



Air Quality and Human Health

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**Australia: State of the Environment
Technical Paper Series (The Atmosphere)**



Environment Australia, part of the Department of the Environment
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Cataloguing-in-Publication data:

Peach, Hedley.
Air quality and human health / Hedley G. Peach.

50p.

29.7 x 21 cm. - (Australia: State of the environment technical paper series (Atmosphere))

Bibliography:
ISBN 0 642 25294 7

1. Air-Pollution-Health aspects-Australia. 2. Air-Pollution-Health aspects.
3. Public health-Effect of air pollution on-Australia. 4. Air quality-Australia.
I. Title. II. Series.

363.7392i0994-dc21

For bibliographic purposes, this document may be cited as:
Peach, H. 1997, *Air quality and human health*, Australia: State of the Environment Technical Paper Series (The Atmosphere), Department of the Environment, Canberra.

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Phone, toll free, 1800 803 772, Facsimile 02 6274 1970

This book was printed in Australia on Australian-made, 100% recycled paper (Tudor RP).

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Preface

Australia: State of the Environment 1996 (the first ever independent and comprehensive assessment of the state of Australia's environment) was presented to the Commonwealth Environment Minister in 1996. This landmark report, which draws upon the expertise of a broad section of the Australian scientific and technical community, was prepared by seven expert reference groups working under the broad direction of an independent State of the Environment Advisory Council. While preparing the report, the former Department of the Environment, Sport and Territories commissioned a number of specialist technical papers. These have been refereed and are being published as the State of the Environment Technical Paper Series. Reflecting the theme chapters of the report, the papers relate to human settlements, biodiversity, the atmosphere, land resources, inland waters, estuaries and the sea, and natural and cultural heritage. The topics covered range from air and water quality to seagrasses and historic shipwrecks.

Abstract

This paper reviews what was known about the impacts of outdoor air quality on human health until June 1995. Some overseas studies had found a relationship between the levels of several pollutants in the outdoor air and death rates, attendances at hospital emergency departments, hospital admissions, respiratory symptoms, use of medication for respiratory disease or lung function. Compared with overseas information, Australian information was limited. The level of many outdoor pollutants are generally lower in Australia than many overseas countries, but the finding that the relationship between level of total suspended particulates, sulphur dioxide or ozone and some health effects may possibly hold over a wide range of concentrations may have implications for Australia.

Further knowledge is needed about the size of the effect from exposure to low level of pollutants over a long period of time; the level to which air pollutants should be reduced to provide a completely 'safe' background level for diseased and healthy populations; and both the benefits and costs of reducing air pollutants to various levels. A consensus on the methodology to be employed in future studies will ensure comparability between them. A program should be designed to explain to the community and respiratory disease patients the nature of the risks to health from air quality and how these can be avoided.

Summary

This paper reviews the state of knowledge of the impacts of air quality on human health in Australia up until June 1995 for the 1996 State of the Environment report. It also identifies possible methodologies for the quantification of the impacts of air quality on human health.

The specific questions addressed by the paper are:

- What is currently known about the association between 'significant' 'adverse' health effects and 'real world' air quality in Australia in urban and rural areas?
- Are any of the associations between 'significant' 'adverse' health effects and 'real world' air quality in Australia likely to represent a causal relationship and, if so, what is the magnitude of the effect?
- What overseas data are there on associations between air quality and human health?
- How relevant are overseas data on associations between air quality and human health to Australian conditions?
- How does Australian data on air quality and 'significant' 'adverse' health effects compare with overseas data?
- What methodologies could be used to quantify 'significant' 'adverse' health effects of air quality?
- What deficiencies in current data collections limit the development of quantitative relationships between air quality and human health?
- What gaps exist in the current knowledge base about the impacts of air quality on human health in Australia?
- What are the options for the development of suitable indicators or indices of the impacts of air quality on human health in Australia?
- What is the cost of respiratory disease in Australia and the possible impact of improving air quality?
- What should be the key elements of a community education program about the health risks from air quality?

The paper focuses on the epidemiological studies of human health impacts of the quality of outdoor air. It does

not focus on the quality of air in specific occupational or indoor locations. Animal studies and experiments involving exposure of volunteers to pollutants are also not a focus of this paper. Experiments involving exposure of volunteers to pollutants have been the focus of at least two published reviews. Because air quality has changed in Australia and many overseas countries with time, this paper concentrates on studies conducted in the late 1980s and 1990s. The paper also concentrates on those pollutants which are regarded as indicators of general air quality (class one indicators).

The paper appraises epidemiological studies of the relationship between air quality and health using the criteria usually employed by epidemiologists when appraising studies purporting to establish whether there is a causal relationship between two events such as a difference in air quality and a difference in health.

Some Australian studies have found a relationship between the levels of pollutants in the outdoor air and death rates, attendances at hospital emergency departments or hospital admissions. The relationships are sometimes difficult to interpret because some of the studies failed to exclude the possibility that people exposed to the pollutants were likely to have higher death rates, attendances at hospital emergency departments or hospital admission rates anyway because of their lower socio-economic status and their including a greater proportion of smokers.

As in Australia, some overseas studies have found a relationship between the levels of several pollutants in the outdoor air and death rates, attendances at hospital emergency departments, hospital admissions, respiratory symptoms, use of medication for respiratory disease or lung function. A number of these studies have found that the greater the level of several pollutants in the air, most often total suspended particulates, sulphur dioxide or ozone, the greater was the death rate, hospital admissions, emergency room attendances or respiratory symptoms in healthy or diseased populations. This relationship between the level of total suspended particulates, sulphur dioxide or ozone and some health effects was found over a wide range of levels in some studies.

Compared with overseas information, Australian information sometimes suffers from inadequate measures of outdoor air quality and a failure to exclude alternative explanations for the relationships found between outdoor air quality and health, other than that outdoor air quality causes harmful effects on health. The levels of many outdoor pollutants are generally lower in Australia than in

many overseas countries, but the finding that the relationship between level of total suspended particulates, sulphur dioxide or ozone and some health effects may possibly hold over a wide range of concentrations may have implications for Australia.

Studies following the health of children and adults with or without respiratory disease living in similar environments but differing in air quality over a number of years would help in deciding whether it is air quality itself which affects health. If a relationship between air quality and loss of lung function or a speeding up of the rate at which lung function is usually lost with ageing could be established, this would allow the effect of air quality on health to be measured. Proof that air quality has a harmful effect on health depends on showing that deliberately changing the quality of air leads to an improvement in health.

Australian information on the relationship between air quality and health would be particularly valuable to people trying to measure the impact of air quality on health if there was an agreement on the aspects of health to be studied as well as agreement over those aspects of air quality to be studied. There should also be agreement over the way in which air quality and health are to be measured and over the information to be collected if alternative explanations for a relationship between air quality and health other than a causal one are to be ruled out. This would ensure comparability between studies.

Further knowledge is needed about the size of the effect, if any, which air quality has on health in the 'real world', particularly exposure to a low level of pollutants over a long period of time. Further knowledge is also needed about the level to which air pollutants should be reduced to provide a completely 'safe' background level for diseased and healthy populations and both the benefits and costs of reducing air pollutants to various levels.

The design of a program to explain to the general public the nature of the risk to health from air quality, the benefits that might arise from reducing these risks, the approaches available for addressing the risks including doing nothing, and the uncertainties about the risks and the benefits from their reduction should be a two-way process between 'experts' and the community. The program should include information on strategies which the community and respiratory disease patients can use to avoid exposure to high levels of air pollution.

1 Causal relationships in epidemiological studies of air quality and health

This paper is concerned with epidemiological studies, the main aim of which have been to identify any associations between air quality and health. The paper therefore appraises these studies using the criteria which epidemiologists usually employ when appraising studies purporting to establish whether there is a causal relationship between two events such as a difference in air quality and a difference in health.

1.1 Assessment of causation in studies of air quality and health

The questions epidemiologists usually ask of studies examining the relationship between air quality and health are listed below (modified from Elwood 1988).

- (a) Description of the evidence
 - What was the difference in air quality?
 - What was the health effect?
 - What study design was used?
 - What population was studied?
 - What was the main result?
- (b) Internal validity - consideration of non-causal explanations
 - Were the associations between air quality and health likely to be affected by observation bias?
 - Were the associations between air quality and health likely to be affected by confounding?
 - Were the associations between air quality and health likely to be affected by chance variation?
- (c) Internal validity - consideration of positive features of causation
 - Was there a correct time relationship between the differences in air quality and health?
 - Was the relationship between air quality and health strong?
 - Was there a dose-response relationship between air quality and health?
 - Were the associations consistent within the study?
 - Was there any specificity within the study?

- (d) External validity - generalisation of the results
 - Could the study results be applied to the eligible population?
 - Could the study results be applied to the source population?
 - Are the results plausible in terms of a biological mechanism?
 - Is any major effect coherent with the distribution of air quality and health?

1.2 Data abstracted from published papers

Because outdoor air quality in Australia, as in many other countries, has changed in recent years, the paper focused mainly on studies of air quality and health undertaken in the late 1980s and 1990s. The paper also focused, although not exclusively, on papers published in refereed journals. However, it must be acknowledged that papers of original studies, which by June 1995 had only appeared in conference proceedings, would have been excluded.

The following types of information were abstracted from the published papers. It is arranged into three parts:

- a description of the evidence
- a consideration of non-causal explanations
- a consideration of explanations for causal relationships.

1.2.1 Description of the evidence

In abstracting information about studies into relationships between air quality and health, the following framework was used to describe the evidence collected from research studies and published papers.

- 1 Differences in air quality studied used data abstracted on:
 - (a) the aspects of air quality studied
 - (b) the measurements made
 - (c) whether exposure of subjects to air of a particular quality was assessed at the level of the Country, State or Region; small area; place of residence, work or schooling; or the individual
 - (d) the meteorological conditions under which the effects of air quality on health were studied.
- 2 Health effects studied used data abstracted on the basis of:
 - (a) the aspects of health studied
 - (b) the measurements made

- (c) whether the information was collected from subjects themselves or from parents or proxies.
- 3 Study design used
- The study designs were classified according to Hennekens et al. (1987) as:
- (a) a correlational study if data were collected at the population level to compare air quality and health between different populations or sub-groups within the same population over a particular period of time or in the same population at different points in time
 - (b) a cross-sectional survey if data were collected at the subject level rather than the population level about their health and the air quality to which they were exposed and both at the same point in time
 - (c) a case-control study if a group of subjects with a particular health effect and a comparison group of subjects without that health effect were selected for investigation and the proportions of subjects in the two groups exposed to air differing in some aspect of quality were then compared
 - (d) a cohort study if subjects were classified on the basis of being exposed or not exposed to air of a particular quality and then followed for a period of time to determine how often an effect on health of interest developed in each group.
- 4 Populations studied
- Data were abstracted on the basis of:
- (a) the source of subjects for the study
 - (b) eligibility criteria by which subjects were selected for the study
 - (c) the response rate among eligible subjects.
- 5 Main result:
- Data were abstracted on the measure, direction and statistical significance of associations between differences in air quality and differences in a health effect sought in the studies.

Data were abstracted on those constituents of air used as indicators of the general quality of air. These included particulates, sulphur dioxide, nitrogen dioxide, ozone (the major photochemical oxidant) and carbon monoxide. An up-to-date and readable account of the nature of air pollution in Australia can be found in Streeton (1990).

Hennekens et al. (1987) provided a clear description for the non-epidemiologist of how correlational studies can generate hypotheses about the relationship, say, between air quality and health, but they are not useful for testing

whether such hypotheses are correct. It is not possible to link exposure to air of a particular quality and a health effect at the level of the individual. There may also be differences between populations other than differences in air quality that might account for an observed difference in health. Such differences cannot easily be taken into account using data which have been collected at the population level.

