390-459Age: All ages. | n/a | n/a | 1.009 (1.005-1.013) per 10 µg/m3([WHO Europe 2004](#_ENREF_131))17 studiesICD9: 390-459Ages: All ages. | Recommended CRF: 1.8% (0.6-3.0%) per 7.53 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory  | No effect([Morgan, Sheppeard et al. 2010](#_ENREF_75))SydneyAge: All ages.24-hour averageICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1,R09.8All ages: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01Age: All ages.All yearHigh heterogeneityMeta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | n/a | n/a | n/a | 1.013 (1.005-1.020) per 10 µg/m3([WHO Europe 2004](#_ENREF_131))18 studiesICD9: 460-519Age: All ages. | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)) and in study by Morgan et al ([Morgan, Sheppeard et al. 2010](#_ENREF_75)).CRF from WHO ([WHO Europe 2004](#_ENREF_131)) may be used in a sensitivity analysis. |
| **Hospitalisation** |  |  |  |  |  |  |
| Cardiovascular | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low heterogeneity Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459; ICD10: I00–I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0),G45 (excluding G45.3), G46, M30, M31, R581.22% (0.41 to 2.03%) per 10 µg/m3 ([Morgan, Sheppeard et al. 2010](#_ENREF_75))Sydney Age: All ages.24-hour averageICD9: 390-459; ICD10: I00-I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0), G45 (excludingG45.3), G46, M30, M31, R58 | 0.8 per 10 µg/m3 (no 95%CI provided) ([DEFRA 2006](#_ENREF_28))(based on COMEAP 1998)No effect([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))CRF not intended for health risk assessment purposes.6 studies ICD9: 390-459Age: All ages. | 0.6% (0.3-0.9%) per 10 µg/m3([AEA Technology Environment 2005](#_ENREF_7)) ICD9: 390-429Age: All ages. | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). CRF from the study by Morgan et al ([Morgan, Sheppeard et al. 2010](#_ENREF_75)) may be used in a sensitivity analysis. |
| Cardiac | 2.4% (1.5-3.4%) per 10 µg/m3([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 3 cities (Sydney, Melbourne, Brisbane)lCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1Age: All ages.1-hour maximum.15-64 years: No effect65+ years: 1.4% (0.5-2.2%) per 7.53 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity. Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 1.4% (0.5-2.2%) per 7.53 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)). This is a more recent study compared to the Simpson et al study ([Simpson, Williams et al. 2005](#_ENREF_103)).Use CRF from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) in a sensitivity analysis. Note that this study is for all ages and has a larger CRF. |
| Cardiac failure | 15-64 years: No effect65+ years: 3.6% (2.0-5.2%) per 7.53 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Moderate heterogeneity for 65+ years.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 428; ICD10: I50 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 3.6% (2.0-5.2%) per 7.53 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)).  |
| Cerebrovascular  | Stroke:15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 430-438; ICD10: I60-I66, I67 (excluding I67.0, I67.3), I68 (excluding I68.0), I69, G45 (excluding G45.3), G46 |  |  |  |  | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Ischaemic heart disease | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low heterogeneityMeta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 410-413; ICD10: 120-122, 124, 125.2 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Arrhythmia | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 437; ICD10: I46-I49 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Myocardial infarction | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low heterogeneity Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 410; ICDI0: I21, I22 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory | 0 year: 2.3% (0.2-4.3%) increase per 7.53 µg/m31-4 years: 2.3% (0.9-3.8%) increase per 7.53 µg/m35-14 years: 2.3% (0.2-4.4%) increase per 7.53 µg/m315-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour average.Lag 01.Low heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9),R09.1, R09.82.7% (1.0-5.9%) per 10 µg/m3 in 2-pollutant model with O3([Chen, Mengersen et al. 2007](#_ENREF_18))Brisbane24-hour averageAge: All agesICD9: 460-519 (excluding 487); ICD10: Joo-J99 (excluding J11)1.04% (0.02- 2.07%) per 10 µg/m3([Morgan, Sheppeard et al. 2010](#_ENREF_75))SydneyAge: All ages.24-hour average.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | 0.080% (0.048-0.112%) per 1µg/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))CRF is a WHO summary finding based on 6 cities All respiratory causes Age: All ages. | 1.14% (0.62-1.67%) per 10µg/m3([AEA Technology Environment 2005](#_ENREF_7)) Age: All ages.ICD9: 460-519 | n/a | 1.0080 (1.0048-1.0112) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?ICD?Age0-14 years: 1.010 (0.998-1.021) per 10 µg/m33 studies14-64years: 1.008 (1.001-1.015) per 10 µg/m33 studies65+ years: 1.007 (1.002-1.013) per 10 µg/m38 studies([WHO Europe 2004](#_ENREF_131))ICD9: 460-519Age: All ages. | Recommended CRF: CRFs from the Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use CRF from the study by Morgan et al ([Morgan, Sheppeard et al. 2010](#_ENREF_75)) in a sensitivity analysis. This CRF is for all ages but from one location only.  |
| Asthma | 0 year: not calculated due to uncertain diagnosis1-4 years: No effect5-14 years: No effect15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low to moderate heterogeneity Meta-analysis of 4 cities - Brisbane, Melbourne, Perth. Sydney.ICD9: 493; ICD10: J45, J46, J44.81-14 years: No effect15-64 years: No effect([Morgan, Sheppeard et al. 2010](#_ENREF_75))Sydney.ICD9: 493; ICD10: J45, J46, J44.824-hour average | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian studies including the Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35))..  |
| Chronic obstructive pulmonary disease (COPD) | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low heterogeneity Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.lCD9: 490-492, 494-496; ICDI0: J40-J44, J47, J67  | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Pneumonia and acute bronchitis | 0 years: No effect1-4 years: No effect15-64 years: No effect65+ years: 1.0% (0.2-3.8%) per 7.53 µg/m3([Environment Protection and Heritage Council 2005](#_ENREF_35))24-hour averageLag 01Low heterogeneity for 65+4 yearsMeta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 466, 480-486; ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J21 | n/a | n/a | n/a | n/a | Recommended CRF: 65+ years: 1.0% (0.2-3.8%) per 7.53 µg/m3 per 7.53 µg/m3 ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| **Emergency department visits** |
| Asthma  | Inner Melbourne: 1.17 (1.05-1.31) per 34.3 µg/m3Eastern Melbourne: 1.09 (1.01-1.18) per 34.3 µg/m3([Erbas, Kelly et al. 2005](#_ENREF_36))MelbourneICD10: J45, J46Age: 1-15 yearsModelled air pollution data using TAPM1-hour maximum1.4% (0.8-2.0%) per 7.6 µg/m3 ([Jalaludin, Khalaj et al. 2008](#_ENREF_54))SydneyAge: 1-14 yearsICD9: 439 | n/a | 1.0374 (1.0121-1.0633) per 10 µg/m3([Schwartz, Slater et al. 1993](#_ENREF_99))([European Commission 1995](#_ENREF_37))Age: All ages. | n/a | n/a | Recommended CRF: 1.4% (0.8-2.0%) per 7.6 µg/m3 ([Jalaludin, Khalaj et al. 2008](#_ENREF_54)).There are few Australian studies. The study by Erbas et al ([Erbas, Kelly et al. 2005](#_ENREF_36)) used modelled air pollution data. |
| Respiratory disease  | n/a | n/a | COPD: 5.7% (4.56-6.84%) per 25 µg/m3([Sunyer, Saez et al. 1993](#_ENREF_107))([European Commission 1995](#_ENREF_37))Age: All ages. | n/a | n/a | No CRF recommended.The CRF from Sunyer et al ([Sunyer, Saez et al. 1993](#_ENREF_107)) may be used in a sensitivity analysis. |
| Cardiovascular disease  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Incidence of myocardial infarction (heart attacks)** |
| Non-fatal heart attacks  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Lung function** |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect in single pollutant models, but significant effects in 2-pollutant models with 1-hour SO2 and 24-hour SO2With 1-hour SO2: -0.0041 (-0.0076 to -0.0006) per 1 µg/m324-hour averageLag 2With 24-hour SO2: -0.0043 (-0.0078 to -0.0008) per 1 µg/m324-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean age 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | -1.2% (-2.3 to -0.1%) per 10 µg/m3([Raizenne, Neas et al. 1996](#_ENREF_91))([WHO Europe 2000](#_ENREF_127))Children?Age -1.0% (95%CI not available) per 10 µg/m3([Ackermann-Liebrich, Leuenberger et al. 1997](#_ENREF_6)) ([WHO Europe 2000](#_ENREF_127))Adults?Age  | Recommended CRF: -0.0043 (-0.0078 to -0.0008) per 1 µg/m3 ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in peak expiratory flow rate (PEF; litres per minute) | No effect([Jalaludin, Chey et al. 2000](#_ENREF_53))Sydney125 children with a history of wheezing in previous 12 months.Age: mean age about 9.6 years.No effect([Jalaludin, Smith et al. 2000](#_ENREF_60))Sydney32 children (mean age about 9.2 years) with a history of wheezing in previous 12 months.-0.0036 (-0.0067 to -0.0005) per 1 µg/m3([Rutherford, Simpson et al. 2000](#_ENREF_94))Brisbane and IpswichMixed-models4-day lagAge: All ages.53 people with history of allergy to pollen or fungi on skin prick testing.No effect in single pollutant models, but significant effects in 2-pollutant models with 1-hour ozone, 1-hour SO2 and 24-hour SO2With 1-hour ozone: -0.3674 (-0.7291 to -0.0057)24-hour averageLag 2With 1-hour SO2: -0.7972 (-1.33148 to -0.2796) per 1 µg/m324-hour averageLag 2With 24-hour SO2: -0.8187 (-1.3325 to -0.3048) per 1 µg/m324-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean age 10.0 years 270 children with current asthma | n/a | n/a | n/a | -0.13% (-0.17 to -0.09%) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?AgeChange in peak expiratory flow relative to mean. | Recommended CRF: -0.8187 (-1.3325 to -0.3048) per 1 µg/m3 ([Williams, Marks et al. 2012](#_ENREF_132)).Note inconsistencies in CRFs from Australian single site studies. |
| **Minor morbidity** |
| Asthma exacerbation  | n/a | n/a | n/a | 1.05 (0.95-1.16) per 10 µg/m3([Yu, Sheppard et al. 2000](#_ENREF_137)) ([US EPA 2006](#_ENREF_114))([Abt Associates Inc. 2005](#_ENREF_4))Asthmatic children Age: 5-13 yearsAt least one asthma symptom: wheeze, cough, chest tightness, shortness of breath. | n/a | No CRF recommended.CRF from Yu et al ([Yu, Sheppard et al. 2000](#_ENREF_137)) was not statistically significant. |
| Restricted activity days (RAD)2 | n/a | n/a | n/a  | n/a | n/a | No CRF recommended. |
| Minor restricted activity days (MRAD)3 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Work lost days (WLD)2  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute bronchitis (incidence) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lower respiratory symptoms  | No effect on wheezing.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney.Wheezing: 3.149 (1.495-6.631) per 10 µg/m3([Jalaludin, O'Toole et al. 2004](#_ENREF_61))32 children (mean age about 9.2 years) with a history of wheezing in previous 12 months.Sydney. | 0-15 years: 0.330% (0.134-0.526%) per 1 µg/m3 15+ years: No effect.([Roemer, Hoek et al. 1993](#_ENREF_93))([Dusseldorp, Kruize et al. 1995](#_ENREF_33))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))CRFs for those with asthma.NOT included in impact assessment in the UK because of doubts about the transferability of the data and lack of UK studies. | 5-14 years: 1.004 (1.002-1.006) per 10 µg/m3([Ward and Ayres 2004](#_ENREF_123))([European Commission 2005](#_ENREF_38)) ([AEA Technology Environment 2005](#_ENREF_7))CRF from meta-analysis. All children.Lower respiratory symptoms include wheeze, chest tightness, shortness of breath, cough.20+ years: 1.017 (1.002-1.032) per 10 µg/m3([European Commission 2005](#_ENREF_38)) ([AEA Technology Environment 2005](#_ENREF_7))CRF from meta-analysis of five panel studies.Symptomatic adults only: wheeze, chest tightness, phlegm, shortness of breath, cough. | n/a | 1.0324 (1.0185-1.0464) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?Age | Recommended CRFs:5-14 years: 1.004 (1.002-1.006) per 10 µg/m3 ([Ward and Ayres 2004](#_ENREF_123)) from a meta-analysis.20+ years: 1.017 (1.002-1.032) per 10 µg/m3 ([European Commission 2005](#_ENREF_38)) from a meta-analysis.Australian studies are single site studies CRFs are for individual symptoms.  |
| Acute respiratory symptoms | n/a | n/a | 1.0049 (0.9999-1.0098) per 1 µg/m3([Krupnick, Harrington et al. 1990](#_ENREF_65))([European Commission 1995](#_ENREF_37))All agesWhole population.Only for sensitivity analysisPresence of any one of 19 respiratory-related symptoms including: head cold, chest cold, sinus trouble, croup, cough with phlegm, sore, throat, asthma, hay fever, wheeze, ear infection, bronchitis, bronchiolitis, pneumonia, influenza. | n/a | n/a | No CRF recommended.CRF from Krupnick et al ([Krupnick, Harrington et al. 1990](#_ENREF_65)) may be used in a sensitivity analysis. Note that CRF is statistically marginally non-significant.  |
| Wheeze | Day wheeze: 1.0288 (1.0049-1.0534) per 1 μg/m3 in 2-pollutant model with 1-hour NO224-hour averageLag 1Night wheeze: 1.0453 (1.0143-1.0774) per 1 μg/m3 in 2-pollutant model with 8-hour CO24-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a  | n/a | n/a | Recommended CRF: Use CRF from Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Cough | No effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney.Day cough: 1.0229 (1.0006-1.0456) per 1 μg/m3 in 2-pollutant model with 8-hour CO24-hour averageLag 1Night cough: 1.0277 (1.0003-1.0559) per 1 μg/m3 in 2-pollutant model with 24-hour SO224-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | 0-15 years: 0.508% (0.226-0.790%) per 1 µg/m3 15+ years: No effect ([Dockery and Pope 1994](#_ENREF_32))([Dusseldorp, Kruize et al. 1995](#_ENREF_33))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))CRFs for those with asthma.NOT included in impact assessment in the UK because of doubts about the transferability of the data and lack of UK studies. | 5-14 years: 1.004 (1.002-1.006) per 10 µg/m3([Ward and Ayres 2004](#_ENREF_123))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))All children20+ years: 1.043 (1.005-1.084) per 10 µg/m3([Ward and Ayres 2004](#_ENREF_123))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))CRF from meta-analysis.Symptomatic adults only: cough, nocturnal cough, cough+phlegm | 8% (0-16%) per 10 μg/m3([Vedal, Petkau et al. 1998](#_ENREF_122))([US EPA 2006](#_ENREF_114))([Abt Associates Inc. 2005](#_ENREF_4))Asthmatic children. Age: 6-13 years. | 1.0356 (1.0197-1.0518) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?Age5-15 years: 0.999 (0.987-1.011) per 10 µg/m334 studies.Symptomatic children. 16-70 years: 1.043 (1.005-1.084) per 10 µg/m3 3 studies.Symptomatic adults. ([WHO Europe 2004](#_ENREF_131)) | Recommended CRF: Use CRF from Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)).May use CRFs from Ward et al ([Ward and Ayres 2004](#_ENREF_123)) in a sensitivity analysis. CRFs from a meta-analysis. |
| Shortness of breath | Day SOB: No effectNight SOB: 1.0417 (1.0031-1.0819) per 1 μg/m3 in 2-pollutant model with CO 8-hour average 24-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | Recommended CRF: 1.0417 (1.0031-1.0819) per 1 μg/m3 ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Bronchodilator use (people with asthma) | No effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney.No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean 10.0 years 270 children with current asthma | 0-15 years: 0.230% (0.073-0.3876%) per 1µg/m3 15+ years: 0.180% (0.004-0.357%) per 1µg/m3 ([Roemer, Hoek et al. 1993](#_ENREF_93))([Dusseldorp, Kruize et al. 1995](#_ENREF_33))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))CRFs for those with asthma.NOT included in impact assessment in the UK because of doubts about the transferability of the data and lack of UK studies. | 5-14 years : No effect20+ years: No effect([WHO Europe 2004](#_ENREF_131))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))People with asthma. | n/a | 1.0305 (1.0201-1.0410) per 10 µg/m3([WHO Europe 2000](#_ENREF_127))?Age5-15 years: No effect31 studiesSymptomatic children.16-70 years: No effect3 studiesSymptomatic adults.([WHO Europe 2004](#_ENREF_131)) | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)).Inconsistent CRFs reported. There is generally a lack of an effect. |
| Upper respiratory symptoms  | n/a | n/a | n/a | 1.0367 (1.0066-1.0676) per 10 µg/m3([Pope, Dockery et al. 1991](#_ENREF_89))([US EPA 2006](#_ENREF_114))Asthmatics 9-11 years.At least one of the following symptoms: runny/stuffy nose, wet cough, burning, aching or red eyes. | n/a | No CRF recommended.The CRF from Pope et al ([Pope, Dockery et al. 1991](#_ENREF_89)) may be used in a sensitivity analysis. |
| Increased respiratory symptoms | Any day symptoms: With 1-hour SO2: 1.0257 (1.00189-1.0502) per 1 μg/m3 (Any cough, wheeze, shortness of breath, runny nose, eye irritation, fever)24-hour averageLag 1With 24-hour SO2: 1.0253 (1.0015-1.0496) per 1 μg/m3 (Any cough, wheeze, shortness of breath, runny nose, eye irritation, fever)24-hour averageLag 1Any night symptoms: 1.0163 (1.0029-1.0298) per 1 μg/m3 (any cough, wheeze, shortness of breath) 24-hour averageLag 2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. |  |  |  |  | Recommended CRF: Use CRFs from Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| General practitioner consultation for asthma | 1.11 (1.04-1.19) per 12 µg/m3([Jalaludin, O'Toole et al. 2004](#_ENREF_58))125 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney. | n/a | 0-14 years: 2.5% (0.0-5.2%) per 10 µg/m315-64 years: 3.1% (1.2-5.0%) per 10 µg/m365+ years: 6.3% (2.1-11.2%) per 10 µg/m3([Hajat, Haines et al. 1999](#_ENREF_43))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))CRFs for warm season only.CRFs only used for sensitivity analysis | n/a | n/a | No recommended CRF.CRFs from Jalaludin et al ([Jalaludin, O'Toole et al. 2004](#_ENREF_58))and Hajat et al ([Hajat, Haines et al. 1999](#_ENREF_43)) may be used in may be used in sensitivity analyses. |
| General practitioner consultation for upper respiratory disease | n/a | n/a | 0-14 years: No effect15-64 years: 1.8% (0.9-2.8%) per 10 µg/m365+ years: 3.3% (1.7-5.0%) per 10 µg/m3([Hajat, Anderson et al. 2002](#_ENREF_41))([European Commission 2005](#_ENREF_38))([AEA Technology Environment 2005](#_ENREF_7))ICD9: 460-3, 465, 470-5, 478.CRFs only used for sensitivity analysis | n/a | n/a | No recommended CRF.CRFs from Hajat et al ([Hajat, Anderson et al. 2002](#_ENREF_41)) may be used in may be used in sensitivity analyses. |

