NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

National Environment Protection (Ambient Air Quality) Measure

Preliminary Work on Ozone for the Review of the Ambient Air Quality NEPM

Issues Paper

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

PURPOSE OF THIS ISSUES PAPER

A full review of the National Environment Protection (Ambient Air Quality) Measure (the Ambient Air Quality NEPM) is due to commence this year. The full range of issues related to the air quality standards for ozone will be considered in that review, including the maximum levels that should be set for ozone in outdoor air.

The Issues Paper has been prepared as part of preliminary work being carried out on a sub-set of issues for ozone, in advance of the full review. The paper:

- reviews recent health information;
- analyses recent Australian monitoring results;
- reviews overseas trends in standard setting; and
- considers the most appropriate averaging period(s) for ozone standards.

The release of this paper gives organizations and individuals the opportunity to be informed about the review of the Ambient Air Quality NEPM, to engage in the review of the ozone standards at an early stage, and to provide comment that can be taken into account as the review progresses.

You are invited to provide comment on a list of specific topics provided in Section 6.10, identify other issues that you consider should be taken into account and provide any information or data that could assist with the review.

Chapter 7 provides information on how to make a submission.

1 INTRODUCTION

1.1 THE AMBIENT AIR QUALITY NEPM

Since 1998, Australia has adopted a broad national framework for air quality management in which the Australian, state and territory governments act jointly to establish benchmarks for ambient air pollutants. These benchmarks are included in National Environment Protection Measures (NEPMs) under the auspices of the National Environment Protection Council (NEPC).

The National Environment Protection Council is a statutory body with law-making powers. It is established under the *National Environment Protection Council Act 1994* (Commonwealth) and corresponding legislation in the other Australian jurisdictions. The members of NEPC are ministers in the Australian, state and territory governments, not necessarily ministers for the environment.

The objectives of National Environment Protection Measures are to ensure that:

- the people of Australia enjoy the benefit of equivalent protection from air, water and soil pollution and from noise, wherever they live and
- decisions by businesses are not distorted and markets are not fragmented by variations between jurisdictions in relation to the adoption or implementation of major environment protection measures.

In addition to making National Environment Protection Measures, the Council also assesses, and reports on, the implementation and effectiveness of the NEPMs in participating jurisdictions.

State and territory governments take primary responsibility for monitoring air quality and applying regulatory and other measures to ensure agreed benchmarks are met. The Australian government supports the objectives of the National Environment Protection Council and the related activities of other jurisdictions, in particular where national coordination is required.

In 1998, the Council made a National Environment Protection Measure for Ambient Air Quality (the Ambient Air Quality NEPM) that includes standards for six major air pollutants - particles (as PM_{10}), photochemical oxidants (as ozone), sulfur dioxide, nitrogen dioxide, carbon monoxide and lead. Each standard specifies the maximum acceptable concentration of the air pollutant and the period of time over which the concentration is averaged. These standards apply in all states and territories and over land controlled by the Commonwealth. In the case of ozone, the goal is to maintain the levels of ozone below the concentrations set out below, with the maximum concentration being exceeded on no more than one day a year by the year 2008.

Standards and Goal for Photochemical Oxidants (as Ozone)

Averaging period	Maximum concentration	Goal within 10 years (by 2008) maximum allowable exceedances
1 hour	0.10ppm	1 day a year
4 hours	0.08ppm	1 day a year

The Ambient Air Quality NEPM includes a protocol for monitoring and reporting the levels of the six air pollutants. It defines the locations for monitoring stations used to measure the concentrations of the six air pollutants for the purposes of reporting under the NEPM. These locations must provide a representative measure of the air quality likely to be experienced by the general population in a region of 25, 000 people or more.