Since their health and the air quality to which they were exposed are assessed in subjects at the same point in time, cross-sectional surveys cannot always distinguish whether the exposure to air of a particular quality preceded the development of the health effect or whether the health effect led to a change in the quality of the air to which the subjects exposed themselves. For air quality that is constant over time and subjects who do not change their place of residence, schooling or work, the cross-sectional survey may provide evidence of a causal relationship.

An association between a health effect and air quality can be tested for causality using either a case-control or cohort study. Cohort studies enrol subjects who are initially healthy and observe the subsequent development of a health effect over time and is best suited to investigations of common health effects that will accrue in sufficiently large numbers over a reasonably short period of follow-up.

1.2.2 Consideration of non-causal explanations

Data were abstracted on:

- (a) the statistical significance of associations between differences in air quality and differences in health effects sought in the study to exclude chance as an explanation;
- (b) the confidence limits on the magnitude of associations between differences in air quality and differences in health effects to exclude chance as an explanation;
- (c) any differences or bias in the way in which information was obtained from the different groups in the studies which may have led to an inaccurate relationship between air quality and health;
- (d) confounding factors that may have been associated with exposure to air quality and, independently of exposure to air quality, the health effect and which may have led to an inaccurate relationship between air quality and health;
- (e) the extent to which studies considered and controlled for such factors.

Whilst epidemiological studies may provide information about the relationships between air quality and health as it exists in the real world, they can never achieve the degree of control that is possible in laboratory studies. While an association between air quality and health found in an epidemiological study may be accurate, it is also possible that the association was due to chance, bias in the way in which the observations were made or inadequate control of confounding factors.

An appropriate test of statistical significance can quantify the degree to which chance may account for associations between air quality and health observed in an epidemiological study. However, the test result reflects not only the magnitude of the difference in health between groups exposed to air of different quality but also the size of the groups. Confidence limits were abstracted because, as Hennekens et al. (1987) explained very well for the non-epidemiologist, they are a more informative measure of the role of chance than are tests of statistical significance. The narrower the confidence limits, the smaller the variability in the estimate of the health effect, reflecting larger group sizes. The wider the confidence limits, the larger the variability in the estimate of the health effect, reflecting smaller group sizes. Narrow confidence limits imply that the observed effect of air quality on health is likely to be real whereas a wide interval suggests that the groups were simply not large enough to have sufficient statistical power to conclude that chance was not a likely explanation of the findings.

Observer bias may have arisen from the researchers eliciting or interpreting information on health effects, or exposure to air of a particular quality in the groups being compared differently (interviewer bias). Alternatively the study subjects themselves may have reported health effects in a non-comparable way (recall bias). Recall bias may have arisen because subjects exposed to air of a particular quality or having an adverse health effect were likely to remember their experiences differently from those not so affected.

Inaccuracies in the collection of air quality and health data are inevitable. Hennekens et al. (1987) provided a clear explanation of how this can occur. For example, when the proportion of accurate data is the same in all groups exposed to air of differing quality, then the effect of such random misclassification will only minimise the differences between the groups, resulting in an under estimate of the true association between air quality and health. In contrast, if the proportions of incorrect data are different in a group exposed to air of a particular quality the estimate of the effect of air quality on health can be

biased in the direction of being either more or less extreme than the true association.

1.2.3 Consideration of positive features of causation

The following data were abstracted to evaluate positive features of causation in relationships between air quality and health in the studies reviewed:

- (a) whether it was clear that the exposure to air of a particular quality preceded the health effect by a period of time consistent with any proposed biological mechanism
- (b) the strength of the association between air quality and health and the likelihood that a weak relationship was due merely to the effect of an uncontrolled confounding variable
- (c) whether there was a gradient between the risk of an adverse health effect and the degree of exposure to air of a particular quality
- (d) whether there was consistency in the associations found between air quality and different aspects of health
- (e) whether there was any specificity in the associations between air quality and health.

The presence of a dose-response relationship between air quality and health does not mean that the association is one of cause-and-effect and conversely, the absence of a dose-response gradient does not mean that a cause-and-effect relationship does not exist. Hennekens et al. (1987) explained how on the one hand an observed dose-response relationship may merely reflect the effect of an uncontrolled confounding factor but on the other hand, a dose-response relationship may be masked by an inability to quantify air quality, say, sufficiently to distinguish between risks of an adverse health effect associated with different levels of air quality. Hennekens et al. (1987) also described how the relationship between air quality and health, for example, may demonstrate a threshold phenomenon where no effect on health is present until a certain level of air quality is reached.

The paper considers the extent to which chance, bias and confounding factors can be excluded as alternative explanations for associations between air quality and health found in epidemiological studies in Australia and overseas. The paper then considers whether the associations can be judged to be ones of cause-and-effect on the basis of the time sequence between exposure to air of a particular quality and a health effect, and the strength, gradient, consistency and specificity of the associations found.

2 Associations between health effects and outdoor air quality in Australia

This section deals with the appraisal of studies conducted in Australia during the late 1980s and 1990s (up to June 1995). The main aims of these studies have been to identify any associations between outdoor air quality and health.

The New South Wales Department of Health has established a program of research into air quality and health, the results of which will be published in the near future (HARP 1994). The studies include two cohort studies. One will examine the effects of air quality on several hundred primary school children from Sydney in which fixed air monitoring stations close to the school of each child will provide daily measures for air pollutants and peak expiratory flow rates (PEFRs), symptoms and medication usage will be recorded. The other cohort study will document changes in lung function and symptoms over time in symptomatic children from the industrial regions of the Hunter and Illawarra areas. A number of other correlational studies of air quality, including that during bushfires, and hospital attendances and admissions with asthma, attendances at general practices with asthma, lung function and bronchial responsiveness in primary school children and PEFR in asthmatics are also underway.

Table 1 summarises the studies in terms of the populations studied, the differences in outdoor air quality and health effects investigated, the main results found and the extent to which non-causal explanations for associations found or features of the associations themselves might or might not favour a cause-and-effect relationship.

2.1 Description of the evidence

2.1.1 Differences in air quality studied

The aspects of outdoor air quality which investigators have chosen to study in Australia have varied from study to study. Some investigators have chosen to study the effects of several 'pollutants' whilst others have chosen to study only one or two 'pollutants'. Some have not been specific about the aspect of outdoor air quality studied. The measure of outdoor air quality which investigators have chosen to use in Australia has also varied from study to study. Table 2 is an example of how the aspect of outdoor air quality chosen and the measure of air quality used has varied in Australia between studies.

The level at which the quality of the outdoor air to which persons might be exposed has been measured or estimated has varied from study to study. Some investigators have used isopleth maps based on fixed monitoring stations to estimate the level of pollutants at the centroid of Local Government Areas (Anonymous 1994) or even at the home address or school (Hunt and Holman 1987), whilst other investigators have used measurements at the metropolitan level.

2.1.2 Health effects studied

The health effects which investigators have chosen to study in Australia have varied from study to study. Some have chosen to study 'hard' outcomes such as all-cause and disease-specific mortality. Others have studied all-cause and respiratory disease admissions to public hospitals, attendances at emergency departments for asthma, still others lung function, intermediate physiological outcomes such as bronchial hyperreactivity. 'Softer' outcomes such as respiratory symptoms and use of medication have also been studied. Respiratory symptoms were most often collected on children from their parents using a questionnaire. Lung function and bronchial hyperreactivity were often performed using standard techniques. Bronchial hyperreactivity was defined as a fall in forced expiratory volume (FEV), or PEF in younger children, of 20 per cent or more during a histamine challenge.

2.1.3 Study design used

Correlational and cross-sectional studies comprised most of the studies of outdoor air quality and health in Australia during the late 1980s and 1990s.

2.1.4 Populations studied

Most investigators chose to study metropolitan or urban populations. School children were the most frequently studied sub-group of the population.

2.1.5 Main results

The most recent cohort study up to June 1995 (Henry et al. 1991(b)) chose to investigate the impact of maximal daily SO₂ and NO_x concentrations in the air on symptoms and use of medication reported daily by asthmatic children. This study found no association.

The most recent case-control study up to June 1995 (Hunt and Holman 1987) investigated the impact of annual mean SO₂ concentrations and hours on which the SO₂ concentration exceeded an arbitrary critical value of 486

g/m³ at home and/or school on hospital admissions for asthma in children and adults. This study found no association.

The most recent cross-sectional studies up to June 1995 (Halliday et al. 1993; Henry et al. 1991(a)) chose to compare the prevalence of respiratory symptoms, lung function and bronchial reactivity in children who lived in a town near power stations compared with those living in other towns. Both studies found greater odds of reporting current wheeze among children resident in the town near power stations.

The most recent correlational studies up to June 1995 found a positive association between mortality from respiratory and other diseases, and the estimated concentration of several 'pollutants' at Local Government Area level (Anonymous 1994); between admissions with asthma and NO₂ levels (Abramson et al. 1994); between attendances of children with asthma at a hospital emergency department and the Airborne Particulate Index (Rennick and Jarman 1992); and between all-cause and respiratory disease admissions to hospital and distance of place of residence from an industrial source of unspecified pollutants (Christie et al. 1992).

2.2 Consideration of non-causal explanations

2.2.1 Chance

The greater odds of reporting current wheeze among children resident in the town near power stations than elsewhere (Halliday et al. 1993, Henry et al. 1991(a)) was statistically significant and the confidence limits were narrow suggesting that the association was unlikely to have arisen by chance. Anonymous (1994), Rennick and Jarman (1992) and Christie et al. (1992) did not publish confidence limits on their regression and correlation coefficients.

2.2.2 Bias

A possible explanation for the association found between air quality and wheezing may be a difference in the reporting of current wheeze between the parents of children living in the town near the power stations and those living elsewhere (Henry et al. 1991(a) (b), Halliday et al. 1993). Such a difference would have produced an inaccurate association between air quality and wheezing in children.

2.2.3 Confounding

One of the studies was unable to exclude a factor such as smoking, which might be associated with mortality and residence in more 'polluted' Local Government Areas as an alternative explanation for the associations found between mortality and outdoor air quality (Anonymous 1994). Similarly Christie et al. (1992) were unable to control for socio-economic status and smoking. Both of these factors might be associated with distance of place of residence from an industrial source and admission to public hospitals. Henry et al. (1991 (a) (b)) and Halliday et al. (1993) were unable to control for meteorological factors and pollen. These may have differed between towns near and away from power stations and they might be associated with the reporting of wheeze in children.

2.2.4 Features of associations

Abramson et al. (1994) and Rennick and Jarman (1992) were able to show that the days on which NO₂ and the Airborne Particulate Index exceeded acceptable levels preceded increased admissions to hospital with asthma and attendances of children with asthma at a hospital emergency department respectively. The cross-sectional studies and other correlational studies were unable to demonstrate that mortality, hospital admission and reporting of current wheeze preceded the exposure to 'pollutants' by the nature of their design.

Many of the associations found between the various health effects and aspects of outdoor air quality were weak. Children resident in the town near the power stations had only an odds of 1.9 (95 per cent confidence limits 1.4 to 2.8) of reporting current wheeze. The association between the Airborne Particulate Index exceeding its acceptable value of 2.35 and increased attendances of children with asthma at a hospital emergency department was also weak. However, there were 3.1 additional hospital admissions with asthma for every 0.01 ppm increase in NO₂.

None of the associations between the aspects of outdoor air quality and health effects studied showed evidence of a dose-response relationship between the two, with the exception of the associations between outdoor air quality and mortality (Anonymous 1994), and NO₂ and hospital admissions with asthma (Abramson et al. 1994).

The associations found between outdoor air quality and mortality (Anonymous 1994) were not specific for only those diseases for which there would be expected to be an association. This suggests that the associations might have been confounded by uncontrolled factors.