1Not available

2A restricted activity days is defined as a day when a person is forced to alter his/her normal activity. A severe restriction include days when it necessary to stay in bed. For employed adults, restricted activity days include Work Loss Days; for children, it would include days off school (whether or not the child is confined to bed). (ExternE 1995)

3Minor restricted activity days do not involve work loss or bed disability but do include some noticeable limitation on ‘normal’ activity (ExternE 1995).

**REFERENCES**

Abbey, D. E., B. L. Hwang, et al. (1995). "Estimated long-term ambient concentrations of PM10 and development of respiratory symptoms in a nonsmoking population." Archives of Environmental Health **50**(2): 139-152.

Abt Associates Inc. (2005). BENMAP: Technical appendices, Prepared by Abt Associates Inc. for the Office of Air Quality Planning and Standards, US EPA, Research Triangle Park, North Carolina.

Ackermann-Liebrich, U., P. Leuenberger, et al. (1997). "Lung function and long term exposure to air pollutants in Switzerland. Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team." American Journal of Respiratory and Critical Care Medicine **155**(1): 122-129.

AEA Technology Environment (2005). Methodology for the cost-benefit analysis for CAFE: Volume 2: Health impact assessment. Oxon, UK, AEA Technology Environment.

Chen, L., K. Mengersen, et al. (2007). "Spatiotemporal relationship between particle air pollution and respiratory emergency hospital admissions in Brisbane, Australia." Science of the Total Environment **373**(1): 57-67.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2006). Cardiovascular disease and air pollution. London, Department of Health, UK.

DEFRA (2006). An Economic Analysis to Inform the Air Quality Strategy Review Consultation. London, UK, Department for Environment, Food and Rural Affair.

Dockery, D. W., J. Cunningham, et al. (1996). "Health effects of acid aerosols on North American children: Respiratory symptoms." Environmental Health Perspectives **104**(5): 500-505.

Dockery, D. W., A. C. Pope, III, et al. (1993). "An association between air pollution and mortality in six U.S. cities [see comments]." New England Journal of Medicine **329**(24): 1753-1759.

Dockery, D. W. and C. A. Pope, III (1994). "Acute respiratory effects of particulate air pollution." Annual Review of Public Health **15**: 107-132.

Dusseldorp, A., H. Kruize, et al. (1995). "Associations of PM10 and airborne iron with respiratory health of adults living near a steel factory." American Journal of Respiratory and Critical Care Medicine **152**(6): 1932-1939.

Environment Protection and Heritage Council (2005). Expansion of the multi-city mortality and morbidity study. Final report. Volume 3. Tabulated results, Environment Protection and Heritage Council.

Erbas, B., A.-M. Kelly, et al. (2005). "Air pollution and childhood asthma emergency hospital admissions: estimating intra-city regional variations." International Journal of Environmental Health Research **15**(1): 11-20.

European Commission (1995). Externalities of Energy "ExternE" Project, Volume 2, Methodology. Method for estimation of physical impacts and monetary valuation for priority impact pathways. Oxfordshire, UK, Prepared by ETSU and others**:** 408.

European Commission (2005). ExternE. Externalities of Energy: Methodology 2005 Update. P. Bickel and R. Friedrich, Luxemburg, European Commission.

Hajat, S., H. R. Anderson, et al. (2002). "Effects of air pollution on general practitioner consultations for upper respiratory diseases in London." Occupational & Environmental Medicine **59**(5): 294-299.

Hajat, S., A. Haines, et al. (1999). "Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London." Thorax **54**(7): 597-605.

Hansen, C., A. Neller, et al. (2006). "Maternal exposure to low levels of ambient air pollution and preterm birth in Brisbane, Australia." BJOG: An International Journal of Obstetrics & Gynaecology **113**(8): 935-941.

Hansen, C., A. Neller, et al. (2007). "Low levels of ambient air pollution during pregnancy and fetal growth among term neonates in Brisbane, Australia." Environmental Research **103**(3): 383-389.

Hansen, C. A., A. G. Barnett, et al. (2009). "Ambient Air Pollution and Birth Defects in Brisbane, Australia." Plos One **4**(4).

Jalaludin, B., T. Chey, et al. (2000). "Acute effects of low levels of ambient ozone on peak expiratory flow rate in a cohort of Australian children." International Journal of Epidemiology **29**(3): 549-557.

Jalaludin, B., B. Khalaj, et al. (2008). "Acute effects of ambient air pollutants on ED visits for asthma in children, Sydney, Australia: a case-crossover analysis." International Archives of Occupational & Environmental Health **81**(8): 967-974.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**.

Jalaludin, B., B. O'Toole, et al. (2004). "Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children." Environmental Research **95**(1): 32-42.

Jalaludin, B., M. Smith, et al. (2000). "Acute effects of bushfires on peak expiratory flow rates in children with wheeze: a time series analysis." Australian & New Zealand Journal of Public Health **24**(2): 174-177.

Jalaludin, B. B., B. I. O'Toole, et al. (2004). "Acute effects of bushfires on respiratory symptoms and medication use in children with wheeze in Sydney, Australia." Environmental Health **4**(2): 20-29.

Krupnick, A., W. Harrington, et al. (1990). "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." Journal of Environmental Economics and Management **18**(1): 1-18.

Lewis, P. R., M. J. Hensley, et al. (1998). "Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales [see comments]." Medical Journal of Australia **169**(9): 459-463.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occupational and Environmental Medicine **62**(8): 524-530.

Morgan, G., V. Sheppeard, et al. (2010). "Effects of bushfire smoke on daily mortality and hospital admissions in Sydney, Australia." Epidemiology **21**(1): 47-55.

Pope, C. A., III, D. W. Dockery, et al. (1991). "Respiratory health and PM10 pollution. A daily time series analysis." American Review of Respiratory Disease **144**(3 Pt 1): 668-674.

Pope, C. A., III, M. J. Thun, et al. (1995). "Particulate air pollution as a predictor of mortality in a prospective study of US adults." American Journal of Respiratory and Critical Care Medicine **151**(3): 669-674.

Raizenne, M., L. M. Neas, et al. (1996). "Health effects of acid aerosols on North American children: Pulmonary function." Environmental Health Perspectives **104**(5): 506-514.

Roemer, W., G. Hoek, et al. (1993). "Effect of ambient winter air pollution on respiratory health of children with chronic respiratory symptoms." American Review of Respiratory Disease **147**(1): 118-124.

Rutherford, S., R. Simpson, et al. (2000). "Relationships between environmental factors and lung function of asthmatic subjects in south east Queensland, Australia." Journal of Occupational & Environmental Medicine **42**(9): 882-891.

Schwartz, J. (1993). "Air pollution and daily mortality in Birmingham, Alabama." American Journal of Epidemiology **137**(10): 1136-1147.

Schwartz, J., D. Slater, et al. (1993). "Particulate air pollution and hospital emergency room visits for asthma in Seattle." American Review of Respiratory Disease **147**(4): 826-831.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on daily mortality in four Australian cities." Australian & New Zealand Journal of Public Health **29**(3): 205-212.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on hospital admissions in four Australian cities " Australian & New Zealand Journal of Public Health **29**(3): 213-221.

Sunyer, J., M. Saez, et al. (1993). "Air pollution and emergency room admissions for chronic obstructive pulmonary disease: a 5-year study." American Journal of Epidemiology **137**(7): 701-705.

US EPA (2006). Regulatory impact analysis. National Ambient Air Quality Standards for particle pollution, Research Triangle Park, North Carolina.

Vedal, S., J. Petkau, et al. (1998). "Acute effects of ambient inhalable particles in asthmatic and nonasthmatic children." American Journal of Respiratory and Critical Care Medicine **157**(4): 1034-1043.

Ward, D. J. and J. G. Ayres (2004). "Particulate air pollution and panel studies in children: a systematic review." Occupational & Environmental Medicine **61**(4): e13.

WHO Europe (2000). Air quality guidelines for Europe: second edition. Copenhagen, WHO Regional Office for Europe.

WHO Europe (2004). Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3). Report of a WHO task group. Copenhagen, World Health Organization.

Williams, G., G. Marks, et al. (2012). Australian Child Health and Air Pollution Study (ACHAPS). Final report. Environment Protection and Heritage Council (in press).

Woodruff, T. J., J. Grillo, et al. (1997). "The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States." Environmental Health Perspectives **105**(6): 608-612.

Yu, O., L. Sheppard, et al. (2000). "Effects of ambient air pollution on symptoms of asthma in Seattle-area children enrolled in the CAMP study." Environmental Health Perspectives **108**(12): 1209-1214.