1.2 PRELIMINARY WORK ON OZONE

During the development of the Ambient Air Quality NEPM, the National Environment Protection Council considered two sets of recommendations for the ozone standards based on what was known about the health effects of ozone. The technical review panel recommended a one hour standard of 0.08ppm and an eight hour standard of 0.06ppm. The health consultant (the Streeton Review) recommended a one hour standard of 0.09ppm and an eight hour standard of 0.05ppm. However, the Council did not adopt these levels on the basis that they were not considered achievable in the foreseeable future. Instead, the Council adopted the one hour and four hour ozone guidelines that had previously been established by the National Health and Medical Research Council, 0.10ppm and 0.08ppm respectively. In the NEPM, the one allowed exceedance day per year caters for rare meteorological events.[1]

When the Council made the Ambient Air Quality NEPM, it agreed to a program of future actions, including a staged review of some of the standards. One of these actions was a review, starting in 2003, of the practicability of lowering the one hour average standard for ozone from 0.10ppm to 0.08ppm within major urban airsheds in the longer term, ie longer than 10 years.

In June 2003, the Commonwealth and New South Wales commissioned the Woolcock Institute to undertake a desktop analysis to establish whether the health evidence for a tighter one hour ozone standard had changed since 1997/98. The analysis included an examination of any developments in health research that may be of significance to the ozone standards as a whole.

The 1997 Streeton Review noted that health effects were observed with both one hour and eight hour averages and recommended that the NEPM ozone standards should be set for both one hour and eight hour averages. The 2003 analysis (the Woolcock Report) found that recent epidemiological studies had confirmed and strengthened the evidence for the findings of the Streeton Review. The Woolcock Report indicated that, internationally, ozone standards have been increasingly set for eight hour averaging periods on the basis that extended exposure to ozone is found to be most significant in terms of risk. The report also noted that there was limited evidence in relation to long-term (annual) averages but this was not conclusive at this time.

The Woolcock Report raises broad questions about the ozone standards and goes beyond the issue of tightening the one hour standard. These questions relate to the most appropriate averaging period(s) for Australian conditions. The Council agreed to start preparatory work for the review of the NEPM to examine the question of whether a one hour, four hour or eight hour ozone standard (or some combination of these) is most appropriate for the protection of the health of the Australian population.

[1] National Environment Protection Council, *Revised Impact Statement for the Ambient Air Quality National Environment Protection Measure*, 26 June 1998

The preparatory work involves:

- a workshop in May 2004 to obtain advice from health experts about health information that will need to be taken into account in assessing the appropriateness of the current ozone standard (a summary of the outcomes is found at www.ephc.gov.au)
- an analysis of the profile, time and duration of elevated ozone levels in the major urban airsheds in Australia (www.ephc.gov.au)
- a workshop in August 2004 to obtain advice from ozone monitoring and modelling experts about ozone trends, formation and exposure patterns and background levels in individual jurisdictions
- the development of an Issues Paper (ie this paper), that includes information on health effects and an analysis of existing monitoring data
- placement of the Issues Paper on the Internet for public comment
- workshops to discuss the Issues Paper, if required
- a report back to the National Environment Protection Council before the end of 2005[2].

1.3 TOPICS COVERED IN THE ISSUES PAPER

Chapters 2 and 3 of the Issues Paper provide a summary of information on the health impacts of ozone and overseas experience in setting standards for ozone, focussing particularly on the issues that have emerged since 1997/98[3].

Chapter 4 presents data on levels of ozone monitored in Australian jurisdictions and jurisdictional compliance with the 1998 NEPM standards. It also provides information on the strategies that jurisdictions have in place to reduce ozone levels.

The averaging times in the standards take into account the length of people's exposure to ozone which results in key health impacts. If no one in Australia was ever exposed to ozone for more than one hour at a time, a one hour standard may offer sufficient protection. Australian ozone patterns differ from other countries and may differ from city to city. The paper therefore includes an analysis of the profile of ozone patterns in Australian cities, and the length of time that episodes last.