Table 1: Australian studies of outdoor air quality and health

(a) Correlational Studies						
Source	Population	Exposure	Health Effects	Result	Causality	
Anonymous (1994)	metropolitan Health Region	level of multiple pollutants at centroid of Local Government area from isopleth map based on fixed monitoring stations	all-cause and disease specific mortality	positive regression slope with respiratory and other diseases	<ul style="list-style-type: none"> control for socio-economic status only weak association no consistency/specificity temporal relationship not proven 	
Abramson et al. (1994)	Victoria	daily maximum one hour levels of NO ₂ , O ₃ , SO ₂ and Airbourne Particulate Index	admissions to hospital for asthma	correlation with NO ₂ , 3.1 additional admissions per 0.01 ppm increase	<ul style="list-style-type: none"> control for airborne pollen, barometric pressure, temperature and day of week 	
Christie et al. (1992)	metropolitan	distance of place of residence from industrial source of unspecified pollutants	all-cause and respiratory disease specific admissions to public hospitals	correlation with respiratory and all diseases	<ul style="list-style-type: none"> no control for socio-economic status or smoking dose-response not proven no specificity temporal relationship not proven 	
Rennick & Jarman (1992)	metropolitan children	one or more fixed monitoring stations recording level of multiple pollutants above acceptable levels	attendances at emergency department for asthma	correction with Airborne Particulate Index >2.35	<ul style="list-style-type: none"> control for season and time of year only dose-response not proven weak effect temporal relationship 	
Cooper et al. (1994)	metropolitan	fixed monitoring station recording hourly average values of multiple pollutants	attendances at emergency department for asthma	no association with particulate matter readings		

Table 1: Australian studies of outdoor air quality and health (cont.)

(b) Cross-Sectional Surveys					
Source	Population	Exposure	Health Effects	Result	Causality
Halliday et al. (1993)	children	residence in town near power stations	<ul style="list-style-type: none"> respiratory symptoms lung function bronchial reactivity 	greater odds of reporting current wheeze in town near power stations	<ul style="list-style-type: none"> control for age, gender, smoker in house, positive dust mite skin test, father's occupation very low levels of SO₂ and NO_x in town near power stations weak effect
Henry et al. (1991(a))	children	residence in town near power stations	<ul style="list-style-type: none"> respiratory symptoms lung function bronchial reactivity 	greater odds of reporting current wheeze in town near power stations	<ul style="list-style-type: none"> control for age, gender, smoker in house, positive dust mite skin test, maternal smoking, socio-economic status possibility of selection bias, response bias, and observation bias by parents and researchers
(c) Case-Control Studies					
Hunt & Holman 1987	metropolitan adults and children	annual mean SO ₂ levels and hours SO ₂ > 486 µg/m ³ at home and/or school from contour maps	<ul style="list-style-type: none"> hospital admissions for asthma 	no association	
(d) Cohort Studies					
Henry et al. (1991 (b))	children with asthma	maximal daily SO ₂ and NO _x	daily reporting of symptoms and use of medication	no association	

Table 2: Examples of aspects and measures of outdoor air quality investigated in Australia

Aspect	Measure Used			
	Hunt & Holman (1987)	Henry et al. (1991(b))	Rennick & Jarman (1992)	Anonymous (1994)
Particles	-	-	<ul style="list-style-type: none"> 1 hour visibility reducing particulates (km) 	<ul style="list-style-type: none"> concentration of respirable and fine particles
SO ₂	<ul style="list-style-type: none"> annual mean concentration number of hours concentration over 'critical value' (486 µ g/m3) 	<ul style="list-style-type: none"> maximum daily concentration µg/m3: 'low' (0), 'medium' (1-29), 'high' (>29). 	<ul style="list-style-type: none"> 1 hour average (ppm) days above 0.17 ppm 24 hour average (ppm) days above 0.06 ppm 	-
NO ₂	-	<ul style="list-style-type: none"> maximum daily concentration (µg/m3): 'low' (0-92), 'medium' (92-246), 'high' (>246). 	<ul style="list-style-type: none"> 1 hour average (ppm) days above 0.15 ppm 24 hour average (ppm) days above 0.06 ppm 	<ul style="list-style-type: none"> maximum average
NO	-	-	-	<ul style="list-style-type: none"> average
O ₃	-	-	<ul style="list-style-type: none"> 1 hour average of oxidant (ppm) days above 0.12 ppm 8 hour average of oxidant (ppm) days above 0.05 ppm 	<ul style="list-style-type: none"> maximum average
CO	-	-	<ul style="list-style-type: none"> 1 hour average (ppm) days above 30 ppm 8 hour average (ppm) days above 10 ppm 	<ul style="list-style-type: none"> 1 hour average 8 hour average
Benzene	-	-	-	<ul style="list-style-type: none"> concentration (µg/m3)

3 Associations between health effects and outdoor air quality overseas - Europe and elsewhere

This section appraises studies, undertaken outside Australia in the late 1980s and 1990s (until June 1995), which have tried to identify any associations between outdoor air quality and health.

Table 3 summarises the studies in terms of the populations studied, the differences in outdoor air quality and health effects investigated, the main results found and the extent to which non-causal explanations for associations found or features of the associations themselves might or might not favour a cause-and-effect relationship.

3.1 Description of the evidence

3.1.1 Differences in air quality studied

The aspects of outdoor air quality studied, as well as the measure of outdoor air quality used, have, as in Australia, varied from study to study.

3.1.2 Health effects studied

These ranged from all-cause and disease-specific mortality, all cause and/or respiratory disease-specific hospital admissions or emergency department attendances, respiratory symptoms, use of respiratory disease medication, lung function and bronchial reactivity.

3.1.3 Study designs used

As in Australia correlational and cross-sectional studies comprised most of the European studies of air quality and health, but there was a far larger proportion of cohort studies.

3.1.4 Populations studied

Most overseas studies have focused on the health of metropolitan or urban populations with school children being the most frequently studied sub-group of the population.

3.1.5 Main results

The cohort studies found associations between:

- outdoor air quality and mortality from lung cancer and cardiopulmonary disease but not all-cause mortality

- particulates and malignant neoplasms in women but not in men
- ozone and Chronic Obstructive Airways Disease (COAD) in men but not between other respiratory diseases or in women
- smoke and asthma
- particulates and ozone and some respiratory symptoms
- particulates and lung function, most frequently in asthmatic children or in adults and smokers with air flow limitation.

The cross sectional studies commonly found associations in school children between particulates or gases and respiratory symptoms and between lung function and ozone.

Correlational studies which have investigated the relationship between outdoor air quality and mortality found no association between outdoor air quality and all-cause mortality except at high levels of sulphur dioxide and temperature. However, such studies found a positive association between:

- sulphur dioxide concentrations and lung cancer mortality, at least in men
- total particulates and specific circulatory and respiratory diseases
- between outdoor air quality and neonatal and post-neonatal mortality.

The correlational studies which had investigated the relationship between outdoor air quality and symptoms, or hospital attendances and admissions, commonly found associations in healthy school children, as well as in symptomatic children between:

- particulate matter and respiratory symptoms
- particulates, sulphur dioxide and ozone and emergency room attendances.

3.2 Consideration of non-causal explanations

Factors which may confound cross-sectional and cohort studies include differences between groups being compared in sex, age, atopy, family history of asthma, passive smoking, smoking, socio-economic status, education, maternal and paternal employment, use of gas or coal for cooking or heating, household crowding, and occupational exposure in adults all of which may be associated with respiratory disease. Correlational studies may be confounded by temperature, humidity, wind speed,

influenza, year, season, month, day of week, socio-economic status and occupational exposure. The extent to which the studies took account of confounding factors varied, but no observational study can take account of all confounding factors.

Table 3: Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
(a) Correlational Studies					
Lang and Polansky 1994	<ul style="list-style-type: none"> Philadelphia 	<ul style="list-style-type: none"> Annual concentration of O₃, CO, NO₂, TP₁₀ and SO₂ 	<ul style="list-style-type: none"> Asthma mortality 	<ul style="list-style-type: none"> Negative association between asthma mortality and pollutants 	<ul style="list-style-type: none"> Controlled for race, age, poverty, sex, ethnicity, age of homes, level of education, crowding, socio-economic status
Burnett et al 1994	<ul style="list-style-type: none"> Ontario 	<ul style="list-style-type: none"> Daily SO₂ and O₃ concentrations 	<ul style="list-style-type: none"> Emergency respiratory disease admissions to hospital 	<ul style="list-style-type: none"> Association between SO₂ and O₃ emergency admissions 	<ul style="list-style-type: none"> Controlled for temperature, season, day of week Specificity Strong effect for O₃
Schwartz et al 1994 (a)	<ul style="list-style-type: none"> Birmingham, Alabama 	<ul style="list-style-type: none"> Daily average O₃ and PM₁₀ 	<ul style="list-style-type: none"> Respiratory admissions to hospital 	<ul style="list-style-type: none"> Positive association between admissions and PM₁₀ 	<ul style="list-style-type: none"> Controlled for time trends, seasonal fluctuations, weather Dose-response
Pope 1991	<ul style="list-style-type: none"> Utah, Salt Lake, Cache Valleys 	<ul style="list-style-type: none"> Daily average PM₁₀ concentration 	<ul style="list-style-type: none"> Respiratory admissions to hospital 	<ul style="list-style-type: none"> Positive association between admissions and PM₁₀ 	<ul style="list-style-type: none"> Controlled for temperature
Schwartz et al 1993	<ul style="list-style-type: none"> Washington Persons under 65 years old 	<ul style="list-style-type: none"> Mean PM₁₀ concentration 	<ul style="list-style-type: none"> Emergency room attendances for asthma 	<ul style="list-style-type: none"> Association between PM₁₀ and emergency room attendances 	<ul style="list-style-type: none"> Controlled for weather, season, time trends, age, hospital, day of week
Ware et al 1993	<ul style="list-style-type: none"> Kanawha County, West Virginia School children 	<ul style="list-style-type: none"> Location of school Concentrations of petroleum-related compounds Concentrations of industrial process related compounds 	<ul style="list-style-type: none"> Respiratory symptoms 	<ul style="list-style-type: none"> Association between chronic respiratory symptoms and exposure to volatile organic compounds 	<ul style="list-style-type: none"> Controlled for parental smoking and socio-economic status Dose-response Weak effect

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Schwartz 1992	<ul style="list-style-type: none"> • Los Angeles • Nursing school residents 	<ul style="list-style-type: none"> • Maximum concentrations of photochemical oxidants, NO₂, SO₂, CO₂ 	<ul style="list-style-type: none"> • Daily respiratory symptoms 	<ul style="list-style-type: none"> • Association between duration of episodes of cough, phlegm and sore throat and photochemical oxidants 	<ul style="list-style-type: none"> • Controlled for temperature, family income and smoking • Dose-response
Schwartz and Dockery 1992	<ul style="list-style-type: none"> • Steubenville, Ohio 	<ul style="list-style-type: none"> • Daily TSP and SO₂ 	<ul style="list-style-type: none"> • All-cause mortality 	<ul style="list-style-type: none"> • Positive association between mortality and TSP 	<ul style="list-style-type: none"> • Controlled for season and temperature • Dose-response
Pope et al 1991	<ul style="list-style-type: none"> • Utah Valley • Symptomatic school children 	<ul style="list-style-type: none"> • Daily concentrations of PM₁₀ 	<ul style="list-style-type: none"> • Respiratory symptoms • Use of medication • Lung function 	<ul style="list-style-type: none"> • Negative association between PEF_R and PM₁₀ • Positive association between symptoms and use of asthma medication and PM₁₀ 	<ul style="list-style-type: none"> • Not controlled for confounding variables • Weak effect • Not generalisable
Buffier et al 1988	<ul style="list-style-type: none"> • Harris County, Texas • White males 	<ul style="list-style-type: none"> • TSP 	<ul style="list-style-type: none"> • Lung cancer mortality 	<ul style="list-style-type: none"> • Positive association between lung cancer mortality and TSP 	<ul style="list-style-type: none"> • Controlled for age, family status, socio-economic status, racial/ethnic status, migration and smoking • Possibility of bias • Weak effect
Thurston et al 1994	<ul style="list-style-type: none"> • Toronto 	<ul style="list-style-type: none"> • Daily concentrations of O₃, TSP and PM₁₀ 	<ul style="list-style-type: none"> • Respiratory admissions to hospital 	<ul style="list-style-type: none"> • Positive association between admissions and O₃ 	<ul style="list-style-type: none"> • Controlled for temperature only • Dose-response • Temporal association
Walters et al 1994	<ul style="list-style-type: none"> • Birmingham 	<ul style="list-style-type: none"> • Average daily value and maxima of smoke and SO₂ 	<ul style="list-style-type: none"> • Hospital admissions for asthma and respiratory disease 	<ul style="list-style-type: none"> • Smoke and SO₂ associated with hospital admissions for respiratory disease and asthma 	<ul style="list-style-type: none"> • Controlling for temperature, pressure and humidity only • Dose-response • Specificity unknown