Table 3: O3 health endpoints and associated concentration-response functions

|  | **Concentration-response function (95%CI)** |
| --- | --- |
| **Health outcomes** | **Australian** | **UK** | **Europe** | **US EPA** | **WHO** | **Recommended** |
| ***Long-term outcomes(annual average concentration)*** |
| **Mortality** |
| All cause  | n/a1 | n/a | n/a | No effect([Jerrett, Burnett et al. 2009](#_ENREF_62))([Abt Associates Inc 2011](#_ENREF_3))Age: 30-99 years.Annual 1-hour average. | n/a | No CRF recommended.  |
| Cardiopulmonary  | n/a | n/a | n/a | Cardiovascular disease: No effect([Jerrett, Burnett et al. 2009](#_ENREF_62))([Abt Associates Inc 2011](#_ENREF_3))Age: 30-99 years.Annual 1-hour average. | n/a | No CRF recommended. |
| Ischaemic heart disease | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lung cancer | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Respiratory | n/a | n/a | n/a | 1.040 (1.013-1.067) per 10 ppb([Jerrett, Burnett et al. 2009](#_ENREF_62))([Abt Associates Inc 2011](#_ENREF_3))ICD9: 460-519Age: 30-99 years.Annual 1-hour average.Adjusted for PM2.5. | n/a | No CRF recommended.Insufficient evidence - only 1 study. |
| Infant (<12 months age) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Life expectancy lost (years of life lost) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Morbidity** |
| Incidence of chronic obstructive pulmonary disease (COPD) or chronic bronchitis | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Incidence of asthma | Ever had wheezing:Protective effect in single and 2-pollutant models with PM, NO2, SO2 and CO.Ever had asthma:Protective effect in single and 2-pollutant models with PM, NO2, SO2 and CO.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly O3 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | 2.8% (0.1-5.6%) per 1 ppb ([McDonnell, Abbey et al. 1999](#_ENREF_72))([US EPA 1999](#_ENREF_112))Age: Non-asthmatic males 27+ years.Annual average 8-hour ozone. | n/a | No CRF recommended. No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)).Study by McDonnell et al ([McDonnell, Abbey et al. 1999](#_ENREF_72)) may be used in a sensitivity analysis. |
| Recent symptoms (in last 12 months) | Cough: 1.14 ( 1.01-1.29) per 3.12 ppb in single pollutant model.1.26 (1.06-1.50) per 3.12 ppb in 2-pollutant model with CO.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly O3 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRF:Cough: 1.26 (1.06-1.50) per 3.12 ppb in 2-pollutant model with CO ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Lung function growth  | n/a | n/a | n/a | n/a | n/a  | No CRF recommended. |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly O3 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a. | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in forced vital capacity (FVC; litres) | No effect.([Williams, Marks et al. 2012](#_ENREF_132))]Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly O3 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a. | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Airway inflammation | Protective effect in single and 2-pollutant models with PM, NO2, SO2 and CO([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly O3 over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a. | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Birth outcomes** |
| Birth defects | Pulmonary artery & valves: 2.96% (1.34- 7.52%) per 5 ppb ([Hansen, Barnett et al. 2009](#_ENREF_46))Brisbane.Birth addresses <6km of air monitoring station. | n/a | n/a | n/a | n/a | No CRF recommended.Only 1 Australian study.  |
| Prematurity | 1.26 (1.10-1.45) per 7.1 ppb([Hansen, Neller et al. 2006](#_ENREF_44))CRF not linear.Brisbane.Preterm: <37 weeks1st trimester exposure.1.604 (1.268-2.030) per 1 ppb 1st month gestation for women living <5km of air quality monitor. No effect for all Sydney. Preterm: <37 weeks.1.014 (1.005-1.022) per 1 ppbSydney widePreterm: <37 weeks gestation1st trimester exposure. 0.807 (0.668-0.976) per 1 ppb for women living <5 km of air quality monitor. Preterm: <37 weeks gestation.1st trimester exposure.Sydney.([Jalaludin, Mannes et al. 2007](#_ENREF_57))  | n/a | n/a | n/a | n/a | No CRF recommended. Only 2 Australian studies are available and evidence is conflicting regarding CRF.  |
| Low birth weight | No effect.Brisbane.([Hansen, Neller et al. 2007](#_ENREF_45))Small for gestational age: 1.00 (1.00-1.01) per 1 ppb1-hour maximumSydneySmall for gestational age >2 standard deviations below the mean birth weight by sex and gestational age.Exposure in 1st, 2nd or 3rd trimesters.Birth weight: grams (-0.12 to -0.09 grams) per 1 ppb2nd trimester exposure.Sydney.([Mannes, Jalaludin et al. 2005](#_ENREF_71)) | n/a | n/a | n/a | n/a | No CRF recommended.Only 2 Australian studies available. |
| Head circumferenceCrown-heel length | No effect on either head circumference or crown-heel length.([Hansen, Neller et al. 2007](#_ENREF_45)) Brisbane. | n/a | n/a | n/a | n/a | No CRF recommended.Only 1 Australian study available. |
| ***Short-term outcomes(daily average concentration)*** |
| **Mortality** |  |  |  |  |  |  |
| Non-trauma | 1.0004 (0.9999-1.0010) per 1 ppb 4-hour maximumLag 01.0004 (0.9999-1.0008) per 1 ppb 1-hour maximumLag 0([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 cities - Sydney, Perth, Melbourne, Brisbane.ICD9: <800ICD10: A-R, Z35.5, Z35.8Age: All ages.1.4% (0.3-2.4%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Age: All ages.All year.No heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: <800; ICD10: A-R, Z35.5, Z35.8 | 0.059% per 1 *µ*g/m3 ([Sunyer, Castellsague et al. 1996](#_ENREF_106)) ([European Commission 2005](#_ENREF_38))Age: All ages.1.027 (1.013-1.039) per 50 *µ*g/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))8-hour average.Age: All ages.All non-trauma deaths.Meta-analysis of 5 European cities. | 0.3% (0.1-0.43%) per 10 *µ*g/m3  ([Anderson, Atkinson et al. 2004](#_ENREF_8))([European Commission 2005](#_ENREF_38))WHO meta-analysis. Daily maximum 8-hour average O3. Assuming linearity without threshold.0.3% (0.1-0.4%) change per 10 *µ*g/m3 ([AEA Technology Environment 2005](#_ENREF_7)) | 0.5-1% increase per 30 ppb ([US EPA 2006](#_ENREF_114))8-hour maximum average.n/a([Abt Associates Inc 2011](#_ENREF_3))Meta-analysis of 6 studies. | 0.3% (0.1-0.43%) increase per 10 *µ*g/m3 ([Anderson, Atkinson et al. 2004](#_ENREF_8)) ([AEA Technology Environment 2005](#_ENREF_7))WHO meta-analysis. Daily maximum 8-hour average.All ages.1.003 (1.001-1.004) per 10 *µ*g/m3 (8-hour average). Estimate revised for possible publication bias 1.002 (1.000-1.003).([Anderson, Atkinson et al. 2004](#_ENREF_8))0.3-0.5% increase in daily mortality per 10 *µ*g/m3 8-hour average O3 above 70 *µ*g/m3.([WHO 2006](#_ENREF_125)) | Recommended CRF: 1.4% (0.3-2.4%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cardiovascular | 1.0008 (0.9999-1.0016) per 1 ppb (4-hour maximum) (lag0)1.0006 (0.9999-1.0013) per 1 ppb 1-hour maximum Lag 0 Pooled CRF from 4 cities - Sydney, Perth, Melbourne, Brisbane.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58Age: All ages.([Simpson, Williams et al. 2005](#_ENREF_102))2.1% (1.1-3.1%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Age: All ages.All year.No heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 0.4% (0.3-0.5%) change per 10 *µ*g/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))8-hour averageNo evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/a | 1.004 (1.003, 1.005) per 10 *µ*g/m3 Estimate revised for possible publication bias 1.004 (1.003-1.005).([Anderson, Atkinson et al. 2004](#_ENREF_8))8-hour average. | Recommended CRF: 2.1% (1.1-3.1%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)).Note that CRFs from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_102)) are very close to being statistically significant.  |
| Respiratory  | 1.0023 (1.0005-1.0042) per 1 ppb 4-hour maximum. Lag 0.1.0020 (1.0003-1.0036) per 1 ppb ([Simpson, Williams et al. 2005](#_ENREF_102))1-hour maximum.Lag 0.Pooled CRF from 4 cities - Sydney, Perth, Melbourne, Brisbane.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8Age: All ages.2.4% (0.1-4.7%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Age: All ages.All year.No heterogeneity.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | n/a | n/a | n/a | 1.000 (0.996-1.005) per 10 *µ*g/m3 Estimate revised for possible publication bias to 0.999 (0.995-1.004).([Anderson, Atkinson et al. 2004](#_ENREF_8))8-hour average. | Recommended CRF: 2.4% (0.1-4.7%) per 9.83 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)).The EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)) used as it is the more recent than the study by Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_102)).  |
| **Hospitalisation** |
| Cardiovascular | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 390-459ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | No effect.([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))8-hour average. No evidence of publication bias.CRF not intended for health risk assessment purposes. | No strong evidence of association between daily O3 and cardiovascular disease admissions.([European Commission 2005](#_ENREF_38)) | n/a | n/aInsufficient studies for meta-analysis([Anderson, Atkinson et al. 2004](#_ENREF_8)) | No CRF recommended.No effect in Australian meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)) and in COMEAP study ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21)). |
| Cardiac | All ages: No effect. 15-64 years: 1.0009 (1.0001-1.0017) per 1 ppb. 4-hour average.Lag 3.Pooled estimate from 4 cities - Sydney, Brisbane, Melbourne, Perth.lCD9: 390-429ICDI0: I00-I52, I97.0, I97.1, I98.1([Simpson, Williams et al. 2005](#_ENREF_103))15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth, Sydney.Low heterogeneity.lCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in more recent Australian meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).CRF for 15-64 years from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) may be used in a sensitivity analysis. |
| Cardiac failure | 15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Canberra, Melbourne, Perth Sydney.Moderate heterogeneity in 15-64 years.ICD9: 428; ICD10: I50 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in the EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cerebrovascular disease | Stroke:15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Canberra, Melbourne, Perth Sydney.Low heterogeneity.ICD9: 430-438 ICD10: I60-I66, I67 (excluding I67.0, I67.3), I68 (excluding I68.0), I69, G45 (excluding G45.3), G46 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in the EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Ischaemic heart disease  | 15-64 years: No effect. 65+years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))Meta-analysis of 4 cities - Brisbane, Melbourne, Perth, SydneyLow heterogeneityICD9: 410-413ICD10: 120-122, 124, 125.2No effect.([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 4 cities - Sydney, Brisbane, Melbourne, Perth.All ages and 65+ years. | -0.1% (-0.7 to 0.4%) per 10 *µ*g/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))8-hour average No evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/a | n/a | No CRF recommended.No effect in the EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)), Simpson study ([Simpson, Williams et al. 2005](#_ENREF_103)) and in COMEAP study ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21)). |
| Arrhythmia | 15-64 years: No effect.65+ years: No effect. ([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.Low heterogeneity.ICD9: 437; ICD10: I46-I49 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in the EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Myocardial infarction | 15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.High heterogeneity. in 65+ yearslCD9: 410; ICDI0: I21, I22 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in the EPHC study ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory  | 65+ years: No effect.([Simpson, Williams et al. 2005](#_ENREF_103))1-hour maximum.lCD9: 460-519ICD10: J00-J99 (excluding J95.4-J95.9), R09.1, R09.8. Pooled analysis from 4 cities - Brisbane, Sydney, Melbourne, Perth.All ages: 1.023 (1.003-1.043) per 1 pphm 0-4 years: Protective effect.1-hour maximum Lag 05-14 years: No effect.1-hour maximum Lag 015-64 years: 1.045 (1.013-1.079) per 1 pphm8-hour averageLag 265+ years: 1.054 (1.016-1.094) per 1 pphm 8-hour averageLag 3([Petroeschevsky, Simpson et al. 2001](#_ENREF_87))BrisbaneICD9: 460-519All ages: No effect0-14 years: No effect.65+ years: No effect.Perth.([Hinwood, De Klerk et al. 2006](#_ENREF_48))0 year: No effect.1-4 years: 1.9% (0.5-3.4%) per 9.83 ppb1-hour maximum.Lag 01.All year.No heterogeneity.5-14 years: No effect.15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 460-519ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | All ages: 3.5% per 50 µg/m3 15-64 years: 1.031 (1.013-1.049) per 50 µg/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))Whole population.8-hour average.Meta-analysis of 4 European cities.ICD9: 460-519 | Various age groups analysed: effect close to significant for 65+ years only.65+ years: No effect.([Anderson, Atkinson et al. 2004](#_ENREF_8)).([European Commission 2005](#_ENREF_38))8-hour average.Meta-analysis of 5 European cities. | n/aPooled analysis of a number of studies – unable to locate CRF.([Abt Associates Inc 2011](#_ENREF_3)) | n/aAll ages: 5% increase per 25 µg/m3 (8-hour average) and 30 µg/m3 1-hour average([WHO Europe 2000](#_ENREF_127))0-14 years: Insufficient numbers for meta-analysis15-64 years: 1.001 (0.991-1.012) per 10 *µ*g/m3 65+ years: 1.005 (0.998-1.012) per 10 *µ*g/m3 ([Anderson, Atkinson et al. 2004](#_ENREF_8))8-hour average. | No CRF recommended.Results are inconsistent. The Brisbane CRFs ([Petroeschevsky, Simpson et al. 2001](#_ENREF_87)) and the 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)) may be used in a sensitivity analysis. |
| Asthma | No effect on three age groups: all ages; <15 years; 65+ years.Perth.([Hinwood, De Klerk et al. 2006](#_ENREF_48))1-14 years No effect.15-64 years: No effect.([Morgan, Corbett et al. 1998](#_ENREF_74))Sydney.All ages: 1.090 (1.042-1.141) per 1 pphmLag 5 average0-14 years: 1.064 (1.015-1.115) per 1 pphmLag 115-64 years 1.084 (1.037-1.133) per 1 pphmLag 2([Petroeschevsky, Simpson et al. 2001](#_ENREF_87))8-hour average.Brisbane.No effect.([Simpson, Williams et al. 2005](#_ENREF_103))Age: 15-64 yearslCD9: 493,ICD10: J45, J46, J44.8Pooled analysis from 4 cities - Brisbane, Sydney, Melbourne, Perth. Age: 1-4 years0.5% (0.3-0.7%) per 1 ppb1-hour maximum.Lag 01.Warm season: November-April.No heterogeneity.([Environment Protection and Heritage Council 2005](#_ENREF_35))Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 493; ICD10: 45, J46, J44.8 | n/a | n/a | n/a | n/a | No CRF recommended. Australian results are inconsistent. The Brisbane CRFs ([Petroeschevsky, Simpson et al. 2001](#_ENREF_87)) and the 4-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)) may be used in a sensitivity analysis. |
| Chronic obstructive pulmonary disease (COPD)  | All ages: No effect.<15 years: No effect.65+ years: No effect.([Hinwood, De Klerk et al. 2006](#_ENREF_48))Perth.65+ years: No effect([Morgan, Corbett et al. 1998](#_ENREF_74))Sydney.Asthma+COPD:65+ years: 1.0013 (1.0001-1.0026) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103))4-hour average.Lag 0.Asthma: lCD9: 493; ICD10: J45, J46, J44.8COPD: lCD9: 490-492, 494-496; ICD10: J40-J44, J47, J67Pooled analysis from 4 cities - Brisbane, Sydney, Melbourne, Perth.15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Moderate to high heterogeneityMeta-analysis of 4 cities - Brisbane, Melbourne, Perth SydneylCD9: 490-492, 494-496ICDI0: J40-J44, J47, J67  | 65+ years: 1.038 (1.018-1.058) per 50 *µ*g/m3 ([Committee on the Medical Effects of Air Pollutants 2002](#_ENREF_20))8-hour averageMeta-analysis of 4 European cities. | n/a | n/a | n/a | No CRF recommended.Inconsistent results from the two Australian multi-city studies. CRF from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) may be used in a sensitivity analysis. |
| Pneumonia and acute bronchitis | All ages: No effect<15 years: No effect65+ years: No effect([Hinwood, De Klerk et al. 2006](#_ENREF_48))PerthNo effect.([Simpson, Williams et al. 2005](#_ENREF_103))65+ years.ICD9: 466, 480-486 ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J21Pooled analysis from 4 cities - Brisbane, Sydney, Melbourne, Perth.0 years: No effect1-4 years: No effect15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))High heterogeneity for 15-64 years only.Meta-analysis of 4 cities - Brisbane, Melbourne, Perth Sydney.ICD9: 466, 480-486 ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J21 | n/a | n/a | n/a | n/a | No CRF recommended. No effect shown in Australian studies. |
| **Emergency department visits** |
| Asthma  | 1-4 years: 2.3% (1.4-3.2%) per 13.6 ppb 5-9 years: 2.1% (0.7-3.5%) per 13.6 ppb 10-14 years: No effect.1-14 years: 1.8% (1.1-2.5%) per 13.6 ppb ([Jalaludin, Khalaj et al. 2008](#_ENREF_54))1-hour maximum.Lag 01.Greater significant effects in warm months but not cool months.ICD9: 493ChildrenSydney1-15 yearsNon-linear significant response for Western & South/South Eastern regions (No CRFs available). No effect of O3 for Inner Melbourne or Eastern Melbourne regions.([Erbas, Kelly et al. 2005](#_ENREF_36))ICD10: J45, J46Melbourne. | n/a | n/a | 1.022 (0.996-1.049) per 25 ppb([Peel, Tolbert et al. 2005](#_ENREF_84))([Wilson, Wake et al. 2005](#_ENREF_133))([Abt Associates Inc 2011](#_ENREF_3))Pooled results from 3 cities and 2 studies.8-hour maximum.Age: 0-99 years. | n/a | Recommended CRF: 1-14 years: 1.8% (1.1-2.5%) per 13.6 ppb ([Jalaludin, Khalaj et al. 2008](#_ENREF_54)). |
| Respiratory disease  | n/a | n/a | n/a | n/a | n/a | No CRF recommended.  |
| Cardiovascular disease  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Incidence of myocardial infarction (heart attacks)** |
| Non-fatal heart attacks | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Lung function** |
| Change in forced expiratory volume in 1 second (FEV1; litres)  | No effect of 1-hour maximum, 4-hour average and 8-hour average on PEF either in all year analysis or in warm season only analysis([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean 10.0 years (n=270)270 children with current asthma | n/a | n/a | n/a | n/aLung function deficits seen in exercising children exposed to daily maximum 8-hour average of 160 *µ*g/m3.([WHO 2006](#_ENREF_125))10% change in FEV1 at 160*µ*g/m3 (8-hour average) and 350*µ*g/m3 (1-hour average). 5% change in FEV1 at 120*µ*g/m3 (8-hour average) and 250*µ*g/m3 (1-hour average) ([WHO Europe 2000](#_ENREF_127))Controlled exposure studies. | No CRF recommended. No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in peak expiratory flow rate (PEF; litres per minute) | Average change in PEF: -0.8823 l/min ( -0.0542 to -1.7104 l/min) per 1 pphm([Jalaludin, Chey et al. 2000](#_ENREF_53))Mean daytime ozone.148 children with history of wheezing in last 12 months.Mean age: 9.6 years.Sydney.15-54 years:-0.2047 l/min (-0.2760 to -0.03342 l/min) per 1 pphm8-hour average3-day averageSpring55+ years:-0.1568 l/min (-0.2864 to -0.0272 l/min) per 1 pphm8-hour averageLag 2Winter([Rutherford, Simpson et al. 2000](#_ENREF_94))BrisbaneAsthmatics allergic to at least one pollen or fungal allergen.No effect of 1-hour maximum, 4-hour average and 8-hour average on PEF either in all year analysis or in warm season only analysis.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years.270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended. No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Minor morbidity** |
| Asthma exacerbation (asthmatics) | n/a | n/aHowever, CRF from Whittemore and Korn 1980 used in health risk assessment | n/a | 1.0018 (1.0004-1.0032) per 1 ppb ([Whittemore and Korn 1980](#_ENREF_124))([US EPA 1999](#_ENREF_112))Asthmatics of all ages1-hour maximum | n/a | Recommended CRF: 1.0018 (1.0004-1.0032) per 1 ppb ([Whittemore and Korn 1980](#_ENREF_124))([US EPA 1999](#_ENREF_112)) |
| Asthma/ respiratory exacerbations (whole population) | n/a | n/a | No effect.([Hoek and Brunekreef 1995](#_ENREF_49); [Declerq and Macquet 2000](#_ENREF_27)))([European Commission 2005](#_ENREF_38))Whole population of children aged 5-14 yearsFrance.8-hour daily maximum . | n/a | n/a25% increased symptoms in adults or asthmatics per 100 *µ*g/m3 (8-hour average) and 200 *µ*g/m3 (1-hour average).([WHO Europe 2000](#_ENREF_127)) | No CRF recommended.CRF from European Commission ([European Commission 2005](#_ENREF_38)) is not statistically significant and CRFs from WHO ([WHO Europe 2000](#_ENREF_127))do not have associated confidence limits.  |
| Increased airway hyper-responsiveness | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Restricted activity days (RAD)2 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Minor restricted activity days (MRAD)3 | n/a | 1.48% (0.57-2.38%) per 10 *µ*g/m3 8-hour average0.11% (0.043-0.179%) per 1 *µ*g/m3 ([Ostro and Rothschild 1989](#_ENREF_83)) in ([European Commission 1995](#_ENREF_37)) ([AEA Technology Environment 2005](#_ENREF_7))Age: Adults.1-hour maximumO3 adjusted for PM2.5 in study. | 1.48% (0.57-2.38%)per 10 *µ*g/m3 8-hour average0.11% (0.043-0.179%) per 1 *µ*g/m31-hour maximum([Ostro and Rothschild 1989](#_ENREF_83)). ([European Commission 2005](#_ENREF_38))Age: 18+ years.Whole population.O3 adjusted for PM2.5 in study. | 1.0022 (1.0009-1.0035) per 1 ppb (Ostro and Rothschild 1989)([US EPA 1999](#_ENREF_112))([Abt Associates Inc 2011](#_ENREF_3))1-hour maximum.Age: 18-65 years.O3 adjusted for PM2.5 in study. | n/a | Recommended CRF: 1.0022 (1.0009-1.0035) per 1 ppb (Ostro and Rothschild 1989)([US EPA 1999](#_ENREF_112))([Abt Associates Inc 2011](#_ENREF_3)) |
| Work lost days (WLD)2 | n/a | n/a | n/a | n/aPooled estimate from 2 studies – unable to locate CRF.([Abt Associates Inc 2011](#_ENREF_3)) | n/a | No CRF recommended. |
| Acute bronchitis | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Upper respiratory illness | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lower respiratory symptoms  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute respiratory symptoms | No effect on cough, wheeze, runny/blocked nose.(Rodriguez et al, 2007)Perth. | n/a | Presence of any 19 acute respiratory symptoms: 1.0055 (1.0002-1.0109) per 10 ppb ([Krupnick, Harrington et al. 1990](#_ENREF_65))([European Commission 1995](#_ENREF_37)).([AEA Technology Environment 2005](#_ENREF_7)) |  Presence of any 19 acute respiratory symptoms: 1.0001 (1.0000-1.0003) per 1 ppb ([Krupnick, Harrington et al. 1990](#_ENREF_65))([US EPA 1999](#_ENREF_112))Age: 18-65 years.Whole population.1-hour maximum. | n/a | No CRF recommended.CRF by Krupnick et al ([Krupnick, Harrington et al. 1990](#_ENREF_65)) may be used in a sensitivity analysis.This endpoint not used by US EPA in its most recent cost-benefit analysis([US EPA 2011](#_ENREF_121)).   |
| Wheeze | No effect.(Rodriguez et al, 2007)Perth.Evening wheeze: No effect([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children.Mean age 9.6 years.Sydney.Day wheeze: No effect of 1-hour maximum, 4-hour average or 8-hour average in either all year analysis or warm season only analysis except for protective effect for 8-hour average in all year analysis.Night symptoms: Protective effects for 1-hour maximum, 4-hour average and 8-hour average in both all year analysis and warm season only analysis([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean 10.0 years 270 children with current asthma | n/a | n/a | n/a | n/a | No CRF recommended.No effects have been shown in Australian studies including the 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Cough | No effect.(Rodriguez et al, 2007)PerthEvening dry/wet cough: No effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children.Mean age 9.6 years.Sydney.Day cough: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysis.Night cough: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysis.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years.270 children with current asthma. | n/a | Incidence night cough: No effect(Just et al. 2002)([European Commission 2005](#_ENREF_38))Based on 1 study (82 children aged 7-15 years with doctor diagnosed asthma taking daily asthma medications). 8-hour daily average.Prevalence cough: No effect.([Declerq and Macquet 2000](#_ENREF_27))([European Commission 2005](#_ENREF_38))Whole population of children aged 5-14 years.France. | n/a | n/a | No CRF recommended. No effects have been shown in Australian studies including the 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Shortness of breath | Day SOB: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysis.Night SOB: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysis([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years.270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effects shown in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Bronchodilator use | No effect([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 childrenMean age 9.6 yearsSydneyDay use: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysisNight use: No effect of 1-hour maximum, 4-hour average and 8-hour average in either all year analysis or in warm season only analysis([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years.270 children with current asthma. | n/a | Days of supplementary bronchodilator use.5-14 years: 1.41 (1.05-1.89) per 10 *µ*g/m3 ([Gielen, van der Zee et al. 1997](#_ENREF_40); [Just, Segala et al. 2002](#_ENREF_63)) Recommended using as upper limit for sensitivity analyses only, as based on 1 study (82 children aged 7-15 years with doctor diagnosed asthma taking daily asthma medications) only with high odds ratios. Odds ratios based on days when children not taking corticosteroids.([European Commission 2005](#_ENREF_38))Adults 20+ years: No effect.([ECRHS 1996](#_ENREF_34); [Hiltermann, Stolk et al. 1998](#_ENREF_47)).([European Commission 2005](#_ENREF_38))Adults with well-established asthma. 8-hour maximum moving average. | n/a | n/a | No CRF recommended.No effects shown in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Upper respiratory symptoms  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Increased respiratory symptoms | Day symptoms: No effect of 1-hour maximum, 4-hour average or 8-hour average on any day symptoms (cough, wheeze, shortness of breath, runny nose, eye irritation, fever) in either all year analysis or warm season only analysis except for protective effect for 8-hour average in all year analysis.Night symptoms: No effect of 1-hour maximum, 4-hour average or 8-hour average on any night symptoms (cough, wheeze, shortness of breath) in either all year analysis or warm season only analysis([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean 10.0 years 270 children with current asthma | n/a | n/a | n/a | n/a | No CRF recommended.No effects shown in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| General practitioner consultation for asthma | No effect([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 childrenMean age 9.6 yearsSydney | n/a | n/a | n/a | n/a | No CRF recommended. |
| General practitioner consultation for upper respiratory disease | n/a | n/a | Consultations for allergic rhinitis: 0-14 years: 8.2% (5.1-11.6%) per 10 *µ*g/m315-64 years: 5.5% (4.2-7.0%) 10 *µ*g/m3([Hajat, Haines et al. 2001](#_ENREF_42)) in ([Hurley, Hunt et al. 2005](#_ENREF_51))([European Commission 2005](#_ENREF_38))London(ICD9: 477)Lag 0-38-hour daily maximumRecommended using only for sensitivity analyses as based on 1 study only. | n/a | n/a | No CRF recommended.May use CRFs from paper by Hajat et al ([Hajat, Haines et al. 2001](#_ENREF_42)) in a sensitivity analysis.  |