Chapter 5 looks at the impact of any change to the standards and whether the issues that were identified in 1998 in relation to achievability have changed. It discusses the impact that background levels of ozone and expected trends may have on achievability and which cities are likely to face particular challenges in meeting any new standards.

Chapter 6 of the paper raises a number of key issues on which your views are sought.

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[2] In 2004 the Environment Protection and Heritage Council established a working group to examine approaches to standard setting for ambient air. Along with the preliminary work on ozone, this work will be incorporated in the full review of the Ambient Air Quality NEPM.

[3] A number of major reviews of ozone standards have recently taken place or are currently underway in overseas jurisdictions eg by the United States Environmental Protection Agency USEPA, the California Environmental Protection Agency (Cal EPA) and the World Health Organisation as part of the European Union Clean Air For Europe Programme (WHO 2003, WHO 2004). These reviews have produced extensive analyses of recent studies, particularly in relation to the health effects of ozone. This paper does not attempt to replicate that work. It is suggested that readers who wish to obtain further details refer to these reviews.

2 HEALTH EFFECTS OF OZONE

2.1 INTRODUCTION

The health effects of ozone have been extensively reviewed and well documented (USEPA, 2005; Californian EPA, 2004; WHO, 2003; WHO, 2000; Woolcock 2003; Streeton, 1997; USEPA, 1996). The evidence associating ozone exposure and health effects has been derived from the results of both controlled exposure and epidemiological studies. Since the 1997 Streeton review that was conducted to inform the development of the Ambient Air Quality NEPM, there has been a considerable growth in the amount of data derived from epidemiological studies that show that exposure to ozone is linked to adverse health effects such as increases in premature mortality, hospital admissions for respiratory and cardiovascular disease and exacerbation of asthma. This body of literature has been extensively reviewed by WHO (2003), the Californian EPA (Cal EPA 2004), and USEPA (USEPA 2005) in the reviews of the ozone standards in the US. Very few new controlled exposure studies have been undertaken that have added evidence on dose-response relationships. However, a number of more recent controlled exposure studies have added to the knowledge base on mechanisms of action.

This section provides an overview of the health effects of ozone, identified thresholds and dose response relationships. Appendix 1 provides a more detailed review of the key studies and discussion on mechanisms of action.

Most controlled exposure studies have shown that exposure to ozone for periods between one and eight hours result in decreases in lung function, increases in respiratory symptoms and inflammation of the airways. Most epidemiological studies have found associations between exposure to ozone and increases in daily mortality, hospital admissions and emergency department attendances (mainly for respiratory and cardiovascular disease), exacerbation of asthma, and decreases in lung function. Though these epidemiological studies have been conducted using daily one hour, four hour or eight hour maximum ozone concentrations, relating them to daily changes in the health outcome of interest, the majority of studies have been conducted using daily one hour maximum ozone levels.

Though there is a general consistency in the published controlled exposure and epidemiological studies that ozone exposure is positively associated with adverse health effects, it is important to note that not all studies have reported positive and statistically significant associations. In addition, it is accepted that publication bias exists leading to a bias in journal publication towards reporting of statistically significant and positive associations (WHO, 2004).

A limited number of recent epidemiological studies have indicated that long-term exposure, for a year or longer, to high levels of ozone may be associated with the incidence of asthma (Peters et al, 2004), lung cancer (Beeson et al, 1998) and permanent decrements in lung function growth (Peters et al, 2004). However, the evidence for health effects associated with long-term exposure (months to years) to ozone is limited compared to that for the health effects of short-term exposure (hours).

In recent years statistical approaches to the assessment of the health effects of air pollution have improved and the approaches to controlling for potential confounders have advanced, making the results of more recent studies more reliable. In addition, approaches to air pollution epidemiology have been standardised internationally making comparison of results from different studies easier. In reviewing the health effects of ozone, the results of the more recent international studies and studies conducted in Australia that have used standardised statistical approaches have been the main focus of the review. These studies should also be the key information used in the final determination of the standards. Results from earlier studies may require careful interpretation.