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Ayers et al 1989	<ul style="list-style-type: none"> General practices in United Kingdom 	<ul style="list-style-type: none"> Average daily SO₂ concentrations Black Smoke 	<ul style="list-style-type: none"> Weekly age specific attendances at general practitioners with respiratory illness in polluted and non-polluted areas 	<ul style="list-style-type: none"> No association 	
Knox 1981	<ul style="list-style-type: none"> England and Wales 	<ul style="list-style-type: none"> Daily average and maximum density of total particulates 	<ul style="list-style-type: none"> Disease-specific mortality 	<ul style="list-style-type: none"> Correlation with mortality from cerebral haemorrhage and thrombosis, hypertension bronchitis 	<ul style="list-style-type: none"> Controlled for temperature and overall seasonal variation only Weak associations
Mackenback et al 1993	<ul style="list-style-type: none"> Netherlands 	<ul style="list-style-type: none"> Average daily SO₂ concentrations 	<ul style="list-style-type: none"> All and disease-specific mortality 	<ul style="list-style-type: none"> No association 	<ul style="list-style-type: none"> Controlled for temperature, humidity, wind speed, influenza, year, month and week day
Kunst et al 1993	<ul style="list-style-type: none"> Netherlands 	<ul style="list-style-type: none"> Median Regional SO₂ from weighted average SO₂ concentrations 	<ul style="list-style-type: none"> Lung cancer mortality 	<ul style="list-style-type: none"> Positive association for men and women over 64 years old 	<ul style="list-style-type: none"> Controlled for average income per capita, proportion of population in large cities, proportion of population Roman Catholic, sex, work in transport and manufacturing Possible inadequate control for smoking
Roemer et al 1993	<ul style="list-style-type: none"> Netherlands non-industrial towns Children with respiratory symptoms 	<ul style="list-style-type: none"> Daily average PM₁₀ and SO₂ 	<ul style="list-style-type: none"> Daily medication use and respiratory symptoms PEFR 	<ul style="list-style-type: none"> Negative association between PEFR and PM₁₀ and SO₂ 	<ul style="list-style-type: none"> Controlled for temperature only Weak effect

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Rossi et al 1993	<ul style="list-style-type: none"> Finland Metropolitan 	<ul style="list-style-type: none"> Mean daily and maxima concentrations of NO₂, SO₂, H₂S, TSP 	<ul style="list-style-type: none"> Emergency room attendances 	<ul style="list-style-type: none"> Positive association between asthma attendances TSP and all gases especially NO₂ 	<ul style="list-style-type: none"> Controlled for temperature, humidity, barometric pressure, rainfall
Ponka A 1991	<ul style="list-style-type: none"> Helsinki 	<ul style="list-style-type: none"> Mean daily concentration of SO₂, NO₂, NO, CO, TSP O₃ 	<ul style="list-style-type: none"> Hospital admissions 	<ul style="list-style-type: none"> Association between admissions and NO₂, NO, SO₂, CO, O₃ and TSP Interaction between air quality and low temperature 	<ul style="list-style-type: none"> Controlled for temperature only No specificity
Bobak and Leon 1992	<ul style="list-style-type: none"> Infants in Czech Republic 	<ul style="list-style-type: none"> Annual geometric mean TSP₁₀, SO₂ and NO_x concentrations 	<ul style="list-style-type: none"> Neonatal and post neonatal total and disease specific mortality 	<ul style="list-style-type: none"> Positive association between neonatal mortality and TSP₁₀ and SO₂; post neonatal mortality and TSP₁₀; post neonatal respiratory mortality and TSP₁₀ 	<ul style="list-style-type: none"> Controlled for income, car ownership, abortion rate Dose-response Weak associations Specificity for post neonatal respiratory mortality only
Sunyer et al 1993	<ul style="list-style-type: none"> Barcelona, Spain 	<ul style="list-style-type: none"> 24 hour average SO₂ and black smoke concentrations Maximum SO₂, CO, NO₂ and O₃ concentrations 	<ul style="list-style-type: none"> Emergency respiratory admissions to hospital 	<ul style="list-style-type: none"> Positive association between admissions and SO₂ and smoke 	<ul style="list-style-type: none"> Controlled for weather and influenza Dose-response Specificity unknown
Sunyer et al 1991	<ul style="list-style-type: none"> Barcelona, Spain 	<ul style="list-style-type: none"> 24 hour average SO₂ and black smoke concentrations Maximum SO₂, CO, NO₂ and O₃ concentrations 	<ul style="list-style-type: none"> Emergency respiratory admissions to hospital 	<ul style="list-style-type: none"> Positive association between admissions and SO₂ smoke and CO 	<ul style="list-style-type: none"> Controlled for seasonal meteorological and temporal variables Weak effect Dose-response Specificity unknown

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Katsouyanni et al 1993	<ul style="list-style-type: none"> • Athens 	<ul style="list-style-type: none"> • Daily 24 hour values of smoke and SO₂ and maximum values of O₃ 	<ul style="list-style-type: none"> • All-cause mortality 	<ul style="list-style-type: none"> • No association with air pollution index • Positive association with high levels of SO₂ and temperature 	<ul style="list-style-type: none"> • Not controlled for confounding factors
Tseng and Li 1990	<ul style="list-style-type: none"> • Hong Kong 	<ul style="list-style-type: none"> • Average monthly SO₂, NO₂, NO, O₃, TSP, RSP measured daily 	<ul style="list-style-type: none"> • Admissions for asthma 	<ul style="list-style-type: none"> • Negative correlation with SO₂ 	
Montealegre et al 1993	<ul style="list-style-type: none"> • Southern Puerto Rico 	<ul style="list-style-type: none"> • Annual level of TSP₁₀ 	<ul style="list-style-type: none"> • Admissions for asthma 	<ul style="list-style-type: none"> • No association 	
(b) Cross Sectional Surveys					
Dockery et al 1989	<ul style="list-style-type: none"> • USA • Metropolitan • School children 	<ul style="list-style-type: none"> • Concentrations of TSP, PM₁₅, PM_{2.5}, FSO₄, SO₂, O₃, NO₂ 	<ul style="list-style-type: none"> • Respiratory symptoms • Lung function 	<ul style="list-style-type: none"> • Positive association between some respiratory symptoms and TSP, PM₁₅, PM_{2.5}, FSO₄, SO₂, O₃, NO₂ 	<ul style="list-style-type: none"> • Controlled for age, sex, parental education, maternal smoking, gas stoves, and city • No consistency • Greater effect in children with history of respiratory disease
Ware et al 1986	<ul style="list-style-type: none"> • USA • Metropolitan • School children 	<ul style="list-style-type: none"> • Daily average concentrations of TSP, TSO₄, SO₂ 	<ul style="list-style-type: none"> • Respiratory symptoms • Lung function tests 	<ul style="list-style-type: none"> • Positive association between TSP, TSO₄, SO₂ and respiratory symptoms 	<ul style="list-style-type: none"> • Controlled for age, sex, parental education and maternal smoking • Strong effect • No consistency
Detels et al 1981	<ul style="list-style-type: none"> • USA • Young adults 	<ul style="list-style-type: none"> • Residence in polluted area 	<ul style="list-style-type: none"> • Respiratory symptoms • Lung function tests 	<ul style="list-style-type: none"> • Greater prevalence of symptoms in polluted area • Lung function tests worse in polluted area 	

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Thomson and Philion 1991	<ul style="list-style-type: none"> • Canada • Children 	<ul style="list-style-type: none"> • Residence in industrial or non-industrial community 	<ul style="list-style-type: none"> • Hospital separations for respiratory disease 	<ul style="list-style-type: none"> • No association between hospital separations and place of residence 	<ul style="list-style-type: none"> • Not controlled for confounding factors
Brabin et al 1994	<ul style="list-style-type: none"> • England • School Children 	<ul style="list-style-type: none"> • Residence in area adjacent to coal handling terminal 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • Greater prevalence of respiratory symptoms in polluted area 	<ul style="list-style-type: none"> • Controlled for maternal and paternal employment, smoking, renting of home, damp in house • Temporal relationship unknown
Forastiere et al 1994	<ul style="list-style-type: none"> • Italy • School Children 	<ul style="list-style-type: none"> • Residence in polluted area 	<ul style="list-style-type: none"> • Lung function tests • Bronchial reactivity 	<ul style="list-style-type: none"> • Greater bronchial reactivity in polluted area 	<ul style="list-style-type: none"> • Controlled for sex, age, father's education, household crowding, household heating type and fuel, parental smoking, season • Temporal relationship unknown
Symington et al 1991	<ul style="list-style-type: none"> • England • School Children 	<ul style="list-style-type: none"> • Residence near foundry emitting formaldehyde 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • No associations 	<ul style="list-style-type: none"> • Controlled for sex, social class, housing tenure, passive smoking, parental history of asthma • No temporal relationship • Temporal relationship unknown
Corbo et al 1993	<ul style="list-style-type: none"> • Italy • School Children 	<ul style="list-style-type: none"> • Residence in industrialised, urban or rural area 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • Greater odds of symptoms in industrial and urban areas • Interaction between symptoms and atopy 	<ul style="list-style-type: none"> • Controlled for atopy, sex, age, passive parental smoking, father's education, and siblings • Weak effect • Temporal association unknown

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Charpin et al 1988	<ul style="list-style-type: none"> France Children 	<ul style="list-style-type: none"> Average daily and maximum daily SO₂ 	<ul style="list-style-type: none"> Respiratory symptoms 	<ul style="list-style-type: none"> Association with symptoms 	<ul style="list-style-type: none"> Controlled for temperature and respirable particles
Schmitzberger et al 1993	<ul style="list-style-type: none"> European Alpine region School Children 	<ul style="list-style-type: none"> Residence in three zones of SO₂, NO₂ and O₃ exposure 	<ul style="list-style-type: none"> Respiratory symptoms and diseases Lung function tests 	<ul style="list-style-type: none"> Negative association between SO₂ and NO₂ and lung function Association between asthma and O₃ 	<ul style="list-style-type: none"> Controlled for age, sex, height, socio-economic status, environmental tobacco smoke Temporal association unknown
Wjst et al 1993	<ul style="list-style-type: none"> Munich School Children 	<ul style="list-style-type: none"> Car density in school district (no. per 24 hours) 	<ul style="list-style-type: none"> Respiratory symptoms Lung function tests 	<ul style="list-style-type: none"> Negative association between lung function and traffic density Positive association between recurrent symptoms and traffic density 	<ul style="list-style-type: none"> Controlled for parental history of asthma, height, weight, month, number of cigarettes smoked at home, use of gas or coal for cooking or heating, education of parents, compliance with test Weak effect No consistency Temporal relationship unknown
Von Mutius et al 1994	<ul style="list-style-type: none"> Germany Children 	<ul style="list-style-type: none"> Residence in West and East Germany 	<ul style="list-style-type: none"> Asthma prevalence Bronchial hyperresponsiveness 	<ul style="list-style-type: none"> No difference 	<ul style="list-style-type: none"> Controlled for atopy
Von Mutius et al 1992	<ul style="list-style-type: none"> Germany School Children 	<ul style="list-style-type: none"> Residence in polluted area 	<ul style="list-style-type: none"> Respiratory symptoms Lung function tests Bronchial reactivity 	<ul style="list-style-type: none"> No association with SO₂ 	
Schwartz et al 1991	<ul style="list-style-type: none"> Germany Urban Children 	<ul style="list-style-type: none"> TSP and NO₂ 	<ul style="list-style-type: none"> Attendances at hospital with croup and obstructive bronchitis 	<ul style="list-style-type: none"> Association with croup Increase from 10µg/m³ to 70µg/m³ led to more than 25% increase in admissions 	<ul style="list-style-type: none"> Controlled for season