1n/a=not available

2A restricted activity days is defined as a day when a person is forced to alter his/her normal activity. A severe restriction include days when it necessary to stay in bed. For employed adults, restricted activity days include Work Loss Days; for children, it would include days off school (whether or not the child is confined to bed) (ExternE 1995).

3Minor restricted activity days do not involve work loss or bed disability but do include some noticeable limitation on ‘normal’ activity (ExternE 1995).

**REFERENCES**

Abt Associates Inc (2011). BENMAP. User's manual appendices, Office of Air Quality Planning and Standards, Research Triangle Park, NC, USA. .

AEA Technology Environment (2005). Methodology for the cost-benefit analysis for CAFE: Volume 2: Health impact assessment. Oxon, UK, AEA Technology Environment.

Anderson, H. R., R. W. Atkinson, et al. (2004). Meta-Analysis of Time-Series Studies and Panel Studies of Particulate Matter (PM) and Ozone (O3). Copenhagen, World Health Organization Regional Office for Europe**:** 80.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2002). Is there a threshold for the effect of ozone on health? 1. Is there an effect on mortality and respiratory or circulatory admissions? London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2006). Cardiovascular disease and air pollution. London, Department of Health, UK.

Declerq, C. and V. Macquet (2000). "Short-term Effects of Ozone on Respiratory Health of Children in Armentieres, North of France." Rev Epidemiol Sante Publique **48**(Suppl 2): S37-43.

ECRHS (1996). "European Community Respiratory Health Survey: Variations in the prevalence of respiratory symptoms, self-reported asthma attacks, and use of asthma medication in the European Community Respiratory Health Survey (ECRHS). ." Eur Respir J **9**: 687-695.

Environment Protection and Heritage Council (2005). Expansion of the multi-city mortality and morbidity study. Final report. Volume 3. Tabulated results, Environment Protection and Heritage Council.

Erbas, B., A.-M. Kelly, et al. (2005). "Air pollution and childhood asthma emergency hospital admissions: estimating intra-city regional variations." International Journal of Environmental Health Research **15**(1): 11-20.

European Commission (1995). Externalities of Energy "ExternE" Project, Volume 2, Methodology. Method for estimation of physical impacts and monetary valuation for priority impact pathways. Oxfordshire, UK, Prepared by ETSU and others**:** 408.

European Commission (2005). ExternE. Externalities of Energy: Methodology 2005 Update. P. Bickel and R. Friedrich, Luxemburg, European Commission.

Gielen, M. H., S. C. van der Zee, et al. (1997). "Acute effects of summer air pollution on respiratory health of asthmatic children." American Journal of Respiratory and Critical Care Medicine **155**(6): 2105-2108.

Hajat, S., A. Haines, et al. (2001). "Association between air pollution and daily consultations with general practitioners for allergic rhinitis in London, United Kingdom." American Journal of Epidemiology **153**(7): 704-714.

Hansen, C., A. Neller, et al. (2006). "Maternal exposure to low levels of ambient air pollution and preterm birth in Brisbane, Australia." BJOG: An International Journal of Obstetrics & Gynaecology **113**(8): 935-941.

Hansen, C., A. Neller, et al. (2007). "Low levels of ambient air pollution during pregnancy and fetal growth among term neonates in Brisbane, Australia." Environmental Research **103**(3): 383-389.

Hansen, C. A., A. G. Barnett, et al. (2009). "Ambient Air Pollution and Birth Defects in Brisbane, Australia." Plos One **4**(4).

Hiltermann, T. J., J. Stolk, et al. (1998). "Asthma severity and susceptibility to air pollution." European Respiratory Journal **11**(3): 686-693.

Hinwood, A., N. De Klerk, et al. (2006). "The relationship between changes in daily air pollution and hospitalizations in Perth, Australia 1992 - 1998: A case-crossover study." International Journal of Environmental Health Research **16**(1): 27-46.

Hoek, G. and B. Brunekreef (1995). "Effect of photochemical air pollution on acute respiratory symptoms in children." American Journal of Respiratory and Critical Care Medicine **151**(1): 27-32.

Hurley, F., A. Hunt, et al. (2005). Methodology Paper (Volume 2) for Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, In Particular in the Clean Air for Europe (CAFE) Programme. Oxon, UK, AEA Technology Environment.

Jalaludin, B., T. Chey, et al. (2000). "Acute effects of low levels of ambient ozone on peak expiratory flow rate in a cohort of Australian children." International Journal of Epidemiology **29**(3): 549-557.

Jalaludin, B., B. Khalaj, et al. (2008). "Acute effects of ambient air pollutants on ED visits for asthma in children, Sydney, Australia: a case-crossover analysis." International Archives of Occupational & Environmental Health **81**(8): 967-974.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**: 16.

Jalaludin, B., B. O'Toole, et al. (2004). "Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children." Environmental Research **95**(1): 32-42.

Jerrett, M., R. T. Burnett, et al. (2009). "Long-term ozone exposure and mortality." New England Journal of Medicine **360**(11): 1085-1095.

Just, J., C. Segala, et al. (2002). "Short-term health effects of particulate and photochemical air pollution in asthmatic children." European Respiratory Journal **20**(4): 899-906.

Krupnick, A., W. Harrington, et al. (1990). "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." Journal of Environmental Economics and Management **18**(1): 1-18.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occupational and Environmental Medicine **62**(8): 524-530.

McDonnell, W. F., D. E. Abbey, et al. (1999). "Long-term ambient ozone concentration and the incidence of asthma in nonsmoking adults: the AHSMOG Study." Environmental Research **80**(Section A): 110-121.

Morgan, G., S. Corbett, et al. (1998). "Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994." American Journal of Public Health **88**(12): 1761-1766.

Ostro, B. D. and S. Rothschild (1989). "Air pollution and acute respiratory morbidity: an observational study of multiple pollutants." Environmental Research **50**(2): 238-247.

Peel, J. L., P. E. Tolbert, et al. (2005). "Ambient air pollution and respiratory emergency department visits." Epidemiology **16**(2): 164-174.

Petroeschevsky, A., R. W. Simpson, et al. (2001). "Associations between outdoor air pollution and hospital admissions in Brisbane, Australia." Archives of Environmental Health **56**(1): 37-52.

Rutherford, S., R. Simpson, et al. (2000). "Relationships between environmental factors and lung function of asthmatic subjects in south east Queensland, Australia." Journal of Occupational & Environmental Medicine **42**(9): 882-891.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on daily mortality in four Australian cities." Australian & New Zealand Journal of Public Health **29**(3): 205-212.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on hospital admissions in four Australian cities " Australian & New Zealand Journal of Public Health **29**(3): 213-221.

Sunyer, J., J. Castellsague, et al. (1996). "Air pollution and mortality in Barcelona." Journal of Epidemiology & Community Health **50**(Suppl 1): s76-s80.

US EPA (1999). The Benefits and Costs of the Clean Air Act 1990 to 2010. Washington, DC, United States Environmental Protection Agency.

US EPA (2006). Regulatory impact analysis. National Ambient Air Quality Standards for particle pollution, Research Triangle Park, North Carolina.

US EPA (2011). The benefits and costs of the Clean Air act from 1990 to 2020, U.S. Environmental Protection agency, USA.

Whittemore, A. S. and E. L. Korn (1980). "Asthma and air pollution in the Los Angeles area." American Journal of Public Health **70**(7): 687-696.

WHO (2006). "WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Global Update 2005. Summary of Risk Asessment.".

WHO Europe (2000). Air quality guidelines for Europe: second edition. Copenhagen, WHO Regional Office for Europe.