2.1.1 Health experts workshop

A workshop was held with health experts in May 2004 in Sydney as part of the preliminary work for the ozone review. The findings of the workshop have informed the discussion of the health issues in this paper and are available on the EPHC website. In particular, the workshop focussed on which subgroups of the population were susceptible to ozone and how those groups could be protected. It considered the uses and limitations of both epidemiological and controlled exposure studies in assessing real world ozone impacts and the need to consider a variety of ways of reporting on health risks. One such approach is the use of a dose response curve, an example of which is included in Appendix 1.

2.2 SUSCEPTIBILITY

Groups that have been identified as being susceptible to the effects of ozone include:

- people with existing conditions such as asthma, chronic obstructive pulmonary disease (COPD) and other respiratory conditions, and cardiovascular disease
- children
- the elderly, and
- people who may have an inherent genetic susceptibility to ozone.

An additional factor influencing an individual's susceptibility to ozone is the potential for exposure. Those most active individuals spending long periods of time in outdoor environments where ozone levels are highest, for example outdoor workers, children and recreational and professional athletes, can also be considered to be susceptible to the effects of ozone exposure.

The response of people to ozone exposure varies considerably with differences in the order of 10 to 100 fold being observed for the same health outcome (Woolcock, 2003; Cal EPA, 2004).

2.3 MECHANISMS OF ACTION

Ozone is known to cause adverse health effects through a number of mechanisms that include neural and inflammatory responses. A number of inflammatory responses have been observed and include:

- increased respiratory symptoms including chest tightness, breathlessness and difficulty breathing, pain on inspiration
- changes in lung function (including reductions in Forced Expiratory Volume in one second (FEV_1) and Peak Expiratory Flow (PEF) leading to additional symptoms of sputum production and cough
- increased bronchial hyper-responsiveness.

Both the major mechanisms (inflammatory and neural) are involved in ozone responses, though their inter-relationships and relative contribution to the responses observed are not well understood. More information on these mechanisms is available in the Californian EPA (2004) and USEPA (2005) review documents.

Though these responses have been observed to occur in healthy individuals as well as sensitive individuals, the underlying integrity of the airways is important for understanding the potential for response to ozone exposure. For example, individuals with asthma are more likely to have existing inflammation and exposure to ozone may exacerbate that condition.

Studies indicate that a large percentage of acute responses to ozone are reversible with recovery occurring 2-3 hours after exposure. However there is some evidence that for some spirometric responses, recovery may take up to 24 hours, or 48 hours in the case of hyper-responsive individuals (USEPA 2005).

There is evidence from some studies that individuals may adapt to ozone exposures with the response decreasing following repeated exposure (ranging from two to 6.6 hours) over a number of days (Gong et al, 1997b; Folinsbee et al, 1994; Christian et al, 1998). In these studies, no increase in adverse health effects, such as reduction in lung function, was observed following two to four days of repeated exposure. However, studies indicate that this tolerance is lost once exposure to ozone ceases (about approximately 1 week without exposure) (USEPA 2005). This finding has typically been observed in studies of healthy individuals and individuals with mild asthma. However, there is some evidence that for other health outcomes, such as small airway dysfunction and some measures of airway inflammation, symptoms persist or even increase with repeated ozone exposure (Frank et al, 2001; Jorres et al, 2000).

WHO (2000) notes that the response to ozone is more strongly dependent on ozone concentration than duration of exposure. It is further noted that prolonged exposure (eight hours) to low concentrations (0.11ppm) of ozone results in a plateau in pulmonary function response after five to six hours, indicating that these responses do not continue to decline with increasing duration of exposure.

The Californian EPA Review (Cal EPA 2004) indicates that though there is some evidence that ozone sensitises people to the effects of other pollutants (eg., NO_2 and SO_2) the results are not consistent and the effect is usually transient. However, there is stronger evidence that exposure to ozone can sensitise people to the effects of allergens exacerbating the allergenic response.