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Hoek et al 1993	<ul style="list-style-type: none"> Netherlands School Children 	<ul style="list-style-type: none"> Maxima concentration of O₃ 	<ul style="list-style-type: none"> PEFR before and after exercise 	<ul style="list-style-type: none"> Negative association between O₃ and PEFR 	<ul style="list-style-type: none"> Controlled for temperature Weak effect Temporal relationship unknown
Jaakkola et al 1991	<ul style="list-style-type: none"> Oulu Pre-school Children 	<ul style="list-style-type: none"> Residence in polluted area 	<ul style="list-style-type: none"> Respiratory symptoms 	<ul style="list-style-type: none"> Positive association with symptoms 	<ul style="list-style-type: none"> Controlled for daily contacts, passive smoking, atopy, sex
Jaakkola et al 1990	<ul style="list-style-type: none"> South Karelia Adults 	<ul style="list-style-type: none"> Residence in polluted area 	<ul style="list-style-type: none"> Symptoms 	<ul style="list-style-type: none"> Positive association with symptoms 	<ul style="list-style-type: none"> Controlled for age, sex, smoking, atopy, occupational exposure only Dose-response Temporal relationship unknown
Tao et al 1992	<ul style="list-style-type: none"> Shanghai, China 	<ul style="list-style-type: none"> Residence in polluted area 	<ul style="list-style-type: none"> Mortality Respiratory symptoms Lung function 	<ul style="list-style-type: none"> No association 	<ul style="list-style-type: none"> Controlled for sex, age, passive smoking, cooking fuel, smoking, occupational exposure, time at home Temporal relationship unknown
Zwi et al 1990	<ul style="list-style-type: none"> Transvaal highveld School Children 	<ul style="list-style-type: none"> Residence in polluted area 	<ul style="list-style-type: none"> Respiratory symptoms Lung function 	<ul style="list-style-type: none"> Symptoms more common in polluted area 	<ul style="list-style-type: none"> Controlled for height, parental smoking and cooking fuel only Temporal relationship unknown

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
(c) Cohort Studies					
Taslikin D P et al 1994	<ul style="list-style-type: none"> • USA • Young & middle aged adults 	<ul style="list-style-type: none"> • Residence in polluted areas 	<ul style="list-style-type: none"> • Lung function 	<ul style="list-style-type: none"> • Greater decline in lung function among male residents in most polluted areas • Greater decline in lung function among female non-smoking residents in polluted areas 	<ul style="list-style-type: none"> • Controlled for baseline FEV₁, age, height, history of allergy, smoking
Greer et al 1993	<ul style="list-style-type: none"> • California Seventh Day Adventists 	<ul style="list-style-type: none"> • Concentrations of O₃ and TSP estimated using monthly interpretations from fixed-site monitoring stations applied to zip code locations 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • COAD associated with O₃ in men • Asthma associated with smoke 	<ul style="list-style-type: none"> • Controlled for smoking occupational vapour or dust exposure, passive smoking, smoking, childhood history of childhood obstructive airways disease, age, sex, education • Possibility of recall bias, non-response bias, misclassification errors
Pope and Kanner 1993	<ul style="list-style-type: none"> • USA • Smokers with airflow limitation 	<ul style="list-style-type: none"> • Concentration of PM₁₀ 	<ul style="list-style-type: none"> • Lung function tests 	<ul style="list-style-type: none"> • Negative association between change in FEV₁ and FEV₁/FVC and PM₁₀ 	<ul style="list-style-type: none"> • Controlled for temperature • Weak effect • Greater effect in men
Abbey et al 1993	<ul style="list-style-type: none"> • USA Seventh Day Adventists 	<ul style="list-style-type: none"> • Mean concentration of TSP, O₃ and SO₂ and number of hours exceeding thresholds 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • Positive association between some symptoms and TSP and O₃ 	<ul style="list-style-type: none"> • Controlled for past and passive smoking and occupational exposure
Dockery et al 1993	<ul style="list-style-type: none"> • Six US cities • Adults 	<ul style="list-style-type: none"> • Annual average concentrations of TSP, suspended sulphates, SO₂ and O₃ 	<ul style="list-style-type: none"> • Mortality all-cause and disease specific 	<ul style="list-style-type: none"> • Positive association between mortality from lung cancer and cardio pulmonary disease 	<ul style="list-style-type: none"> • Controlled for smoking, sex occupational exposure

Table 3 (cont.): Overseas studies of outdoor air quality and health

Source	Population	Exposure	Health Effects	Result	Causality
Koenig et al 1993	<ul style="list-style-type: none"> • Seattle • Metropolitan • Asthmatic children 	<ul style="list-style-type: none"> • Concentration of PM_{2.5} 	<ul style="list-style-type: none"> • Lung function 	<ul style="list-style-type: none"> • Inverse association between FEV₁ and FVC and PM_{2.5} 	
Abbey et al 1991	<ul style="list-style-type: none"> • USA • Seventh Day Adventists 	<ul style="list-style-type: none"> • Mean concentration of O₃ and TSP and number of hours exceeding thresholds 	<ul style="list-style-type: none"> • Respiratory symptoms • Cancer incidence and mortality 	<ul style="list-style-type: none"> • Association between TSP and all neoplasms in females • Association between TSP and respiratory symptoms • Association between O₃ and incidence of asthma 	<ul style="list-style-type: none"> • Controlled for past and passive smoking and occupational exposure • Dose-response • No specificity in cancer • Weak effect on symptoms
Mills PK et al 1991	<ul style="list-style-type: none"> • California • Seventh-Day Adventists 	<ul style="list-style-type: none"> • Annual average concentrations of TSP and O₃ and number of hours annual means exceeding specified cut-offs 	<ul style="list-style-type: none"> • Malignant neoplasms • Respiratory cancers 	<ul style="list-style-type: none"> • Malignant neoplasms in females associated with TSP 	<ul style="list-style-type: none"> • Controlled for smoking, age, education, occupational exposure, passive smoking • Dose-response • No consistency
Krzyzanowski and Lebowitz 1992	<ul style="list-style-type: none"> • Cracow, Poland and Tucson, Arizona • Adults 	<ul style="list-style-type: none"> • Residence in polluted area 	<ul style="list-style-type: none"> • Respiratory symptoms 	<ul style="list-style-type: none"> • Greater incidence of asthma and bronchitis in Tucson and Cracow respectively 	<ul style="list-style-type: none"> • Controlled for age, gender, smoking
Jedrychowski and Krzyzanowski 1989	<ul style="list-style-type: none"> • Cracow • Urban • Adults 	<ul style="list-style-type: none"> • Residence in three areas with high intermediate and low levels of SO₂ and PM 	<ul style="list-style-type: none"> • Chronic respiratory symptoms • Lung function 	<ul style="list-style-type: none"> • Reduced FEV₁ in high level area • Faster rate of FEV₁ decline in high level (both sexes) and intermediate (males only) areas 	<ul style="list-style-type: none"> • Controlled for age smoking, education and occupation • Actual SO₂ and PM levels not correlated with FEV₁ decline (both sexes) and symptom prevalence in males
Goren et al 1991	<ul style="list-style-type: none"> • Israel • School Children 	<ul style="list-style-type: none"> • Residence in polluted area 	<ul style="list-style-type: none"> • Respiratory symptoms • Lung function 	<ul style="list-style-type: none"> • Greater increase in prevalence of symptoms in polluted area 	<ul style="list-style-type: none"> • Not controlled for confounding factors • Inconsistency

4 Comparison between Australian and overseas data on health effects of outdoor air quality

Australian data on outdoor air quality and health compares poorly with overseas data.

Up to June 1995, there had been only one cohort study of the impact of outdoor air quality on health conducted in Australia (Henry et al. 1991(b)) so there were little data on the impact of outdoor air quality on the health of the Australian population followed over a number of years. This study involved children with asthma and examined the effect of sulphur dioxide and nitrogen oxides on the reporting of symptoms and use of medication. Overseas cohort studies involved adults and school children in general and examined the effects of multiple aspects of outdoor air quality including particulates and ozone on mortality and lung function as well as symptoms.

Cross-sectional studies in Australia involved only children and had not measured the actual exposure of the children to 'pollutants' (Henry et al. 1991(a), Halliday et al. 1993). Overseas cross-sectional studies also concentrated on children but measured the exposure of children to a number of pollutants including particles and ozone.

The only Australian studies to have examined exposure to a number of pollutants by June 1995 had been correlational studies (Rennick and Jarman 1992, Abramson et al. 1994, Anonymous 1994). The cohort and case-control studies measured exposure to only the nitrogen oxides and/or sulphur dioxide (Hunt and Holman 1987, Henry et al. 1991(b)). Policy analysts wanting recent information on the health effects of multiple pollutants, including particles and ozone, will have to rely largely on recent overseas data.

The health effects investigated by Australian studies included mortality, all-cause and respiratory disease hospital admissions or attendances, respiratory symptoms, lung function, bronchial reactivity and use of medication. Because of the different populations and exposures studied it will be necessary to glean the following from overseas studies:

- information about the impact of outdoor air quality on cancer incidence; hospital admissions or emergency department attendances for specific diseases other than respiratory diseases
- respiratory symptoms or lung function in adults, particularly the elderly.

It is difficult to know whether the associations found in Australian studies between outdoor air quality and mortality, hospital admissions or emergency department attendances for respiratory diseases in adults and children, and respiratory symptoms, particularly current wheezing in children, are due to causation or some other explanation such as confounding or bias in the way in which the data were collected.

Outdoor air quality is different in Australia and has been assessed differently and under different conditions to that in other countries. Caution is therefore required in extrapolating to Australia from overseas data on the health impact of outdoor air quality. Table 4 summarises the outdoor air quality to which subjects overseas happened to be exposed when epidemiological studies of the impact of outdoor air quality on health were conducted. This table should be read in conjunction with Table 3. It should be noted that some of the studies used different measures of outdoor air quality when describing the air to which communities were exposed than they used when analysing the relationship between outdoor air quality and health. Only a small number of the overseas studies have used measures to describe the quality of the outdoor air (to which their communities were exposed) which are directly comparable to the measures which have been used to describe outdoor air quality in Australia. The reader needs to be aware of the bias which will be introduced in overseas and Australian comparisons by being able to use only a small proportion of overseas data.

The Australian guideline for Total Suspended Particles (TSP) is an annual mean concentration of 90 $\mu\text{g}/\text{m}^3$. Some of the epidemiological studies conducted in the USA and Canada have examined the health of populations exposed to air where the annual mean TSP concentration has been known.

Dockery et al. (1993) found no association between annual mean TSP at levels below the Australian guideline and mortality, although they did find an association with the fine particles concentrations. Buffler et al. (1988) found only a weak association between lung cancer mortality and TSP levels below 90 $\mu\text{g}/\text{m}^3$. Thurston et al. (1994) found no association between hospital admissions and emergency department attendances and summer mean TSP levels below 90 $\mu\text{g}/\text{m}^3$. Ware et al. (1986) conducted their study in a community with an annual mean TSP concentration of 32 to 163 $\mu\text{g}/\text{m}^3$ and found an association between the daily average concentration of TSP and frequency of cough and bronchitis but not lung function in childhood. Dockery et al. (1989) also found an association between TSP concentration and cough and

bronchitis but not lung function in communities whose annual mean TSP concentration was below 90 $\mu\text{g}/\text{m}^3$. It should be noted that Dockery et al. (1989) found no association between persistent wheeze or asthma and TSP concentration. The study by Tashkin et al (1994) was conducted in communities exposed to annual mean TSP concentrations of 85 to 133 $\mu\text{g}/\text{m}^3$. They found an association between air quality and loss of lung function in males and at least non-smoking females, but the effect of the TSP themselves could not be isolated from that of other pollutants.