Williams, G., G. Marks, et al. (2012). Australian Child Health and Air Pollution Study (ACHAPS). Final report. Environment Protection and Heritage Council (in press).

Wilson, A. M., C. P. Wake, et al. (2005). "Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study." Environmental Research **97**(3): 312-321.

Table 4: NO2 health endpoints and associated concentration–response functions

|  | **Concentration-response function (95%CI)** |
| --- | --- |
| **Health outcomes** | **Australian** | **UK** | **Europe** | **US EPA** | **WHO** | **Recommended** |
| ***Long-term outcomes (annual average concentration)*** |
| **Mortality** |
| All cause  | n/a1 | n/a | n/a | n/aResults inconsistent.([US EPA 2008](#_ENREF_116)) | n/a | No CRF recommended. |
| Infant (<12 months age) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Life expectancy lost (years of life lost; YOLL) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Morbidity** |
| Incidence of chronic obstructive pulmonary disease (COPD) or chronic bronchitis | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Incidence of asthma | Ever had wheezing:No effect in single pollutant model.Largest effect in 2-pollutant model with PM2.5: 1.15 (1.01-1.31) per 4.31 ppbEver had asthma:No effect in single pollutant model. Largest effect in 2-pollutant model with CO: 1.27 (1.04-1.56) per 4.31 ppb([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly NO2  over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/aResults inconsistent.([US EPA 2008](#_ENREF_116)) | n/a | Recommended CRF for asthma incidence: 1.27 (1.04-1.56) per 4.31 ppb (in 2-pollutant model with CO) ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Recent symptoms (in last 12 months) | Wheeze: 1.25 (1.07-1.46) per 4.31 ppb in 2-pollutant model with PM2.5Wheeze after exercise: 1.43 (1.05-1.96) per 4.31 ppb in 2-pollutant model with COCurrent asthma: 1.51 (1.08-2.12) per 4.31 ppb in 2-pollutant model with COVisit to doctor/hospital: 1.51 (1.04-2.19) per 4.31 ppb in 2-pollutant model with O3Use of bronchodilators: 1.35 (1.05-1.76) per 4.31 ppb in 2-pollutant model with CO([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly NO2  over lifetime .Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRFs:Wheeze: 1.25 (1.07-1.46) per 4.31 ppb in 2-pollutant model with PM2.5Wheeze after exercise: 1.43 (1.05-1.96) per 4.31 ppb in 2-pollutant model with COCurrent asthma: 1.51 (1.08-2.12) per 4.31 ppb in 2-pollutant model with COVisit to doctor/hospital: 1.51 (1.04-2.19) per 4.31 ppb in 2-pollutant model with O3Use of bronchodilators: 1.35 (1.05-1.76) per 4.31 ppb in 2-pollutant model with CO([Williams, Marks et al. 2012](#_ENREF_132)). |
| Lung function growth  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Change in forced expiratory volume in 1 second (FEV1; litres) | -26.2 mls (-42.2 to -10.1 mls) per 4.31 ppb in single pollutant modelMinimal change in estimates in 2-pollutant models with PM2.5, PM10, O3. Effect increased in 2-pollutant model with CO: -45.4 mls (-74.3 to -16.5 mls) per 4.31 ppb([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly NO2  over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRF: -45.4 mls (-74.3 to -16.5 mls) per 4.31 ppb (in 2-pollutant model with CO) ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in forced vital capacity (FVC; litres)  | -25.3 mls (-40.6 to -10.0 mls) per 4.31 ppb in single pollutant model.Minimal change in estimates in 2-pollutant models with PM2.5, PM10, O3. Effect increased in 2-pollutant model with O3: -43.1 mls (-72.2 to -14.1 mls) per 4.31 ppb([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly NO2  over lifetime. Age: mean age10.0 years. 2,860 children.  |  |  |  |  | Recommended CRF: -43.1 mls (-72.2 to -14.1 mls) per 4.31 ppb (in 2-pollutant model with O3) ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Airway inflammation | 1.03 (1.01-1.05) per 1 ppb in single pollutant model. Remains significant in 2-pollutant models with PM2.5, PM10, O3 and SO2 and CO.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly NO2  over lifetime. Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | Recommended CRF: 1.03 (1.01-1.05) per 1 ppb ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Birth outcomes** |
| Birth defects | No significant associations for cleft lip and/or palate and cardiac defects.([Hansen, Barnett et al. 2009](#_ENREF_46))Brisbane | n/a | n/a | n/a | n/a | No CRF recommended.Only 1 Australian study. |
| Prematurity | 1.03 (0.86–1.23) per 4.5 ppb([Hansen, Neller et al. 2006](#_ENREF_44))Brisbane24-hour averageExposure period 3 months preceding birth.1.006 (0.993-1.019) per 1 ppb([Jalaludin, Mannes et al. 2007](#_ENREF_57))Sydney1-hour maximumExposure period 3 months preceding birth. | n/a | n/a | n/a | n/a | No CRF recommended.Only 2 Australian studies - no effect shown.  |
| Low birth weight | 1.01 (1.00-1.02) per 1 ppb for small for gestation age-1.48 (-2.70 to -0.26) grams per 1 ppb([Mannes, Jalaludin et al. 2005](#_ENREF_71))Sydney1-hour maximumExposure period third trimester for both metrics.Small for gestation age <2 standard deviations from mean for sex and gestational age. | n/a | n/a | n/a | n/a | No CRF recommended.Only a few Australian studies.  |
| ***Short-term outcomes(daily average concentration)*** |
| **Mortality** |
| Non-trauma | 1.0012 (1.0006-1.0018) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 citiesICD9: <800; ICD10: A-R, Z35.5, Z35.8Age: All1.7% (0.3-3.2%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Age: All All year.Moderate heterogeneity.Meta-analysis of 5 cities-Brisbane, Canberra, Melbourne, Perth, Sydney.ICD9: <800; ICD10: A-R, Z35.5, Z35.8 | 3.5% (1.6-5.4%) per 100 ug/m3  ([Touloumi, Katsouyanni et al. 1997](#_ENREF_111)) ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))Pooled CRF from 6 cities. | n/a | n/a([US EPA 2008](#_ENREF_116))Suggestive but not sufficient to infer a causal relationship as it is difficult to attribute effects to NO2 alone. However, estimates were robust to adjustment for co-pollutants. | n/a | Recommended CRF: 1.7% (0.3-3.2%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cardiovascular | 1.0018 (1.0008-1.0027) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 cities.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58Age: All1.6% (0.4-2.8%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Age: All agesAll yearNo heterogeneity.Meta-analysis of 5 cities-Brisbane, Canberra, Melbourne, Perth, Sydney.ICD9: 390-459ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 1.0% (0.8-1.3%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Moderate evidence of publication bias. CRF not intended for health risk assessment purposes. | n/a | n/aSuggestive but not sufficient to infer a causal relationship as it is difficult to attribute effects to NO2 alone. However, estimates were robust to adjustment for co-pollutants.([US EPA 2008](#_ENREF_116)) | n/a | Recommended CRF: 1.6% (0.4-2.8%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory  | 1.0038 (1.0017-1.0058) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_102))Pooled CRF from 4 cities.ICD9: 460-519ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 Age: All3.9% (0.6-7.4%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Age: All agesAll yearNo heterogeneityMeta-analysis of 5 cities-Brisbane, Canberra, Melbourne, Perth, Sydney.ICD9: 460-519ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8 | No effect.([Zmirou, Schwartz et al. 1998](#_ENREF_139))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19)) | n/a | n/a | n/a | Recommended CRF: 3.9% (0.6-7.4%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| **Hospitalisation** |
| Cardiovascular | n/a for all cardiovascular diseaseFour cities study.([Simpson, Williams et al. 2005](#_ENREF_103))No effect ([Petroeschevsky, Simpson et al. 2001](#_ENREF_87))BrisbaneICD9: 390-459Age: AllHeart disease: 7.52% (5.21-9.88%) per 17 ppb([Morgan, Corbett et al. 1998](#_ENREF_74))SydneyAge: AllICD9: 410, 413, 427, 42824-hour average15-64 years: 1.3% (0.3-2.3%) per 8.98 ppb65+ years: 2.6% (1.8-3.3%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01([Barnett, Williams et al. 2005](#_ENREF_12))Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, SydneyLow heterogeneityICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | n/a | n/a | n/a | n/a | Recommended CRF: 1.3% (0.3-2.3%) per 8.98 ppb in 15-64 years;  2.6% (1.8-3.3%) per 8.98 ppb in 65+ years ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cardiac  | 1.0022 (1.0016-1.0028) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 4 cities (Sydney, Perth, Melbourne, Brisbane)lCD9: 390-429ICDI0: I00-I52, I97.0, I97.1, I98.1Age: All1-hour maximum15-64 years: 1.2% (0.0-2.4%) per 8.98 ppb65+ years: 3.3% (2.4-4.3%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, SydneyLow heterogeneitylCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1 | 1.3% (1.0-1.7%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))No evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/aInadequate evidence for causal relationship, but generally positive associations seen with cardiovascular disease hospitalisations or emergency department presentations.([US EPA 2008](#_ENREF_116)) | n/a | Recommended CRF:15-64 years: 1.2% (0.0-2.4%) per 8.98 ppb in 15-64 years; 3.3% (2.4-4.3%) per 8.98 ppb in 15-64 years ([Environment Protection and Heritage Council 2005](#_ENREF_35)). Chosen as it is a more recent study.In a sensitivity analysis use the following CRFs:1.0022 (1.0016-1.0028) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103)).This study applies to all ages. |
| Cardiac failure | 15-64 years: No effect65+ years: 7.5% (5.3-9.7%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, SydneyLow heterogeneityICD9: 428; ICD10: I50 | 1.3% (0.4-2.3%) change per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Weak evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/a | n/a | Recommended CRF: 7.5% (5.3-9.7%) per 8.98 ppb in 65+ years([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cerebrovascular  | Stroke:15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Low heterogeneity.ICD9: 430-438; ICD10: I60-I66, I67 (excluding I67.0, I67.3), I68 (excluding I68.0), I69, G45 (excluding G45.3), G46 | 0.4% (0.0-0.8%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))No evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/a | n/a | No CRF recommended. This CRF may be used in a sensitivity analysis: 0.4% (0.0-0.8%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21)).However note that CRF not intended for health risk assessment purposes. |
| Ischaemic heart disease | 1.0017 (1.0007-1.0027) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 4 cities (Sydney, Perth, Melbourne, Brisbane)lCD9: 410-413; ICDI0: I20-I22, I24, I25.2 Age: All1-hour maximum15-64 years: No effect65+ years: 2.7% (1.5-4.0%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Low heterogeneity.lCD9: 410-413; ICDI0: I20-I22, I24, I25.2 | 0.6% (-0.1 to 1.4%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))No evidence of publication bias.CRF not intended for health risk assessment purposes. | n/a | n/a | n/a | Recommended CRF: 1.0017 (1.0007-1.0027) per 1ppb ([Simpson, Williams et al. 2005](#_ENREF_103)).The following CRF may be used in a sensitivity analysis:2.7% (1.5-4.0%) per 8.98 ppb in 65+ years ([Environment Protection and Heritage Council 2005](#_ENREF_35)). Note the restricted agegroup. |
| Arrhythmia | 15-64 years: 3.4% (0.7-6.3%) per 8.98 ppb 65+ years: No effect ([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Low heterogeneity.ICD9: 437; ICD10: I46-I49 | n/a | n/a | n/a | n/a | Recommended CRF: 3.4% (0.7-6.3%) per 8.98 ppb in 15-64 years([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Myocardial infarction | 15-64 years: No effect65+ years: 4.8% (2.3-7.4%) per 8.98 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Low heterogeneity.lCD9: 410; ICDI0: I21, I22 | n/a | n/a | n/a | n/a | Recommended CRF: 4.8% (2.3-7.4%) per 8.98 ppb in 65+ years([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory | 65+ years: 1.0016 (1.0006-1.0026) per 1 ppbPooled estimate from 4 cities - Sydney, Perth, Melbourne, Brisbane.lCD9: 460-519ICDI0: J00-J99 (excluding J95.4-J95.9), R09.1, R09.8  1-hour maximum1-4 years: 3.6% (1.5-5.7%) per 9.0 ppb5-14 years: 4.0% (1.1-7.1%) per 9.0 ppb15-64 years: 1.6% (0.5-2.8%) per 9.0 ppb65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Low heterogeneity.lCD9: 460-519; ICDI0: J00-J99 (excluding J95.4-J95.9), R09.1, R09.8 1-hour maximum | No effect([Spix, Anderson et al. 1998](#_ENREF_104))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19)), Pooled CRF from 5 cities. 2.5% (95%CI not available) per 10 ug/m3 ([DEFRA 2006](#_ENREF_28))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))ICD9: 460-519 | n/a | n/aConsistent evidence of positive associations.([US EPA 2008](#_ENREF_116)) | n/a | Recommended CRF: 1-4 years: 3.6% (1.5-5.7%) per 9.0 ppb; 5-14 years: 4.0% (1.1-7.1%) per 9.0 ppb; 15-64 years: 1.6% (0.5-2.8%) per 9.0 ppb ([Environment Protection and Heritage Council 2005](#_ENREF_35)).65+ years: 1.0016 (1.0006-1.0026) per 1 ppb ([Simpson, Williams et al. 2005](#_ENREF_103)) |
| Asthma | 1-14 years: 5.29% (1.07-9.68%) per 29 ppb([Morgan, Corbett et al. 1998](#_ENREF_74))SydneyICD9: 4931-hour maximumNo effect([Simpson, Williams et al. 2005](#_ENREF_103))Pooled CRF from 4 cities (Sydney, Perth, Melbourne, Brisbane)lCD9: 493; ICDI0: J45, J46, J44.8  1-hour maximum1-4 years: No effect5-14 years: No effect15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.Moderate heterogeneityBrisbane, Canberra, Melbourne, Perth, Sydney.lCD9: 493; ICDI0: J45, J46, J44.8 1-hour maximum | 2.6% (0.6-4.9%) per 50 ug/m3 ([Sunyer, Spix et al. 1997](#_ENREF_108))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))Pooled CRF from 4 cities.24-hour average?Age | n/a | n/aConsistent evidence of positive associations, particularly for asthma.([US EPA 2008](#_ENREF_116))0-29 years: 1.0243 (1.0084-1.0405) per 10 ppb 30-99 years: 1.0141 (1.0042-1.0241) per 10 ppb([Linn, Szlachcic et al. 2000](#_ENREF_69))([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))ICD9: 493 All ages | n/a | No CRF recommended. 2 Australian multi-cities studies have shown no effects.May use either Morgan et al ([Morgan, Corbett et al. 1998](#_ENREF_74)) CRF in a sensitivity analysis. Note the restricted age group.  |
| Chronic obstructive pulmonary disease (COPD)  | 65+ years: 1.0019 (1.0005-1.0033) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 4 cities - Sydney, Perth, Melbourne, Brisbane.lCD9: 490-496; ICDI0: J40-47, J67 1-hour maximumAsthma+COPD15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))Moderate heterogeneity for 65+ years.Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.lCD9: 490-492, 494-496; ICDI0: J40-J44, J47, J67 1-hour maximum | 1.9% (0.2-4.7%) per 50 ug/m3 ([Anderson, Spix et al. 1997](#_ENREF_10))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))Pooled CRF from 6 cities | n/a | Pooled CRF from 2 analyses shown below (pooled CRF not available)LA County: 1.0182 (1.0144-1.0219) per 10 ppbCook County: 1.0243 (1.0083-1.0405) per 10 ppb([Moolgavkar 2003](#_ENREF_73))([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))ICD9: 490-496Age: > 65 years | n/a | No CRF recommended.No effect in the 5-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). May use the CRF (65+ years: 1.0019 (1.0005-1.0033) per 1 ppb) from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) in a sensitivity analysis. |
| Pneumonia and acute bronchitis | 65+ years: 1.0018 (1.0002-1.0033) per 1 ppb([Simpson, Williams et al. 2005](#_ENREF_103))Pooled estimate from 4 cities - Sydney, Perth, Melbourne, Brisbane.ICD9: 466, 480-486; ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J210 years: No effect1-4 years: No effect15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))Moderate heterogeneity. Meta-analysis of 5 cities - Brisbane, Canberra, Melbourne, Perth, Sydney.ICD9: 466, 480-486; ICD10: J12-J17, J18.0, J18.1, Jl8.8, JI8.9, J20, J21 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in the 5-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). May use the CRF (65+ years: 1.0018 (1.0002-1.0033) per 1 ppb) from Simpson et al ([Simpson, Williams et al. 2005](#_ENREF_103)) in a sensitivity analysis. |
| **Emergency department visits** |
| Asthma | Western Melbourne: 1.15 (1.03-1.27) per 28.9 ppb([Erbas, Kelly et al. 2005](#_ENREF_36))MelbourneICD10: J45, J46Age: 1-15 yearsModelled air pollution data using TAPM.Lag 2 daily 1-hour maximum.Single pollutant model: 2.3% (1.4, 3.2%) per 9.5 ppbTwo pollutant model with PM2.5: 1.1% (0.6-1.6%) per 9.5 ppb([Jalaludin, Khalaj et al. 2008](#_ENREF_55))SydneyAge: 1-14 years1-hour maximum1.21 (1.03–1.43) per 1ppb([Pereira, Cook et al. 2010](#_ENREF_85))PerthAge: 0-4 years24-hour average | n/a | n/a | No CRFConsistent evidence of positive associations.([US EPA 2008](#_ENREF_116))Pooled CRF from 3 studies (pooled CRF unavailable).1.14 (1.09-1.19) per 24 ppb([Ito, Thurston et al. 2007](#_ENREF_52))1.08 (1.00-1.17) per 34 ppb([NYDOH 2006](#_ENREF_79))1.047 (1.011-1.085) per 20 ppb([Peel, Tolbert et al. 2005](#_ENREF_84))1-hour maximum([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))ICD9: 493Age: All | n/a | Recommended CRF: Two pollutant model with PM2.5: 1.1% (0.6-1.6%) per 9.5 ppb ([Jalaludin, Khalaj et al. 2008](#_ENREF_55)).US EPA ([Abt Associates Inc 2011](#_ENREF_3)) pooled CRF, if available, would be more suitable as it applies to all ages. |
| Cardiovascular disease | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Respiratory disease | n/a | n/a | n/a | No CRFConsistent evidence of positive associations.([US EPA 2008](#_ENREF_116)) | n/a | No CRF recommended. |
| **Incidence of myocardial infarction (heart attacks)** |
| Non-fatal heart attacks(24-hour PM) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Lung function** |
| Change in forced expiratory volume in 1 second (FEV1; litres) | Morning FEV1: -0.0025 (-0.0047 to -0.0002) per 1 ppb([Williams, Marks et al. 2012](#_ENREF_132))1-hour maximumLag 2Two-pollutant model with O3Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/aInconsistent evidence.([US EPA 2008](#_ENREF_116)) | n/a | Recommended CRF:Morning FEV1: -0.0025 (-0.0047 to -0.0002) per 1 ppb([Williams, Marks et al. 2012](#_ENREF_132)).. |
| Change in peak expiratory flow rate (PEF; litres per minute) | No effect.([Jalaludin, Chey et al. 2000](#_ENREF_53))Sydney125 children with a history of wheezing in previous 12 monthsAge: mean age about 9.6 yearsNo effect.([Rutherford, Simpson et al. 2000](#_ENREF_94))Brisbane and IpswichMixed-modelsAge: All(n=53)History of allergy to pollen or fungi on skin prick testingMorning PEF: -0.4042 (-0.7318 to -0.0767) per 1 ppb([Williams, Marks et al. 2012](#_ENREF_132))1-hour maximumLag 2Two-pollutant model with O3Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | Recommended CRF:Morning PEF: -0.4042 (-0.7318 to -0.0767) per 1 ppb([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Minor morbidity** | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Asthma exacerbation | n/a | n/a | n/a | Pooled CRF from 3 studies (pooled CRF unavailable). Not clear from the reports how asthma symptoms were combined.([O'Connor, Neas et al. 2008](#_ENREF_80))Slow play, missed school days,Night-time asthma.([Ostro, Lipsett et al. 2001](#_ENREF_81))Cough, cough (new cases), shortness ofbreath, shortness of breath (new cases), wheeze, wheeze(new cases).([Schildcrout, Sheppard et al. 2006](#_ENREF_95))One or more symptoms.([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))Age: 4–12 years No effect([Delfino, Zeiger et al. 2002](#_ENREF_29))([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))Asthmatic children Age: 13–18 yearsOne or more symptoms8-hour maximum  | n/a | No CRF recommended.Uunable to locate pooled CRF used by US EPA.  |
| Increased airway hyper-responsiveness | n/a | n/a | n/a | n/aIncreases observed in healthy adults with 1.5-2.0ppm (3-hour) and in asthmatics with 0.3ppm (30 minutes) or 0.1ppm (60 minutes).([US EPA 2008](#_ENREF_116)) | n/a ([WHO 2006](#_ENREF_126))Chamber studies of bronchial responsiveness in asthmatics-effects seen > 200 µg/m3 (1-hour average). | No CRF recommended. |
| Restricted activity days (RAD)2 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Minor restricted activity days (MRAD)3 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Work lost days (WLD)2 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute bronchitis (incidence, 8-12 years) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lower respiratory symptoms  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute respiratory symptoms | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Wheeze | No effect.([Rodriguez, Tonkin et al. 2007](#_ENREF_92))Age: 0-5 yearsPerth24-hour averageNo effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months Sydney.*1-hour maximum*Day wheeze: 1.0356 (1.0130-1.0586) per 1 ppbLag 0Day wheeze: No effect in 2-pollutant model with O3Night wheeze: No effect *24-hour average*Day wheeze: 1.0722 (1.0130-1.1348) per 1 ppb in 2-pollutant model with O3Lag 0Night wheeze: 1.0640 (1.0186-1.1114) per 1 ppbNight wheeze: No effect in 2-pollutant model with O3([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | Recommended CRF in sensitivity analysis: *24-hour average*Day wheeze: 1.0722 (1.0130-1.1348) per 1 ppb in 2-pollutant model with O3 ([Williams, Marks et al. 2012](#_ENREF_132)).Note inconsistency of results between single and 2-pollutant models. Also note that two other Australian studies have not shown any effects. |
| Cough | 1.028 (1.002-1.055) per ?1 ppm([Rodriguez, Tonkin et al. 2007](#_ENREF_92))Age: 0-5 yearsPerth24-hour meanNot clear from the paper the metric for NO2 concentration used in the calculation of CRF.Wet cough: 1.05 (1.00-1.10) per 8.2 ppbDry cough: No effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney.*1-hour maximum*Day cough: 1.0186 (1.0013-1.0362) per 1 ppbLag 2Day cough: No effect in 2-pollutant model with O3Night cough: 1.0282 (1.0096-1.0473) per 1 ppbLag 2Night cough: No effect in 2-pollutant model with O3*24-hour average*Day cough:1.0535 (1.0219-1.0861) per 1 ppbLag 0Day cough: No effect in 2-pollutant model with O3Night cough: 1.0447 (1.0015-1.0898) per 1 ppb in 2-pollutant model with O3Lag 3 ([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAge: mean 10.0 years 270 children with current asthma | n/a | n/a | 1.17 (0.94-1.46) for a 10 ppb([Schwartz, Dockery et al. 1994](#_ENREF_97))([US EPA 2010](#_ENREF_118))([Abt Associates Inc 2011](#_ENREF_3))Age: 7-14 yearsLag 0-4 days | n/a | Recommended CRF in sensitivity analysis: *24-hour average*Night cough: 1.0447 (1.0015-1.0898) per 1 ppb in 2-pollutant model with O3([Williams, Marks et al. 2012](#_ENREF_132)).Note inconsistency of results between single and 2-pollutant models.  |
| Shortness of breath (SOB) | *1-hour maximum*Day SOB: No effectNight SOB: No effect *24-hour average*Day SOB:1.0594 (1.0134-1.1075) per 1 ppbLag 0Day SOB: No effect in 2-pollutant model with O3Night SOB: 1.0771 (1.01835-1.1392) Lag 3Night SOB: No effect in 2-pollutant model with O3([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended as no effect in 2-pollutant models in ACHAPS ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Bronchodilator use | No effect([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney.No effect of either 1-hour maximum or 24-hour average([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended. |
| Upper respiratory symptoms | Runny/blocked nose: No effect.([Rodriguez, Tonkin et al. 2007](#_ENREF_92))Age: 0-5 yearsPerth24-hour mean  | n/a | n/a | n/a | n/a | No CRF recommended. |
| Increased respiratory symptoms | No effect on any day symptoms (cough, wheeze, shortness of breath, runny nose, eye irritation, fever) in 2-pollutant models with O3.No effect on any night symptoms (cough, wheeze, shortness of breath) in 2-pollutant models with O3.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a. Increased symptoms & medication use in asthmatic children seen for median ranges of 18-26 ppb (24-hour average) ([Schildcrout, Sheppard et al. 2006](#_ENREF_95)) and mean NO2 of 32 ppb (4-hour average) ([Mortimer, Neas et al. 2002](#_ENREF_76))([US EPA 2008](#_ENREF_116))2.8% (0.2-5.5%) per 1ppb ([US EPA 1999](#_ENREF_112)) | n/a | No CRF recommended. |
| General practitioner consultation for asthma | No effect.([Jalaludin, O'Toole et al. 2004](#_ENREF_58))148 children (mean age about 9.6 years) with a history of wheezing in previous 12 months.Sydney. | n/a | n/a | n/a | n/a | No CRF recommended. |
| General practitioner consultation for upper respiratory disease | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |

1n/a=not available

2A restricted activity days is defined as a day when a person is forced to alter his/her normal activity. A severe restriction include days when it necessary to stay in bed. For employed adults, restricted activity days include Work Loss Days; for children, it would include days off school (whether or not the child is confined to bed) (ExternE 1995).

3Minor restricted activity days do not involve work loss or bed disability but do include some noticeable limitation on ‘normal’ activity (ExternE 1995).

**REFERENCES**

Abt Associates Inc (2011). BENMAP. User's manual appendices, Office of Air Quality Planning and Standards, Research Triangle Park, NC, USA. .

Anderson, H. R., C. Spix, et al. (1997). "Air pollution and daily admissions for chronic obstructive pulmonary disease in 6 European cities: results from the APHEA project [see comments]." European Respiratory Journal **10**(5): 1064-1071.

Barnett, A. G., G. M. Williams, et al. (2005). "Air pollution and child respiratory health. A case-crossover study in Australia and New Zealand." American Journal of Respiratory and Critical Care Medicine **171**(11): 1272-1278.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2006). Cardiovascular disease and air pollution. London, Department of Health, UK.

DEFRA (2006). An Economic Analysis to Inform the Air Quality Strategy Review Consultation. London, UK, Department for Environment, Food and Rural Affair.

Delfino, R. J., R. S. Zeiger, et al. (2002). "Association of asthma symptoms with peak particulate air pollution and effect modification by anti-inflammatory medication use." Environmental Health Perspectives **110**(10): A607-A617.

Environment Protection and Heritage Council (2005). Expansion of the multi-city mortality and morbidity study. Final report. Volume 3. Tabulated results, Environment Protection and Heritage Council.

Erbas, B., A.-M. Kelly, et al. (2005). "Air pollution and childhood asthma emergency hospital admissions: estimating intra-city regional variations." International Journal of Environmental Health Research **15**(1): 11-20.

Hansen, C., A. Neller, et al. (2006). "Maternal exposure to low levels of ambient air pollution and preterm birth in Brisbane, Australia." BJOG: An International Journal of Obstetrics & Gynaecology **113**(8): 935-941.

Hansen, C. A., A. G. Barnett, et al. (2009). "Ambient Air Pollution and Birth Defects in Brisbane, Australia." Plos One **4**(4).

Ito, K., G. Thurston, et al. (2007). "Characterization of PM2.5 gaseous pollutants and meteorological interactions in the context of time-series health effects models." Journal of Exposure Science and Environmental Epidemiology **17**(S2): S45-S60.

Jalaludin, B., T. Chey, et al. (2000). "Acute effects of low levels of ambient ozone on peak expiratory flow rate in a cohort of Australian children." International Journal of Epidemiology **29**(3): 549-557.

Jalaludin, B., B. Khalaj, et al. (2008). "Air pollution and ED visits for asthma in Australian children: a case-crossover analysis." International Archives of Occupational and Environmental Health **81**(8): 967-974.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**: 16.

Jalaludin, B., B. O'Toole, et al. (2004). "Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children." Environmental Research **95**(1): 32-42.

Linn, W. S., Y. Szlachcic, et al. (2000). "Air pollution and daily hospital admissions in metropolitan Los Angeles." Environmental Health Perspectives **108**(5): 427-434.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occupational and Environmental Medicine **62**(8): 524-530.

Moolgavkar, S. H. (2003). Air pollution and daily deaths and hospital admissions in Los Angeles and Cook counties. Revised analyses of time-series studies of air pollution and health. Special report. Boston, MA, Health Effects Institute**:** 183-198.

Morgan, G., S. Corbett, et al. (1998). "Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994." American Journal of Public Health **88**(12): 1761-1766.

Mortimer, K. M., L. M. Neas, et al. (2002). "The effect of air pollution on inner-city children with asthma." European Respiratory Journal **19**(4): 699-705.

NYDOH (2006). A study of ambient air contaminants and asthma in New York City, New

York State Department of Health Center for Environmental Health.

O'Connor, G. T., L. Neas, et al. (2008). "Acute respiratory health effects of air pollution on children with asthma in US inner cities." Journal of Allergy & Clinical Immunology **121**(5): 1133-1139.

Ostro, B., M. Lipsett, et al. (2001). "Air pollution and exacerbation of asthma in African-American children in Los Angeles." Epidemiology **12**(2): 200-208.

Peel, J. L., P. E. Tolbert, et al. (2005). "Ambient air pollution and respiratory emergency department visits." Epidemiology **16**(2): 164-174.

Pereira, G., A. Cook, et al. (2010). "A case-crossover analysis of traffic-related air pollution and emergency department presentations for asthma in Perth, Western Australia." Medical Journal of Australia **193**(9): 511-514.

Petroeschevsky, A., R. W. Simpson, et al. (2001). "Associations between outdoor air pollution and hospital admissions in Brisbane, Australia." Archives of Environmental Health **56**(1): 37-52.

Rodriguez, C., R. Tonkin, et al. (2007). "The relationship between outdoor air quality and respiratory symptoms in young children." International Journal of Environmental Health Research **17**(5): 351-360.

Rutherford, S., R. Simpson, et al. (2000). "Relationships between environmental factors and lung function of asthmatic subjects in south east Queensland, Australia." Journal of Occupational & Environmental Medicine **42**(9): 882-891.

Schildcrout, J. S., L. Sheppard, et al. (2006). "Ambient air pollution and asthma exacerbations in children: an eight-city analysis." American Journal of Epidemiology **164**(6): 505-517.

Schwartz, J., D. W. Dockery, et al. (1994). "Acute effects of summer air pollution on respiratory symptom reporting in children." American Journal of Respiratory and Critical Care Medicine **150**(5): 1234-1242.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on daily mortality in four Australian cities." Australian & New Zealand Journal of Public Health **29**(3): 205-212.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on hospital admissions in four Australian cities " Australian & New Zealand Journal of Public Health **29**(3): 213-221.