2.4 CONTROLLED EXPOSURE STUDIES

Much has been learned about dose-response relationships and mechanisms of action from controlled ozone exposure studies in humans and animals. These studies have provided information on responses such as change in lung function and respiratory symptoms following multi-hour exposures, in a range of individuals and for a range of doses. Results from these studies complement the findings of epidemiological studies.

Since 1998 when the NEPM was made, very few additional controlled exposure studies have been reported that include low ozone doses, in the order of 0.08-0.12ppm. These lower dose studies are important in the context of standard setting as they most closely represent the range of maximum exposures most likely experienced in Australia.

The concept of 'effective dose' is critical for understanding a health response to ozone because the acute response is generally proportional to effective dose. Controlled exposure studies have indicated that effective dose for ozone is a function of ozone concentration, ventilation (eg breathing rate), and duration of exposure. Ozone concentration is the most important factor, followed by ventilation and then duration of exposure. Controlled exposure studies have also indicated that the higher the ozone concentration, the more rapid the health response.

2.4.1 One to Three Hour Ozone Exposures

Exposures to 0.12ppm ozone for one to three hours with moderate exercise have been reported to be associated with reductions in lung function for some healthy subjects (Horstman et al, 1990; Folinsbee et al, 1988; McDonnell et al, 1995). Though a number of studies have included exposures less than 0.12ppm, there are no studies that indicate significant changes in the mean group response to ozone concentrations below this level (although some individuals did respond to concentrations lower than 0.12ppm) (Cal EPA, 2004).

Based on the mean response of the study group, these findings indicate a LOAEL for the health outcomes investigated in these studies of 0.12ppm and a NOAEL of 0.10ppm for an exposure to ozone of one to three hours in healthy, moderate to heavy exercising individuals. The LOAEL represents the level at which a statistically significant mean reduction in lung function was observed, hence it could be expected that some individuals in these studies responded to lower levels of ozone.

Controlled exposure studies have consistently reported significant variability in individual response to ozone. For example, Horstman et al (1990) reported individual FEV_1 responses to ozone in normal subjects ranging from +7.0 to -25.9% at 0.08ppm and from +2.8 to -38.9% at 0.12ppm.

2.4.2 Six to Eight Hour Ozone Exposures

Several controlled exposure studies of healthy non-smoking adults investigating exposure durations of six to eight hours for a range of concentrations (including concentrations potentially experienced by the community eg 0.08, 0.10 and 0.12ppm) indicate statistically significant lung function decrements at 0.08ppm ozone (the lowest concentration evaluated) after moderate exertion (Horstman et al, 1990; McDonnell et al, 1991, 1995, Adams, 2002).

The level of 0.08ppm represents a LOAEL for six to eight hour exposure to ozone for the health outcomes examined in these studies in moderately exercising, healthy individuals. As this represents the level at which a mean group response was observed, it could be expected that sensitive individuals would respond to lower levels of ozone. With the exception of Adams (2002), very few published studies have investigated ozone concentrations between 0.04 and 0.08ppm for multi-hour exposures. Adams (2002) included an ozone dose of 0.04ppm and reported no significant pulmonary function or symptoms responses in the study group after 6.6 hours of ozone exposure. On the basis of this study, a NOAEL of 0.04ppm could be assumed.

2.4.3 Summary – Controlled Exposure Studies

A summary of the Lowest Observed Adverse Effect Levels (LOAEL) for various exposure times and various health outcomes are provided in Table 1.