Streeton (1990) has published sulphur dioxide concentrations as found in Victoria's LaTrobe Valley in 1989. The one hour maximum sulphur dioxide concentration was 0.12 ppm or 343 $\mu\text{g}/\text{m}^3$. The twenty four hour maximum sulphur dioxide concentration was 0.010 ppm or 286 $\mu\text{g}/\text{m}^3$. Some of the overseas epidemiological studies have examined the health of populations exposed to air where the one hour or twenty four hour maximum sulphur dioxide concentrations have been known.

Walters et al. (1994) found an association between daily maximum sulphur dioxide concentrations during winter and hospital admissions for asthma in a population exposed to air for which maximum daily sulphur dioxide concentration was below that found in the LaTrobe Valley. There was a gradient between maximum daily sulphur dioxide concentrations and hospital admissions. A 100 $\mu\text{g}/\text{m}^3$ rise in daily maximum sulphur dioxide concentration was estimated to result in four (95% CI zero to seven) more asthma admissions and 16 (95% CI six to 25) more respiratory admissions each day. Sunyer et al. (1991) found a weak association between emergency department admissions for COAD and sulphur dioxide levels in a population exposed to air with a maximum daily sulphur dioxide concentration whose value was on average below that of the LaTrobe Valley. Daily emergency department admissions for COAD increased by 0.01 to 0.02 for each microgram of sulphur dioxide. Rossi et al. (1993) also found a positive association between daily attendances for asthma attacks at a hospital emergency department and daily maximum sulphur dioxide concentration in a population exposed to air with a maximum daily sulphur dioxide concentration below that found in the LaTrobe Valley.

Jaakkola et al. (1991) found an association between sulphur dioxide levels and symptoms in a community with low daily maximum sulphur dioxide levels. However, Higgins et al. (1990) found no association between one hour maximum sulphur dioxide concentrations and

morbidity in a community with a daily maximum sulphur dioxide concentration below that of the LaTrobe Valley. The population in which the study of Tashkin et al (1994) was conducted had a one hour maximum daily sulphur dioxide concentration below that of the LaTrobe Valley. As noted above, they found an association between air quality and loss of lung function in males and non-smoking females. However, the effect of individual 'pollutants' could not be isolated.

Streeton (1990) also published ozone concentration. The one hour maximum ozone concentration was 0.197 ppm or 394 $\mu\text{g}/\text{m}^3$.

A number of the overseas epidemiological studies were conducted in communities exposed to air whose one hour maximum concentration ozone was known. Neither Katsouyanni et al. (1993) nor Abbey et al. (1991) found an association between one hour maximum ozone concentration and mortality in populations exposed to air with a one hour maximum ozone concentration below and even above the level found Victoria respectively. Burnett et al. (1994) did not find an association between one hour maximum ozone concentration and hospital admissions in a population whose one hour maximum ozone concentration was below that in Victoria. Hoek et al. (1993), Higgins et al. (1990) and Spektor et al. (1988 (a) (b)) found an association between one hour maximum ozone levels and respiratory morbidity in three populations exposed to air with a one hour maximum ozone level below that found in Victoria.

Overseas studies suggest that exposure to air with TSP concentrations below the Australian goal for TSP concentration may be associated with respiratory symptoms but not impaired lung function and, possibly mortality. Overseas studies also suggest that exposure to sulphur dioxide at concentrations found in Victoria may be associated with hospital admissions for asthma and respiratory disease and possibly respiratory symptoms. Overseas studies suggest that there may be an association, too, between exposure to ozone at concentrations found in Victoria and respiratory morbidity.

When faced with conflicting results such as these, meta-analysis is a useful statistical technique which can provide an overall measure of health effects. Schwartz (1994b) has undertaken such a meta-analysis of eleven studies conducted between 1976 and 1992 in Greece, the United Kingdom and the USA into the impact of airborne particle concentration on mortality. Airborne particle concentration was a significant risk factor for elevated mortality. However, the relative risk was only 1.06.

Table 4: Air quality investigated for health effects in some overseas studies

Source	Air Quality		
	Aspect	Value ($\mu\text{g}/\text{m}^3$ or as shown)	
MORTALITY			
Dockery et al. 1993	Fine Particles * TSP SO ₂ (ppb) NO ₂ (ppb) O ₃ (ppb)	Average annual (range) Average annual (range) Average annual (range) Average annual (range) Average annual (range)	11–30 34–90 2–24 6–22 20–28
Schwartz and Dockery 1992	SO ₂ (ppb) TSP *	Daily average Daily average	28 111
Abbey et al. 1991	O ₃ (ppm) TSP	1 hour maximum 1 hour maximum	10 100
Buffler et al. 1988	TSP *	Geometric mean (range)	59–84
Mackenbach et al. 1993	SO ₂	Average daily	18 (maximum 398)
Kurst et al. 1993	SO ₂ *	Average daily	22
Katsouyanni et al. 1993	Smoke O ₃	Average daily (range) Daily maximum (range)	50–250 75–250
Bobak and Leon 1992	SO ₂ * NO _x TSP ₁₀ *	Annual geometric mean Annual geometric mean Annual geometric mean	32 35 69
Knox 1981	TSP *	Average daily (range)	10–50
HOSPITAL ADMISSIONS AND EMERGENCY ROOM PATIENTS			
Burnett et al. 1994	Sulphates * O ₃ (ppb)	Average daily (range) 1 hour maximum (range)	3.1–6.4 32–70
Thurston et al. 1994	TSP PM ₁₀ O ₃ *(ppb)	Summer average (range) Maximum (range) Summer average (range) Maximum (range) Maximum (range)	62–87 121–180 32–47 68–116 86–159
Schwartz et al. 1993	PM ₁₀ * Ozone (ppb)	Daily average Daily average	45 25
Pope 1991	PM ₁₀ *	Annual average (range) Winter average (range)	<40–55 <60–95

Table 4 (cont.): Air quality investigated for health effects in some overseas studies

Source	Air Quality		
	Aspect	Value ($\mu\text{g}/\text{m}^3$ or as shown)	
Walters et al. 1994	Smoke *	Average daily	13
		Daily maximum	188
	SO ₂ *	Average daily	39
		Daily maximum	126
Montealegre et al. 1993	TSP ₁₀	Annual (range)	50–90
Rossi et al. 1993	SO ₂ *	Average daily (range)	10 (0–56)
		Daily maximum (range)	31 (1–241)
	NO ₂ *	Average daily (range)	13 (0–69)
		Daily maximum (range)	39 (0–154)
	TSP*	Average daily (range)	18 (0–90)
		Daily maximum (range)	39 (0–202)
H ₂ S*	Average daily (range)	3 (0–34)	
	Daily maximum (range)	15 (0–172)	
Sunyer et al. 1993	SO ₂ *	Average daily (range)	0–61
	Smoke*	Average daily (range)	0–77
Ponka 1991	SO ₂ *	Average daily	19
	NO ₂ *	Average daily	39
	CO*	Average daily	1
	O ₃ *	Average daily	22
	TSP*	Average daily	76
Sunyet et al. 1991	SO ₂ *	Average daily (range)	57 (17–160)
		Daily maximum (range)	142 (14–720)
	Smoke*	Average daily (range)	73 (39–310)
		Daily maximum (range)	124 (6–536)
	CO*	Average daily (range)	5.4 (0.4–42)
	O ₃ *	Average daily (range)	63 (2–253)
RESPIRATORY SYMPTOMS/LUNG FUNCTION			
Tashkin et al. 1994	SO ₂ (ppm)*	1 hour maximum (range)	0.01–0.04
	Oxidants (ppm)*	1 hour maximum (range)	0.04–0.12
	NO ₂ (ppm)*	1 hour maximum (range)	0.03–0.11
	SO ₄ *	Daily average (range)	4–11
	TSP*	Annual geometric mean (range)	85–133
Pope and Kanner 1993	PM ₁₀ *	Daily average	55
		Maximum	181
Koenig et al. 1992	PM _{2.5} *	Weekly average (range)	5–45

Table 4 (cont.): Air quality investigated for health effects in some overseas studies

Source	Air Quality		
	Aspect	Value ($\mu\text{g}/\text{m}^3$ or as shown)	
Pope et al. 1991	PM ₁₀ *	Daily average (range) Maximum	29–134 200
Higgins et al. 1990	PM ₁₀ O ₃ * (ppb) NO ₂ (ppb) SO ₂ (ppb)	Daily average 1 hour average 1 hour maximum 1 hour average 1 hour maximum 1 hour average 1 hour maximum	59 87 245 40 11 4 8
Dockery et al. 1989	TSP* PM ₁₅ * PM _{2.5} * SO ₂ * O ₃ * NO ₂ *	Annual mean (range) Annual mean (range) Annual mean (range) Annual mean (range) Annual mean (range) Annual mean (range)	34–80 20–59 12–37 4–28 22–38 7–23
Spektor et al. 1988	O ₃ * (ppb)	1 hour maximum (range)	40–120
Ware et al. 1986	TSP* SO ₂	Annual average (range) Annual average (range)	32–163 3–184
Roemer et al. 1993	PM ₁₀ SO ₂	Average daily (range) Average daily (range)	0–100 0–50
Corbo et al. 1993	SO ₂ * TSP*	Median daily (range) Median daily (range) Median daily (range) Median daily (range) Median daily (range)	39–97 (urban) 25–50 (industrial) 0–5 (rural) 86–248 (urban) 15–66 (industrial)
Hoek et al. 1993	O ₃ *	1hour maximum (range)	50–250
Tao et al. 1992	SO ₂	Average daily (range)	100–162
Von Mutius et al. 1992	SO ₂ TSP	Average monthly (range) Average monthly (range)	0–350 50–300
Zwi et al. 1990	Smoke* SO ₂ *	Winter average (range) Winter average (range)	0–85 0–43

Table 4 (cont.): Air quality investigated for health effects in some overseas studies

Source	Air Quality		
	Aspect	Value ($\mu\text{g}/\text{m}^3$ or as shown)	
Jaakkola et al. 1991	SO ₂ *	Average daily (range)	9–23
		Daily maximum (range)	37–83
	TSP*	Average daily (range)	20–33
		Daily maximum (range)	73–198
	NO _x *	Average daily (range)	15
		Daily maximum (range)	48
H ₂ S*	Average daily (range)	2	
	Daily maximum (range)	42	
Jaakkola et al. 1990	SO ₂ *	Average daily	10
Goren et al. 1991	SO ₂ *	Average daily (range)	3–22
	NO _x (ppm)*	Average daily (range)	3–26
	CO (ppm)*	Average daily (range)	20–640

* Association found between air quality and health. The measures used to describe the quality of the air to which a community was exposed were not always the same measures used in the analysis of the relationship between air quality and health.

5 Methodological approaches to the quantification of health effects of air quality

Appropriate and carefully conducted epidemiological studies are needed to isolate and quantify any effect of differences in outdoor air quality on the health of the Australian population. Epidemiological studies are the only studies which will enable the importance of differences in real world air quality on the health of the population to be assessed. It may be difficult to extrapolate to the general population from studies in which volunteers are deliberately exposed to pollutants or animal studies. There may also be ethical problems associated with the former. Experiments involving exposure of volunteers to pollutants have been the focus of at least two published reviews (Abramson and Voigt 1991, Marks 1994).