Spix, C., H. R. Anderson, et al. (1998). "Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe: a quantitative summary of APHEA study results. Air Pollution and Health: a European Approach." Archives of Environmental Health **53**(1): 54-64.

Sunyer, J., C. Spix, et al. (1997). "Urban air pollution and emergency admissions for asthma in four European cities: the APHEA Project." Thorax **52**(9): 760-765.

Touloumi, G., K. Katsouyanni, et al. (1997). "Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Air Pollution and Health: a European Approach." American Journal of Epidemiology **146**(2): 177-185.

US EPA (1999). The Benefits and Costs of the Clean Air Act 1990 to 2010. Washington, DC, United States Environmental Protection Agency.

US EPA (2008). Integrated science assessment for oxides of nitrogen-health criteria, EPA/600/R-08/071. US Enviromental Protection Agency.

US EPA (2010). Final Regulatory Impact Analysis (RIA) for the NO2 National Ambient Air Quality Standards (NAAQS), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, North Carolina, USA**:** 155.

WHO (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global Update 2005. Summary of risk assessment. Geneva, World Health Organization.

Williams, G., G. Marks, et al. (2012). Australian Child Health and Air Pollution Study (ACHAPS). Final report. Environment Protection and Heritage Council (in press).

Zmirou, D., J. Schwartz, et al. (1998). "Time-series analysis of air pollution and cause-specific mortality." Epidemiology **9**(5): 495-503.

Table 5: SO2 health endpoints and associated concentration-response functions

|  | **Concentration-response function (95%CI)** |
| --- | --- |
| **Health outcomes** | **Australian** | **UK** | **Europe**  | **USEPA** | **WHO** | **Recommended** |
| ***Long-term outcomes (annual average concentration)*** |
| **Mortality** |  |  |  |  |  |  |
| All cause  | n/a1 | n/a | n/a | n/aEvidence is inadequate to confer causal relationship.([US EPA 2008](#_ENREF_117)) | n/a | No CRF recommended. |
| Infant (<12 months of age) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Life expectancy lost (years of life lost; YOLL) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Morbidity** |
| Incidence of chronic obstructive pulmonary disease (COPD) or chronic bronchitis | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Incidence of asthma | Ever had wheezing:No effect in single pollutant model and protective effects in 2-pollutant models with CO.Ever had asthma:No effect in single pollutant model and protective effects in 2-pollutant models with NO2 and CO.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAverage hourly SO2 over lifetime Age: mean age10.0 years 2,860 children  | n/a | n/a | n/a | n/a | No CRF recommended.No effects in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Recent symptoms (in last 12 months) | Wheeze, night cough or chest cold: No effect.([Lewis, Hensley et al. 1998](#_ENREF_68))Hunter and Illawarra regions.Primary school children.No effect or protective effects for wheeze, wheeze after exercise, current asthma, use of bronchodilators, cough, visit to doctor/hospital, rhinitis and itchy rash in various single and 2-pollutant models.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Average hourly SO2 over lifetime Age: mean age10.0 years. 2,860 children.  | n/a | n/a | n/a | n/a | No CRF recommended.No effects in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Lung function growth | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Change in forced expiratory volume in 1 second (FEV1; litres) | No effect in single pollutant model.-6.62 mls (-12.3 to -0.96 mls) per 0.74 ppb in 2-pollutant model with NO2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAverage hourly SO2 over lifetime Age: mean age10.0 years 2,860 children  | n/a | n/a | n/a | n/a | Recommended CRF: -6.62 mls (-12.3 to -0.96 mls) per 0.74 ppb in 2-pollutant model with NO2 ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in forced vital capacity (FVC; litres) | No effect in single pollutant model-8.92 mls (-16.0 to -1.84 mls) per 0.74 ppb in 2-pollutant model with NO2([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAverage hourly SO2 over lifetime Age: mean age10.0 years 2,860 children  | n/a | n/a | n/a | n/a | Recommended CRF: -8.92 mls (-16.0 to -1.84 mls) per 0.74 ppb in 2-pollutant model with NO2 ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Airway inflammation | Protective effect in single and 2-pollutant models with PM, NO2, O3 and CO([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, SydneyAverage hourly SO2 over lifetime Age: mean age10.0 years 2,860 children  | n/a | n/a | n/a | n/a | No CRF recommended. No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Birth outcomes** |
| Birth defects | Cleft lip±cleft palate: 1.27 (1.01, 1.62) per 0.6ppbAll birthsAortic artery and valve: 10.76 (1.50, 179.83) per 0.6ppbBirths within 6km of air monitoring station([Hansen, Barnett et al. 2009](#_ENREF_46))Brisbane | n/a | n/a | n/aEvidence is inconsistent.([US EPA 2008](#_ENREF_117)) | n/a | No CRF recommended.Only 1 Australian study. |
| Prematurity | First trimester, autumn: 6.489 (4.365–9.648) per 1ppb.First trimester, winter: 1.323 (1.027–1.704) per 1ppb3 months preceding birth: 2.330 (1.344–4.040) per 1 ppb.Births within 5km of air monitoring station([Jalaludin, Mannes et al. 2007](#_ENREF_57))Sydney1-hour maximum | n/a | n/a | n/a | n/a | No CRF recommended.Only 1 Australian study. |
| Low birth weight | Not assessed([Mannes, Jalaludin et al. 2005](#_ENREF_71))SydneyNot assessed([Hansen, Neller et al. 2007](#_ENREF_45))Brisbane | n/a | n/a | n/a | n/a | No CRF recommended.  |
| ***Short-term outcomes (daily average concentration)*** |
| **Mortality** |
| Non-trauma | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_102))Brisbane, Melbourne, Perth, SydneyNo effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01Age: All ages.All year.Moderate heterogeneity.Meta-analysis of 2 cities – Brisbane, Sydney.ICD9: <800; ICD10: A-R, Z35.5, Z35.822.3% (6.4-40.5%) per 1 pphm in multi-pollutant models([Hu, Mengersen et al. 2008](#_ENREF_50))Sydney24-hour average.Age: All ages.All causes (ICD codes not stated). | 1.029 (1.035-1.023) per 50 ug/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))24-hour average. APHEA estimates for 7 western European cities. | n/a | Non-trauma mortality: range 0.4-2% per 10 ppb ([US EPA 2008](#_ENREF_117))24-hour average.Effects reduced when co-pollutants added to model. | n/aVarious studies showed increased mortality with levels between 5-10 ug/m3 24-hour average. ([Burnett, Stieb et al. 2004](#_ENREF_17))([WHO 2006](#_ENREF_126)) | No CRF recommended. No effect in Australian 2-cities study ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))or Hu et al ([Hu, Mengersen et al. 2008](#_ENREF_50)) in a sensitivity analysis. |
| Cardiovascular | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_102))Brisbane, Melbourne, Perth, Sydney.No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Age: All ages.All year.Moderate heterogeneity.Meta-analysis of 2 cities – Brisbane, Sydney.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 0.8% (0.6-1.0%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects estimate.24-hour average. Moderate-strong evidence of publication bias.CRF not intended for health risk assessment.1.04 (1.01-1.06) per 50 ug/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))24-hour average.APHEA estimates for 5 western European cities. | n/a | n/a | n/a | No CRF recommended. No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))in a sensitivity analysis.  |
| Respiratory  | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_102))Brisbane, Melbourne, Perth, Sydney.No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Age: All ages.All year.Moderate heterogeneity.Meta-analysis of 2 cities – Brisbane, SydneyICD9: 460-519; ICD10: J00-J99 (excluding J95.4 to J95.9), R09.1, R09.8. | 1.05 (1.03-1.07) per 50 ug/m3 ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))24-hour average.APHEA estimates for 5 western European cities. | n/a | n/a | n/a | No CRF recommended. No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))in a sensitivity analysis.  |
| **Hospitalisation** |
| Cardiovascular | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_103))15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 2 cities - Brisbane, Sydney.Low heterogeneity.ICD9: 390-459; ICD10: I00-I99 (excluding I67.3,I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31, R58 | 0.6% ( 0.1-1.2%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects estimate.24-hour average. Weak evidence of publication bias.CRF not intended for health risk assessment. | n/a | n/aSome evidence from epidemiological studies but inconsistent toxicological studies, and effect estimate not robust to co-pollutant adjustment.([US EPA 2008](#_ENREF_117)) | n/aHowever, cited Hong Kong study which showed no evidence of threshold for effect at 5-40ug/m3 24-hour average. ([Wong, Atkinson et al. 2002](#_ENREF_134))([WHO 2006](#_ENREF_126)) | No CRF recommended. No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))in a sensitivity analysis. |
| Cardiac  | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_103))15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.High heterogeneity. for 65+ yearslCD9: 390-429; ICDI0: I00-I52, I97.0, I97.1, I98.1 | 2.4% (1.6-3.3%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects estimate.24-hour average.No evidence of publication bias.CRF not intended for health risk assessment. | n/a | n/a | n/a | No CRF recommended. No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))in a sensitivity analysis. |
| Ischaemic heart disease  | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_103))15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Low to moderate heterogeneity. lCD9: 410-413; ICDI0: I20-I22, I24, I25.2 | 1.2% (0.5-1.9%) per 10 ug/m3 ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects estimate.24-hour average. No evidence of publication bias.CRF not intended for health risk assessment. | n/a | n/a | n/a | No CRF recommended. No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).May use the CRF from COMEAP ([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))in a sensitivity analysis. |
| Cardiac failure | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Low to moderate heterogeneity. ICD9: 428; ICD10: I50 | No effect([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects estimate.24-hour average. No evidence of publication bias.CRF not intended for health risk assessment. | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Cerebrovascular | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_103))Stroke:15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Low heterogeneity. ICD9: 430-438; ICD10: I60-I66, I67 (excluding I67.0, I67.3), I68 (excluding I68.0), I69, G45 (excluding G45.3), G46 | No effect([Committee on the Medical Effects of Air Pollutants 2006](#_ENREF_21))Random effects. estimate24-hour average. No evidence of publication bias.CRF not intended for health risk assessment. | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Arrhythmia | 15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Low heterogeneity. ICD9: 437; ICD10: I46-I49 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Myocardial infarction | 15-64 years: No effect.65+ years: No effect.([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Moderate to high heterogeneity. lCD9: 410; ICDI0: I21, I22 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Respiratory | Not assessed in 4 cities study([Simpson, Williams et al. 2005](#_ENREF_103))0 years: No effect1-4 years: No effect5-14 years: No effect15-64 years: No effect65+ years: 2.8% (1.0-4.7%) per 5.4 ppb([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.High heterogeneity in 5-14 years only.lCD9: 460-519; ICDI0: J00-J99 (excluding J95.4-J95.9), R09.1, R09.8  | 65+ years: 1.020 (1.005-1.046) per 50 ug/m3 15-64 years: No effect.([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19))Based on APHEA estimates for 5 western European cities. | 0.5% per 10 ug/m3([AEA Technology Environment 2005](#_ENREF_7)) | n/aEffect ranges from -5 to +20% risk per 10 ppb increase in SO2 (24-hour average), with effects observed at levels of 4 ppb, but marked increases in effect at only higher SO2 (>90th percentile values).([US EPA 2008](#_ENREF_117))0.4% (0-1.02%) per 1 ppb([US EPA 1999](#_ENREF_112)) | n/a | Recommended CRF: For 65+ years age-group, 2.8% (1.0-4.7%) per 5.4 ppb from Australian study ([Environment Protection and Heritage Council 2005](#_ENREF_35)).No CRF recommended for all other age-groups as there were no effects in the Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)).  |
| Asthma | 1-4 years: No effect5-14 years: No effect15-64 years: No effect65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.High heterogeneity. in 5-14 years onlylCD9: 493; ICDI0: J45, J46, J44.8 Age: 0-14 years | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Chronic obstructive pulmonary disease (COPD) | 15-64 years: No effect64+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximum.Lag 01.Meta-analysis of 2 cities - Brisbane, Sydney.Moderate to high heterogeneity lCD9: 490-492, 494-496; ICDI0: J40-J44, J47, J67 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| Pneumonia and acute bronchitis | 0 years: No effect.1-4 years: 8.5% (3.0-14.3%) per 5.4 ppb.1-4 years, two pollutant model with PM2.5: No effect.15-64 years: No effect.65+ years: No effect([Environment Protection and Heritage Council 2005](#_ENREF_35))1-hour maximumLag 01Meta-analysis of 2 cities - Brisbane, SydneyModerate to high heterogeneity ICD9: 466, 480-486; ICD10: J12-J17, J18.0, J18.1, J18.8, J18.9,J20, J21 | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 2-cities meta-analysis ([Environment Protection and Heritage Council 2005](#_ENREF_35)). |
| **Emergency department visits** |
| Asthma | Not assessed.([Erbas, Kelly et al. 2005](#_ENREF_36))Melbourne1.6% (0.7- 2.4%) per 0.8 ppb.([Jalaludin, Khalaj et al. 2008](#_ENREF_54))SydneyICD9: 493Age: 1-14 years.24-hour average.Not assessed.([Pereira, Cook et al. 2010](#_ENREF_85))Perth | n/a | n/a | n/a | n/a | Recommended CRF: 1.6% (0.7- 2.4%) per 0.8 ppb([Jalaludin, Khalaj et al. 2008](#_ENREF_54)). |
| **Incidence of myocardial infarction (heart attacks)** |
| Non-fatal heart attacks(24-hr PM) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| **Lung function** |
| Change in forced expiratory volume in 1 second (FEV1; litres) | No effect of 1-hour maximum or 24-hour average.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a 3-8% decrements in FEV1 in children are associated with ambient annual SO2 and SO4 concentrations >100 ug/m3. ([Lebowitz 1996](#_ENREF_66))([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19)) | n/a | n/a.Toxicological studies: Reduction in FEV1 (≥15%) and increased airway resistance (≥100%) in 5-30% of exercising asthmatics at 0.2-0.3 ppm and 20-60% at 0.4-1.0 ppm (5-10 minutes exposure). Epidemiological studies: inconsistent for lung function effects in children and adults.([US EPA 2008](#_ENREF_117)) | n/aHowever, cited chamber studies that showed changes in lung function at levels >500 ug/m3 after 10 minutes leading to air quality guidelines of 500 ug/m3 (10-minute average).([WHO 2006](#_ENREF_126))No CRF, but set guideline of 125 ug/m3 (0.04 ppm) (24-hour average) and 50 ug/m3 (annual average).([WHO Europe 2000](#_ENREF_127)) | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Change in peak expiratory flow rate (PEF; litres per minute) | *1-hour maximum*No effect.*24-hour average*Morning PEF: 1.2686 (0.0857-2.4514) per 1 ppb. Lag 2Morning PEF: No effect in model with PM10.Evening PEF: 1.6946 (0.1918-3.1973) per 1 ppb in model with PM10.Lag 0([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended. SO2 shows a positive effect on lung function in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| **Minor morbidity** |
| Asthma exacerbation | n/aHowever, based on evidence recommends that SO2 not exceed 0.175 ppm (500 ug/m3) (10 minute average).([Streeton 1997](#_ENREF_105)) | n/aNo CRF reported, but judgement is that 60-140 ug/m3 and 140-200 ug/m3 SO2 (annual mean of 24-hour mean) associated with increased respiratory symptoms in adults and children respectively. No threshold level evident. UK Department of Health Advisory Group, cited in COMEAP, 1998([Committee on the Medical Effects of Air Pollutants 1998](#_ENREF_19)) | n/a | n/aToxicological studies: increase in severity and incidence of symptoms in asthmatic adults with increasing SO2 between 0.2-0.6 ppm for 5-10 minutes. Epidemiological studies: increased symptoms in children (especially those with asthma or chronic respiratory) at median range of 17-37 ppb (3-hour average) and for 2.2-7.4 ppb (24-hour average). Epidemiological evidence for adults is inconsistent for short-term SO2 concentrations.([US EPA 2008](#_ENREF_117))0.6% (0.1-1.1%) per 1 ppb ([US EPA 1999](#_ENREF_112)) | n/aRecommended that 500 ug/m3 (0.175 ppm) not be exceeded (10 minute exposure). Based on clinical studies of exercising asthmatics.([WHO Europe 2000](#_ENREF_127)) | No CRF recommended. |
| Increased airway hyper-responsiveness | n/a | n/a | n/a | n/aLimited evidence of an effect of airway hyper-responsiveness in atopic individuals.([US EPA 2008](#_ENREF_117)) | n/a | No CRF recommended. |
| Restricted activity days (RAD)2 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Minimal restricted activity days (MRAD)3 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Work lost days (WLD) days2 | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute bronchitis (incidence, 8-12 years) | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Lower respiratory symptoms  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Acute respiratory symptoms | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Wheeze | Day wheeze: Protective effects of 1-hour maximum and 24-hour average in 2-pollutant models with PM10.Night wheeze: No effect of 1-hour maximum or 24-hour average in 2-pollutant models with PM10.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Cough | Day cough: No effect of 1-hour maximum or 24-hour average in 2-pollutant models with PM10.Night cough: No effect of 1-hour maximum or 24-hour average in 2-pollutant models with PM10.([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Shortness of breath | *1-hour maximum*Day SOB: No effect in 2-pollutant. models with PM10Night SOB: No effect in 2-pollutant models with PM10.*24-hour average*Day SOB: No effect in 2-pollutant models with PM10.Night SOB: Protective effect in 2-pollutant models with PM10.Lag 3([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Bronchodilator use | *1-hour maximum*Night use: 1.0247 (1.0021-1.0478) per 1 ppb in 2-pollutant models with PM10*24-hour average*No effect([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. | n/a | n/a | n/a | n/a | Recommended CRF for night bronchodilator use: 1.0247 (1.0021-1.0478) per 1 ppb in 2-pollutant models with PM10 from Marks et al ([Williams, Marks et al. 2012](#_ENREF_132)). |
| Upper respiratory symptoms  | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| Increased respiratory symptoms | No effect on any night symptoms (cough, wheeze, shortness of breath) in 2-pollutant models with PM10No effect on any day symptoms (cough, wheeze, shortness of breath, runny nose, eye irritation, fever) in 2-pollutant models with PM10([Williams, Marks et al. 2012](#_ENREF_132))Six cities – Adelaide, Brisbane, Canberra, Melbourne, Perth, Sydney.Age: mean 10.0 years. 270 children with current asthma. |  |  |  |  | No CRF recommended.No effect in Australian 6-cities study ([Williams, Marks et al. 2012](#_ENREF_132)). |
| General practitioner consultation for asthma | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |
| General practitioner consultation for upper respiratory disease | n/a | n/a | n/a | n/a | n/a | No CRF recommended. |