Table 1: Lowest Observed Adverse Effects Levels (LOAELs) derived from controlled exposure studies of healthy exercising adults investigating a range of health outcomes for a range of exposure times

Health Outcome	1-3 hour exposure	4-8 hour exposure
FEV_1	0.12ppm[1]	0.08ppm[4,5]
Airway resistance	0.17ppm[2]	0.08ppm[4]
FVC	0.12ppm[3]	0.08ppm[5]
Increased airway responsiveness	-	0.08ppm[4]
Total symptoms score		0.08ppm[5]

[1] McDonnell et al, 1983; Gong et al, 1986; Horstman et al, 1990,
[2] Seal et al, 1993
[3] McDonnell et al, 1983; Gong et al, 1986
[4] Horstman et al, 1990
[5] Adams 2002

It is important to note that the LOAELs summarised in Table 2.1 relate to the response of healthy individuals. It is likely that the LOAEL for people susceptible to the effects of ozone would be lower. Controlled exposure studies have consistently reported significant variability in individual response to ozone.

2.5 EPIDEMIOLOGICAL STUDIES

Epidemiological studies conducted in various parts of the world have shown links between exposure to ozone and adverse health effects such as premature mortality, emergency department visits and hospitalisations, reductions in lung function and increases in respiratory symptoms. In general the effects are greater during the warmer months than for other times of the year. Like controlled exposure studies, there are some limitations in utilising results from epidemiological studies. These include issues around exposure assessment and controls for covariates and confounders. However, one key advantage of epidemiological studies is that they measure the health response of the broad population, including the most susceptible groups, to the effects of ozone.

The most common averaging period used for ozone in epidemiological studies is daily one hour maxima although eight hour maxima and twenty-four hour averaging periods have been used in some studies. The Australian studies have also included analysis of four-hour maximum ozone concentrations.

2.5.1 International Studies

The findings of studies investigating the association between ozone and increases in daily mortality have been variable although a large number of recent studies provide an increasing body of information that links exposure to ozone (especially in the warm months) with increases in daily mortality for all causes, respiratory and cardiovascular causes. Studies from the US and Europe have found increases in daily mortality during the warm months are associated with daily one hour and eight hour maximum ozone concentrations (Gryparis et al, 2004; Anderson et al, 1996). Other studies from various parts of the world have also found significant positive associations between ozone in the warm season and increases in mortality. These include analyses of Netherlands data (Hoek et al, 2000, Fischer et al, 2003), Australia (EPA Victoria, 2000; Simpson et al, 1997; Morgan et al, 1998a and b; WA Department of Environment, 2003), Montreal Canada (Goldberg and Burnett, 2003) and Vancouver Canada (Vedal et al, 2003). All these studies found stronger associations in the warm season than in the cool season.

From an analysis of the international literature, the Californian EPA estimate that the median effect estimate for all cause mortality for one hour maximum ozone is 3% per 0.04ppm change in one hour ozone (Californian EPA, 2004). Using the data from European cities, WHO (2004) reports an effect estimate of 0.6% per 0.04ppm change in eight hour ozone.

The most consistent short-term health effects observed in epidemiological studies with exposure to ozone (and other pollutants) are increased hospital admissions and emergency department visits for respiratory causes (such as pneumonia, asthma attacks and exacerbation of other respiratory diseases such as COPD) and cardiovascular disease. These effects are observed for people with existing diseases. There is no evidence that healthy individuals are affected by ambient levels of ozone to such an extent that it results in admission to hospital or treatment at an emergency department of a hospital (USEPA, 1996b). Although some studies have reported associations between ozone and increases in hospital admissions for cardiovascular causes, these studies are limited and the results are variable (Cal EPA, 2004b).