Correlational studies comprise most of the studies of outdoor air quality and health in Australia up to June 1995. These studies have shown a relationship between outdoor air quality and mortality, and hospital admissions and attendances at emergency departments for all-causes and respiratory disease in children and adults. Unfortunately it is not easy to separate the effect of air quality from other factors such as socio-economic status or meteorological conditions which might go hand in hand with exposure to air of a particular quality.

Cross-sectional surveys are the next most common studies of outdoor air quality and health in Australia. These studies have shown a relationship between outdoor air quality and respiratory symptoms such as current wheeze. Since respiratory symptoms and the quality of the air to which subjects are exposed are assessed at the same point in time, it is sometimes difficult to know whether exposure to air of a particular quality did precede the onset of symptoms or not. It is also necessary to separate the effect of air quality from other factors which might differ between subjects exposed to air of a different quality and which might also impact on health. Such confounding factors in studies of outdoor air quality include socio-economic status, meteorological conditions, pollen count, allergy, indoor air quality, and exposure to active or passive smoking.

There have been few cohort studies of the impact of outdoor air quality on health in Australia. In cohort studies subjects are classified on the basis of being exposed or not exposed to air of a particular quality and then followed for a period of time to determine how often

an effect on health of interest developed in each group. Cohort studies have the advantage over cross-sectional surveys because they enable the investigator to collect reliable information on factors which might confound an association between air quality and health. The investigator can also be sure that the health effect did follow the exposure to air of a particular quality. Cohort studies are best suited to investigate health effects of air quality which are common and which will accrue in sufficiently large numbers over a reasonably short period of follow-up. Loss of lung function or an acceleration of the rate at which lung function is lost with time is an objective measure of the impact of air quality on health. If a relationship between air quality in Australia and loss or accelerated loss of lung function were to be established this would allow the quantification of the adverse effects of air quality. Subjects enrolled into such a cohort study could be those believed to be particularly susceptible to a difference in air quality such as asthmatics or patients with other chronic air flow limitations.

Proof that any dose-response relationship between air quality and an adverse health effect is really due to air quality will depend upon demonstrating that deliberately changing the quality of the air leads to a reduction in adverse health effects.

6 Limitations of current data collections in quantifying associations between air quality and health in Australia

Epidemiological studies of outdoor air quality and health conducted in this country up to June 1995 (Table 1) are of limited value in quantifying associations between outdoor air quality and health in Australia. Specific limitations include a lack of consensus on:

- health effects or aspects of air quality to be studied
- confounding factors
- measurement of health effects, exposure or confounding factors.

There was an attempt to reach a consensus about what constitutes an adverse health effect of air quality in the mid 1980s (American Thoracic Society 1985). However there needs to be a consensus among investigators on which health effects should be studied to promote comparability between studies. The health effects investigated to June 1995 range from all-cause and disease specific mortality, all-cause and respiratory disease specific admissions to hospital, attendances at emergency departments for asthma, respiratory symptoms, use of medication, lung function and bronchial reactivity. Consequently we have data on whether there is or is not an association between outdoor air quality and mortality and hospital admissions and attendances at emergency departments in both adults and children. However, data were available on the relationship between outdoor air quality and respiratory symptoms, use of medication and lung function in children only.

There is no consensus or comparability between studies on the aspects of outdoor air quality to be studied. The aspects of outdoor air quality investigated so far range from the concentration of sulphur dioxide alone through sulphur dioxide and oxides of nitrogen to multiple aspects such as sulphur dioxide, oxides of nitrogen, ozone, carbon monoxide and particles. There is also no consensus, or comparability between studies, on how a particular aspect of outdoor air quality is to be measured. For example, the measurement of sulphur dioxide used in studies varies from 1 hour to 24 hour averages, through maximum daily concentrations to number of hours or days above a 'critical value' which itself varies.

There is no consensus or comparability between studies, too, on the confounding variables which need to be considered in epidemiological studies of air quality and health. One correlational study of outdoor air quality and mortality controlled for socio-economic status only. Another correlational study of outdoor air quality and hospital admissions controlled for neither socio-economic status nor smoking, whilst another correlational study of outdoor air quality and attendances at a hospital emergency department controlled for season and time of year only but not meteorological variables or pollen count. Cross-sectional studies of respiratory symptoms, lung function and bronchial reactivity among children in different towns controlled for allergy, passive smoking, and fathers' occupation but not meteorological factors, pollen count, or type of heating or cooking fuel. The studies also varied in the way a particular confounding factor was measured. The Ross Index of Social Disadvantage was used as a measure of socio-economic status in the correlational study of outdoor air quality and mortality but father's occupation was used in other cross-sectional studies of respiratory symptoms and lung function in children.

7 Gaps in knowledge base of the impacts of air quality on health

Although there had been a number of epidemiological studies of outdoor air quality and health in Australia by June 1995, there were a number of major gaps in our knowledge base about the impact of outdoor air quality on health. These gaps include:

- impact of multiple ‘pollutants’ on respiratory symptoms and lung function
- interaction between ‘pollutant’ and meteorological effects
- impact of chronic exposure to low level ‘pollutants’
- safe background level for diseased and healthy populations
- cost-benefit of improving air quality.

Information exists on the relationship between multiple pollutants and mortality, hospital admissions and attendances at emergency departments from correlational studies. However, there is little information on associations between multiple ‘pollutants’ and respiratory symptoms and lung function in children or adults.

There is some intriguing overseas evidence suggesting interactions between gaseous pollutants and allergens from epidemiological studies (Corbo et al. 1993) and experimental studies (Molfino et al. 1991, Tunnicliffe et al. 1994, Devalia et al. 1994). However, the public health implications of these findings are not yet clear (Anto and Sunyer 1995).

There is little recent information on the impact of multiple ‘pollutants’ on health under various topographical and meteorological conditions.

There is also little information on the health impact of exposure to low levels of ‘pollutants’ over a long period of time.

There is little information, too, on the level to which pollutants need to be reduced to provide a completely safe background level for diseased as well as healthy populations. Only one epidemiological study undertaken by June 1995 had investigated the effect of outdoor air quality on health in susceptible individuals, namely asthmatic children. There are other sub-groups of the

population on which there is no information, such as adults with COAD or the elderly.

Epidemiological studies in Australia had found an association between outdoor air quality and mortality, hospital admissions and attendances at emergency departments, and, in children, with respiratory symptoms. Assuming that these are causal associations, there is some but not a lot of information on the costs and benefits of improving outdoor air quality in Australia.

8 Options for the development of suitable indicators of the impacts of air quality on human health in Australia

Particulates, sulphur dioxide, nitrogen dioxide, ozone and carbon monoxide are used as indicators of the general quality of outside air overseas. Section 3 of this paper has described how a number of overseas studies have demonstrated a dose-response relationship between levels of several of these pollutants in outside air (most commonly some measure of total suspended particulates, sulphur dioxide or ozone levels) and mortality, hospital admissions or emergency department attendances or respiratory symptoms in healthy or diseased populations. Some studies have shown that the relationship between the level of ozone, sulphur dioxide or total suspended particulates and health extends over a wide range.

Outdoor air quality is different in Australia. Caution is therefore required in adopting overseas indicators of the impacts of air quality on health in Australia.

Australian guidelines for total suspended particles (TSP) is an annual mean concentration of 90 µg/m³. Section 4 described how some overseas studies had found an association between TSP at levels below the Australian guideline and lung cancer mortality, frequency of cough and bronchitis in children and loss of lung function in adults.

Section 4 also described how some overseas studies had found an association between sulphur dioxide concentrations below those found in the LaTrobe Valley, and hospital admissions for respiratory disease in general or asthma in particular, emergency department admissions for COAD or asthma, symptoms and loss of lung function.

Also described in Section 4 were studies which found an association between ozone levels below those in the LaTrobe Valley and respiratory morbidity.

Section 4 cautions against extrapolating from selected overseas data. However:

- TSP levels in Australia may be an indicator of the impact of air quality on lung cancer
- sulphur dioxide levels may be a useful indicator of the impact of air quality on hospital admissions

- TSP, sulphur dioxide and ozone levels may be useful indicators of the impact of air quality on respiratory symptoms
- TSP and sulphur dioxide levels may be useful indicators of the impact of air quality on lung function.

There is no consensus that lung cancer, hospital admissions, respiratory symptoms and lung function are the health effects which need to be included in studies of the impact of air quality, but it seems reasonable to assume that they would be among chosen health outcomes.

Conducting epidemiological studies of the impact of TSP, sulphur dioxide and ozone levels on lung function, respiratory symptoms, hospital admissions or lung cancer in Australia (taking into account the comments already made in Section 5) would appear to be an important option for the development of suitable indicators of the impact of air quality on human health in Australia.

9 Health related cost-benefits of improving air quality in Australia

The quality of outdoor air has been changing in Australia over the years (Streeton 1990). Section 2 described how the correlational studies undertaken in Australia by June 1995 had found a positive association between mortality from respiratory and other diseases and the estimated concentration of several ‘pollutants’; between attendances of children with asthma at a hospital emergency department and the Airborne Particulate Index; and between all-cause and respiratory disease admissions to hospital and distance of place of residence from an industrial source of unspecified pollutants. Cross-sectional studies found a greater odds of reporting current wheeze among children resident in a town near power stations.

Overseas data on the impact of air quality on health is more extensive than that in Australia (Section 3). Air quality is different in Australia and has been assessed differently and under different conditions to overseas (Section 4). Caution is therefore required in extrapolating to Australia from overseas data on the health impact of air quality. However, overseas studies do suggest that exposure to air with TSP concentrations below the Australian goal for TSP concentrations, may be associated with respiratory symptoms. Overseas studies also suggest that exposure to sulphur dioxide at concentrations found in the LaTrobe Valley may be associated with hospital admissions for asthma and respiratory disease, and probably with respiratory symptoms. Overseas studies suggest there may be an association, too, between exposure to ozone at concentrations found in the LaTrobe Valley and respiratory morbidity.

Obtaining data on the health effects of air quality is the first step in assessing the health benefits of changing air quality in Australia. Epidemiological studies are needed in Australia to confirm the health effects found in overseas studies of exposure to TSP, sulphur dioxide and ozone at levels which occur in Australia. This is because great care is needed in extrapolating from selected overseas studies to Australia. Overseas studies suggest that there may be a dose-response relationship between daily maximum sulphur dioxide concentrations and hospital admissions for asthma and respiratory disease. It is important to establish whether there is a dose-response relationship between exposure to TSP and respiratory symptoms; sulphur dioxide and hospital admissions and respiratory symptoms; and ozone and respiratory morbidity at the levels of these ‘pollutants’ which occur in Australia.

Early studies in Europe (OECD 1981) of the costs of the health effects of ‘pollutants’ suffered from the following shortcomings:

- having information on some health effects such as mortality but not use of health services, disablement or absence from school and work
- information on long-term but not short-term concentrations of ‘pollutants’
- no information on whether there was a dose-response effect between the health effect and the exposure to sulphur dioxide or whether there was a threshold level below which there is no health effect and if so whether there was a dose-response effect above the threshold level
- no information on health effects at low levels of exposure
- no information on whether the effects of several co-existing pollutants are mutually exclusive or synergistic
- no information on how the effects of ‘pollutants’ may be modified by meteorological factors or characteristics of the exposed pollution such as age, social background, occupation, medical conditions and leisure pursuits
- little information on the extent to which the results from animal or clinical studies can be extrapolated to whole populations. Australia appears to be in this situation.

Despite these limitations, attempts have been made in Europe to quantify the health effects of ‘pollutants’ in terms of mortality and the cost of morbidity, out-patient services and hospitalisations assuming a linear dose-response between the health effect and exposure to a ‘pollutant’. In Australia, attempts have been made to quantify the effect of ozone on health in terms of the cost of asthma treatment and the savings from a reduction in ozone levels (Guest et al. 1996). Further work on the costs and benefits of improving air quality in Australia is needed.