1n/a=not available

2A restricted activity days is defined as a day when a person is forced to alter his/her normal activity. A severe restriction include days when it necessary to stay in bed. For employed adults, restricted activity days include Work Loss Days; for children, it would include days off school (whether or not the child is confined to bed) (ExternE 1995).

3Minor restricted activity days do not involve work loss or bed disability but do include some noticeable limitation on ‘normal’ activity (ExternE 1995).

**REFERENCES**

AEA Technology Environment (2005). Methodology for the cost-benefit analysis for CAFE: Volume 2: Health impact assessment. Oxon, UK, AEA Technology Environment.

Burnett, R. T., D. Stieb, et al. (2004). "Associations between short-term changes in nitrogen dioxide and mortality in Canadian cities." Archives of Environment Health **59**: 228-236.

Committee on the Medical Effects of Air Pollutants (1998). Quantification of the effects of air pollution on health in the United Kingdom. London, Department of Health, United Kingdom.

Committee on the Medical Effects of Air Pollutants (2006). Cardiovascular disease and air pollution. London, Department of Health, UK.

Environment Protection and Heritage Council (2005). Expansion of the multi-city mortality and morbidity study. Final report. Volume 3. Tabulated results, Environment Protection and Heritage Council.

Erbas, B., A.-M. Kelly, et al. (2005). "Air pollution and childhood asthma emergency hospital admissions: estimating intra-city regional variations." International Journal of Environmental Health Research **15**(1): 11-20.

Hansen, C., A. Neller, et al. (2007). "Low levels of ambient air pollution during pregnancy and fetal growth among term neonates in Brisbane, Australia." Environmental Research **103**(3): 383-389.

Hansen, C. A., A. G. Barnett, et al. (2009). "Ambient Air Pollution and Birth Defects in Brisbane, Australia." Plos One **4**(4).

Hu, W., K. Mengersen, et al. (2008). "Temperature, air pollution and total mortality during summers in Sydney, 1994–2004." International Journal of Biometeorology **52**(7): 689-696.

Jalaludin, B., B. Khalaj, et al. (2008). "Acute effects of ambient air pollutants on ED visits for asthma in children, Sydney, Australia: a case-crossover analysis." International Archives of Occupational & Environmental Health **81**(8): 967-974.

Jalaludin, B., T. Mannes, et al. (2007). "Impact of ambient air pollution on gestational age is modified by season in Sydney, Australia." Environmental Health **6**: 16.

Lebowitz, M. D. (1996). "Epidemiological studies of the respiratory effects of air pollution." The European Respiratory Journal **9**: 1029-1054.

Lewis, P. R., M. J. Hensley, et al. (1998). "Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales [see comments]." Medical Journal of Australia **169**(9): 459-463.

Mannes, T., B. Jalaludin, et al. (2005). "Impact of ambient air pollution on birth weight in Sydney, Australia." Occupational and Environmental Medicine **62**(8): 524-530.

Pereira, G., A. Cook, et al. (2010). "A case-crossover analysis of traffic-related air pollution and emergency department presentations for asthma in Perth, Western Australia." Medical Journal of Australia **193**(9): 511-514.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on daily mortality in four Australian cities." Australian & New Zealand Journal of Public Health **29**(3): 205-212.

Simpson, R., G. Williams, et al. (2005). "The short-term effects of air pollution on hospital admissions in four Australian cities " Australian & New Zealand Journal of Public Health **29**(3): 213-221.

Streeton, J. (1997). A review of existing health data on six pollutants. National environment protection (ambient air quality) measure. Adelaide, National Environment Protection Council**:** 278.

US EPA (1999). The Benefits and Costs of the Clean Air Act 1990 to 2010. Washington, DC, United States Environmental Protection Agency.

US EPA (2008). Integrated science assessment for sulfur oxides-health criteria, ISA: EPA/600/R-08/047F US Environmental Protection Agency

WHO (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global Update 2005. Summary of risk assessment. Geneva, World Health Organization.

WHO Europe (2000). Air quality guidelines for Europe: second edition. Copenhagen, WHO Regional Office for Europe.

Williams, G., G. Marks, et al. (2012). Australian Child Health and Air Pollution Study (ACHAPS). Final report. Environment Protection and Heritage Council (in press).

Wong, C. M., R. W. Atkinson, et al. (2002). "A tale of two cities: effects of air pollution on hospital admissions in Hong Kong and London compared." Environmental Health Perspectives **110**(1): 67-77.

Table 6: Sources of health data

| **Type of health data** | **Data custodian** | **Years of available data** | **Variables in dataset** | **Process for accessing data** | **Time frame for accessing data** |
| --- | --- | --- | --- | --- | --- |
| Mortality  | ABS (aggregate and coded data available to SLA level (lowest geographic idenitifier)).\*Individual State Registrars of Births, Deaths and Marriages (unit record data available but not coded). | ABS: 2002-2012 (last 10 years). Some data back to 1968 but would incorporate ICD8, ICD9 and ICD10 coding. | Variables include : age or DOB, gender, underlying cause of death (ABS), multiple causes of death (ABS), SLA (geographic identifier), ICD codes. | National Information Referral Service (NIRS) 1300 135 070 or complete Inquiry form located at [http://www4.abs.gov.au/ web/survey.nsf/inquiryform/](http://www4.abs.gov.au/%20web/survey.nsf/inquiryform/)Specify requirements and work is quoted. Minimum charge of $650 for 3 hrs.State level data available free of charge at: [http://www.abs.gov.au/AUSSTATS](http://www.abs.gov.au/AUSSTATS%20/abs) [/abs](http://www.abs.gov.au/AUSSTATS%20/abs)@.nsf/DetailsPage/3302.02010?OpenDocument | Up to 1 month. |
| Hospitalisation | National Hospital Morbidity Database (NHMD) administered by AIHW.State health agencies, eg. NSW Ministry of Health. | NSW Admitted Patient Data - 1988/89-current (June 2011) | Data by State; annual frequency of reporting (Australian Institute of Health and Welfare).Data to SLA & postcode levels. Other geographic level may be available on request.Variables include: age, DOB, gender, postcode, primary diagnosis, additional diagnoses, readmission within 28 days, date of admission and date of separation, length of stay, ICD codes, other demographic & hospital data. | AIHW, Head, Hospitals Data Unit, 02 6244 1157; hospitaldata@aihw.gov.au Apply in writing to NSW Chief Health Officer whereupon data needs will be assessed.Data Custodian: DirectorDemand & Performance Evaluation Branch, NSW Ministry of HealthTel: 02 9391 9590. | 2 weeks to a few months, depending on nature of request. |
| Emergency department (ED) visits | State health agencies, for example, NSW Ministry of Health.ED visit data for asthma available for NSW, Victoria & WA, but method of data collection differs ([ACAM 2011](#_ENREF_5)). | For example, NSW Emergency Department Database; July 1996-year to date (2012). | Data to SLA & postcode levels. Other geographic level may be available on request.Age, DOB, gender, postcode, arrival date and time, triage date and time, diagnosis- ICD9 and ICD 10, type of visit, mode of separation, other demographic data. | Apply in writing to NSW Chief Health Officer whereupon data needs will be assessed. Data Custodian: DirectorDemand & Performance Evaluation Branch, NSW Ministry of HealthTel: 02 9391 9590 | 2 weeks to a few months, depending on nature of request. |
| Perinatal | State health agencies, for example, NSW Ministry of Health. | For example, Perinatal Data Collection (PDC), encompasses all live births >20 weeks gestation or ≥400 grams birth weight. 1987-1988; 1989 (missing);1990-current (2009). | Data to SLA & postcode levels of mother’s residence. Other geographic level may be available on request.Variables include: mother’s demographic details, baby’s DOB, gender; date of last menstrual period, birth order, gestational age, birth weight, APGAR scores (1 & 5 minutes), mother’s smoking status, diabetes status. Other details related to pregnancy. | Apply in writing to NSW Chief Health Officer whereupon data needs will be assessed Data Custodian: Manager, Surveillance MethodsCentre for Epidemiology & Research, NSW Ministry of HealthTel: 02 9391 9223 | 2 weeks to a few months, depending on nature of request. |
| Chronic obstructive pulmonary disease (COPD) incidence | No geographic based data for COPD incidence. Data available for hospital separations for COPD. Data on COPD mortality and hospitalisations-national estimates ([Australian Institute of Health and Welfare 2005](#_ENREF_11)). Prevalence of COPD in 2007-08 National Health Survey estimated at 5.3%, but is likely to be an under-estimation ([ACAM 2011](#_ENREF_5)). COPD (Stage 2) prevalence from BOLD study (Sydney) 9.4% ([Buist, McBurnie et al. 2007](#_ENREF_16)). Prevalence in Australia BOLD study (Stage 2 or higher) 7.5% in 40 years+ and 29.2% in 75 years+ ([Toelle 2012](#_ENREF_109)).Incidence data will have to be obtained from published studies and reports. |  |  |  |  |
| Asthma prevalence | Asthma prevalence estimated at 9.8% in 16+ years; 17.8% in 0-15 years.Prevalence of “current asthma” in adults 9.8% (9.2-10.4%) and in children 10.4% (9.1-11.7%) ([ACAM 2011](#_ENREF_5)). |  |  |  |  |
| Asthma incidence | Cumulative incidence of diagnosed “ever asthma or illness with wheezing” 24.4 (23.5-25.3) per 100 person years (infant cohort at 4-5 years); and 22.0 (21.0-23.0) per 100 person years (Kindergarten cohort aged 8-9 years). Source: Longitudinal Study of Australian Children, Australia, 2004-2008, in ([ACAM 2011](#_ENREF_5)). |  |  |  |  |
| Asthma exacerbation | No standardised routine data collection. Asthma exacerbation will have to be obtained from published studies and reports. |  |  |  |  |
| Lung function | No standardised data collection. Data available will have to be obtained from published studies and reports.  |  |  |  |  |
| GP encounters for asthma | In 2009-2010: 8.6 encounters per 100 adults; 16.9 encounters per 100 children ([ACAM 2011](#_ENREF_5)). |  |  |  |  |
| Mortality attributed to asthma | 1.6 deaths per 100,000 population (0.29% of all deaths) for 2009. Rate fell 45% between 1997 and 2009 ([ACAM 2011](#_ENREF_5)). |  |  |  |  |
| Activity restriction & disability (time off work or school) | 8.2% of people with asthma reported to have some level of disability associated with asthma (2003 Survey of Disability, Ageing and Carers in ([Australian Institute of Health and Welfare 2005](#_ENREF_11))).National Health Survey, 2007-2008, reports on days away from work, school or study in last 12 months: 5+ years: with asthma 24.2% (22.2-26.2%): without asthma 8.8% (8.2-9.4%) (ACAM, 2011, from National Health Survey, 2007-2008). |  |  |  |  |

ABS Australian Bureau of Statistics

SLA Statistical Local Area (geographic identifier). The following information is sourced directly from the ABS website: [http://www.abs.gov.au/websitedbs/D3110124.NSF/24e5997b9bf2ef35ca2567fb00299c59/53bbe9630b24d6f4ca256c3a000475b8!OpenDocument#Statistical%20Local%20Area%20(SLA)](http://www.abs.gov.au/websitedbs/D3110124.NSF/24e5997b9bf2ef35ca2567fb00299c59/53bbe9630b24d6f4ca256c3a000475b8%21OpenDocument#Statistical%20Local%20Area%20(SLA)) The Statistical Local Area (SLA) is an Australian Standard Geographical Classification (ASGC) defined area which consists of one or more Collection Districts (CDs). SLAs are Local Government Areas (LGAs), or parts thereof. Where there is no incorporated body of local government, SLAs are defined to cover the unincorporated areas. SLAs cover, in aggregate, the whole of Australia without gaps or overlaps. CDs are the smallest geographic area defined in the ASGC. They are designed for use in the Census of Population and Housing as the smallest unit for collection, processing and output of data. A CD is represented by a unique seven digit code. For the 2001 Census there is an average of about 225 dwellings in each CD. In rural areas the number of dwellings per CD declines as population densities decrease. CDs are defined for each census and are current only at census time. For the 2001 Census, there are about 37,000 CDs throughout Australia.

\*A project is underway to pilot the process for release of national coded unit record data.

**REFERENCES**

ACAM (2011). Asthma in Australia 2011 Canberra, AIHW Asthma Series no 4. Cat. No. ACM. Australian Centre for Asthma Monitoring, AIHW.

Australian Institute of Health and Welfare (2005). Chronic respiratory diseases in Australia. Their prevalence, consequences and prevention AIHW Cat. No. PHE 63. Canberra: AIHW.

Buist, A. S., W. M. McBurnie, et al. (2007). "International variation in the prevalence of COPD (The BOLD Study): a population-based prevalence study." The Lancet **370**: 741-750.

Toelle, B. (2012). Airflow obstruction, respiratory symptoms and respiratory illnesses in Australians aged 40 years and older: the Burden of Obstructive Lung Disease (BOLD) study in Australia (personal communication; manuscript currently under review with the Medical Journal of Australia).