10 Risk communication strategies

A major element in managing the risks to health from air quality is communication with the public about those risks to health.

Growing concern that risk communication was becoming a major problem in the United States led to the chartering of a National Research Council Committee to examine possibilities for improving social and personal decision making by improving risk communication. The report of that Committee discusses the basis for successful risk communication (Committee on Risk Communication 1989).

Correlational studies undertaken in Australia found a positive association between mortality from respiratory and other diseases and the estimated concentration of several 'pollutants'; between attendances of children with asthma at a hospital emergency department and the airborne particulate index; and between all-cause and respiratory disease admissions to hospital and distance of place of residence from an industrial source of unspecified pollutants. Moreover, overseas studies suggest that there may be associations between other health effects and pollutants at the levels at which pollutants occur in Australia.

Australia has not developed strategies for communicating with the public about those possible risks to their health from air quality. The Report of the National Research Council's Committee on Risk Communication (1989) contains very good advice on how such a risk communication program should be developed.

In developing strategies for communicating the risks to health from the quality of Australia's air to the general public, the following points need to be borne in mind (Committee on Risk Communication 1989).

- Risk messages are difficult to formulate in ways that are accurate, clear and not misleading. Placing the risk to health from air quality in juxtaposition to a more familiar risk may help Australians understand the magnitude of the risk to health from air quality. However, this may be misleading if it does not specify the respective levels of exposure, focuses on mortality and leaves out relevant non-lethal consequences of air quality or uses language unfamiliar to many Australians. The involuntary nature of the risk should also be kept in mind. The risks to health from air quality are likely to be controversial. There is enough uncertainty in the

knowledge base of the health effects of air quality to allow different experts to draw contradictory conclusions.

- A message about the risks to health from air quality that is precise and accurate should not be so complex that the general public will not understand it. On the other hand, a message that the general public can understand must not be so selective as to be perceived by Australians as being inaccurate, incomplete or manipulative.
- Communication about the risk to health from Australia's air quality must not be a one-way process between experts and the general public but an interactive process between experts and the public.
- The success of communication with the general public must be judged by the extent to which it raises the level of understanding of relevant issues about air quality and health and satisfies the public that they are adequately informed and not by the extent to which the general public accepts the arguments of the communicators about the health impact of air quality.
- Communicating with the general public about the risks to health of air quality may increase their desire to participate in or otherwise influence decisions about the control of those risks and the extent to which this is possible should be thought through in advance.
- The health effects of air quality addressed in any risk message should be important to the general public.
- The information about the health effects of air quality should not be slanted, distorted or misrepresented.
- Messages about the health effects of air quality should emphasise information about any practical actions which the general public could take. Skov et al. (1991) have described how people in Europe modify their behaviour in response to air pollution notifications whilst Ayres (1994) describes the action which asthmatics could take.
- Messages about the health effects of air quality should not minimise the gaps which exist in knowledge about the health effects of air quality in Australia.

11 Other indicators of air quality: benzene

This paper has focused on those substances which are widespread in the urban environment and which are used as an indicator of the general quality of the air. Source-specific wastes fall within a second class of indicators. Wastes which should be subject to particularly stringent emission controls because of recognised carcinogenic, mutagenic, teratogenic, highly toxic or highly persistent nature comprise a third class of indicators. One of the class three indicators is benzene. The Atmosphere Reference Group for the 1996 State of the Environment report had asked that brief comments about the health effects of benzene in the air in Australia be included in this report because of public interest.

Cigarettes and the combustion of petroleum fuels by motor vehicle engines are the major sources of benzene in the air. Animal studies have shown that benzene exposure can lead to leukaemia through damage to genetic material in cells. The only epidemiological studies of the health effects of benzene in Australia, as overseas, had been of people exposed to benzene in the workplace. By June 1995, there appeared to have been no studies of the effects of benzene in the outdoor air on the health of the general population in Australia.

Consideration needs to be given to whether an epidemiological study of the impact of benzene in the air on the health of the Australian population is worthwhile. If so, then agreement needs to be reached on whether benzene in the outdoor environment should be studied and whether the study should be mounted in urban or rural areas or both. Agreement also needs to be reached over how the concentration of benzene in the air is to be measured, whether the study should focus on adults or children or both, and the particular health effects to be examined. A decision will need to be made on whether the study is to be a correlational, case-control or cohort study.

Combustion of petroleum fuels by vehicle engines is said to be the major source of benzene in the outdoor environment, whilst cigarette smoke is said to be the major source of benzene in the indoor environment. Cigarette smoke, certain foods and drinking water are said to be the major source of benzene in unpolluted rural areas. Automatic gas chromatography has meant that it is now practicable to obtain information on benzene concentrations in the air from multiple sites.

Non-lymphocytic leukaemia is the health effect which has been found in workers in the synthetic rubber and petroleum industries after long-term exposure to 'high' levels of benzene. The low incidence of leukaemia in the general population will influence the choice of study design and the size of the population sample to be studied (Department of the Environment 1994; Canadian Environmental Protection Act 1993).

The expert panel on air quality standards established by the Department of the Environment in the United Kingdom were unable to define an absolutely safe exposure level for benzene (Department of the Environment 1994). For practical purposes the panel believed that an annual average concentration of 5 ppb could be proposed, based on the data from cohort studies of workers exposed to benzene. At this level the risk of non-lymphocytic leukaemia even in young children is so small that it is unlikely to be detected by any practicable method.

12 Conclusions

Correlational studies of air quality and health in Australia conducted in the late 1980s and 1990s by June 1995 found a positive association between:

- mortality from respiratory and other diseases and the estimated concentration of several 'pollutants'
- attendances of children with asthma at a hospital emergency department and the Airborne Particulate Index
- all-cause and respiratory disease admissions to hospital and distance and place of residence from an industrial source of unspecified pollutants.

Cross-sectional studies conducted in Australia found a greater odds of reporting current wheeze among children resident in a town near power stations. It is difficult to be certain that the associations found between these various indicators of air quality and health represent cause-and-effect because of the failure to exclude non-causal explanations for the associations and/or features of the associations themselves.

Case-control and cohort studies of air quality and health in Australia found no association with the aspects studied.

Overseas correlational studies of air quality and health have found an association between

- air quality and all-cause mortality at high levels of sulphur dioxide
- sulphur dioxide concentrations and lung cancer mortality (at least in men)
- total particulates and specific circulatory and respiratory diseases
- air quality and neonatal and post-neonatal mortality.

These studies have commonly found associations in both healthy and symptomatic children between respiratory symptoms and particulate matter and between emergency room attendances and particulates, sulphur dioxide and ozone.

Overseas cross-sectional studies commonly found associations in school children between respiratory symptoms and particulates or gases and between lung function and ozone.

Cohort studies conducted overseas have found associations between:

- air quality and mortality from lung cancer and cardio-pulmonary disease
- particulates and malignant neoplasms at least in women
- COAD and ozone in men
- asthma and smoke
- some respiratory symptoms and particulates and ozone
- lung function and particulates in asthmatic children, or adults or smokers with air flow limitation.

Australian data on air quality and health compare poorly with overseas data as a result of:

- the lack of cohort studies
- the lack of information on the health effects of multiple pollutants, including particles and ozone
- the lack of information about the effects of air quality on cancer incidence, hospital admissions or emergency department attendances for specific diseases other than respiratory diseases and on respiratory symptoms or lung function in adults, particularly the elderly.

Air quality is different in Australia and has been assessed differently and under different conditions to overseas. Caution is therefore required in extrapolating to Australia from overseas data on the health impact of air quality. Overseas studies suggest that exposure to air with TSP concentrations below the Australian goal for TSP concentrations may be associated with respiratory symptoms but not impaired lung function and possibly with mortality. Overseas studies also suggest that exposure to sulphur dioxide at concentrations found in the LaTrobe Valley may be associated with hospital admissions for asthma and respiratory disease and possibly with respiratory symptoms. Overseas studies suggest there may be an association, too, between exposure to ozone at concentrations found in Victoria and respiratory morbidity.

Caution is required in extrapolating from selected overseas studies to Australia. Appropriate and carefully conducted epidemiological studies are needed in Australia to isolate and quantify any current effect of geographical differences in air quality on the health of the Australian population.

Prior to undertaking further epidemiological studies of air quality and health in Australia, there needs to be a consensus on the particular health effects and on the aspects of air quality to be studied. Consensus is also

required on the confounding factors to be taken account of in these studies including how these are to be measured.

There was an attempt to reach a consensus about what constitutes an adverse health effect of air quality in the mid 1980s (American Thoracic Society 1985). A consensus on how some of these effects are to be measured has also emerged during the late 1980s and 1990s, for example in the case of asthma (Toelle et al. 1992). There are also validated instruments for measuring many relevant confounders, for example, atopy, cigarette smoking and socio-economic status. A consensus conference would be valuable to promote comparability among Australian investigators.

Major gaps in the current knowledge base of the impact of air quality on health in Australia include the impact of multiple 'pollutants'; the interaction between 'pollutant' and meteorological effects; the impact of chronic exposure to low levels of 'pollutants'; what is a safe background level for diseased and healthy populations and the costs and benefits of improving air quality in Australia.

13 Suggestions for future work

1. Further epidemiological studies of the impact of air quality on health should be conducted in Australia. These studies should investigate the impact of multiple 'pollutants' on mortality, cancer incidence, symptoms, lung function and bronchial reactivity as well as attendances at general practitioners' offices and emergency departments and hospital admissions in the same population. Exposure to 'pollutants' should be measured at the level of the home, school or individual. The populations studied should include persons with asthma or other chronic obstructive airways disease, the elderly and children as well as healthy adults. The sample should be of sufficient size to exclude chance results. The collection of data should be free of bias and account should be taken of confounding factors. Cohort studies and the impact of long-term exposure to low levels of 'pollutants' should be given priority.
2. An attempt should be made to obtain a consensus among experts in Australia, and comparability between studies, on the aspects of air quality to be studied; the health effects to be investigated; and the protocols to be used for measuring exposure to 'pollutants', health effects and confounders.
3. Loss of lung function over time in adults and children, including those with chronic obstructive airways disease, should be considered as a model for studying the magnitude of the impact of air quality on health, although such data may take some years to collect.
4. Further studies should be undertaken in Australia into the costs and benefits of reducing the level of those 'pollutants' for which a dose-response relationship between air quality and health has been demonstrated over a wide range of levels.
5. A community education program should be undertaken about the risks of adverse health effects associated with air quality. The design, development and distribution of educational material should be an interactive process between 'experts' and the community. The material should explain the nature of the risk to health from air quality; the nature of the benefits that might be affected if the risks were reduced; the available alternatives; and uncertainties in knowledge about risks and benefits. Strategies which the community and respiratory disease patients can use to avoid exposure to high levels of air pollution should also be included.
6. Any future epidemiological studies, including pilot studies, should be multicentre studies, involving at least Melbourne and Sydney, overseen in their design and execution and specially commissioned by a steering group. The steering group should include epidemiologists, statisticians, clinicians, and environmental scientists. The secretariat and funding could be provided by an appropriate Commonwealth Government department.

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Glossary of technical terms

Visibility reducing particulates: an aspect of air quality based on aesthetic considerations and determined by reference to the light scattering properties of the air environment at relative humidities of less than 70%.

Airborne Particulate Index: an indirect measurement of fine particulate matter in the atmosphere which is correlated with PM_{2.5}.

Abbreviations used in this paper

CO	Carbon monoxide
COAD	Chronic Obstructive Airways Disease
FEV	Forced Expiratory Volume
FEV ₁	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
O ₃	Ozone
PEF	Peak Expiratory Flow
PEFR	Peak Expiratory Flow Rate
ppm	Parts per million
ppb	Parts per billion
SO ₂	Sulphur dioxide
PM ₁₀	Total Particulates less than 10 ((m diameter
PM _{2.5}	Total Particulates less than 2.5 ((m diameter
TSP	Total Suspended Particles