The studies examining the association between ozone and emergency department visits for asthma and respiratory disease in children have found consistent significant effects (for example Stieb et al, 1996; Jaffe et al, 2003; Tolbert et al, 2000; Linn et al, 1996; Martins et al, 2002). Several studies have investigated the concentration response function for the association between ozone and emergency department visits. These studies give some insight into the ozone concentrations that may be of concern. Stieb et al (1996) found an increased risk of emergency room visits in adults exposed to one hour ozone concentrations above 0.075ppm (maximum 0.160ppm). Emergency department visits for childhood asthma in summer in Atlanta indicated a significantly elevated risk at one hour ozone concentrations above 0.110ppm (maximum 0.160ppm) (White et al, 1994). Weisel et al (1995) reported significantly significant effects for one hour summertime ozone concentrations and emergency room visits for asthma above 0.060ppm (maximum 0.160ppm). Romieu et al (1996) reported an association between emergency room visits for childhood asthma and one hour ozone concentrations in Mexico City. The strongest associations were observed when consecutive days had ozone concentrations above 0.110ppm. Tolbert et al (2000) reported an association between paediatric emergency room visits for asthma and ozone in Atlanta with elevated risks becoming apparent at eight hour ozone concentrations greater than 0.070ppm. The effects became statistically significant when eight hour concentrations were between 0.100ppm and 0.113ppm.

In addition to broad population studies examining the association between increases in daily mortality, hospital admissions and emergency department visits, a number of studies have also examined the effects of exposure to ozone on people in high exposure groups such as children on summer camps (Kinney et al, 1996), hikers (Korrick et al, 1998) and outdoor workers (Brauer et al, 1996). The summer camp studies have focussed on individuals with asthma and usually involve small groups of subjects. The common health outcomes used in these studies include lung function, respiratory symptoms and asthma medication usage. The value of these types of studies are that they provide information on exposure-response at an individual level and allow for control of individual level factors that may influence the health outcome of interest.

A large body of literature (reviewed by the USEPA, 1996) from past clinical and field studies demonstrates reversible decrements in lung function following ozone exposure. In the past decade only a few studies have provided new insights regarding these effects. In the study by Brauer et al (1996), lung function was measured in a group of 58 berry pickers (10-69 years of age) before and after outdoor summer work shifts in the Fraser Valley in British Columbia. Statistically significant changes in measures of lung function were reported with increases in one hour maximum ozone concentration. A study by Gent et al (2003) investigated daily respiratory symptoms in 271 asthmatic children in New England over a six month period. Significant effects were found with both one hour and eight hour ozone at levels above 0.052ppm at lag 1 (previous day exposure). A variety of symptoms were investigated including chest tightness and shortness of breath in children who used asthma medication. Of particular importance in this study was the finding that significant associations were observed at one hour maximum ozone concentrations of 0.0432ppm and higher and eight hour maximum concentrations of 0.0633ppm and higher.

A number of other panel studies have also found significant associations with ozone and respiratory symptoms mainly in asthmatic children (Desqueyroux et al, 2002a and b; Gielen et al, 1997; Gold et al, 1999; Hiltermann et al, 1998; Romieu et al, 1996; Ross et al, 2002). Three studies conducted in Mexico City found significant associations between symptoms (such as cough, phlegm and difficulty breathing) and daily one hour maximum ozone concentrations (Romieu et al, 1996; Romieu et al, 1997; Gold et al, 1999). A study by Gielen et al (1997) of 61 mostly asthmatic children aged 7-13 years in Amsterdam found only limited evidence of an association between symptoms and ozone exposure. Of 14 symptoms analysed, only upper respiratory symptoms were associated with ozone concentration.

2.5.2 Australian Studies

Studies have been conducted in Australian cities (Melbourne, Sydney, Brisbane and Perth) examining the effects of ozone on daily respiratory and cardiovascular mortality and hospital admissions (WA Department of Environment, 2003; EPA Victoria, 2000 and 2001; Petroechevsky et al, 2001; Morgan et al, 1998a and b; Simpson et al, 1997. See tables in Appendix 1 which summarise the results and provide information on ambient levels at which health effects were observed). With the exception of the Perth study, all of these studies used a time series design investigating the relationship between daily one hour, four hour or eight hour maximum ozone concentrations and daily changes in mortality or hospital admissions. The study in Perth was analysed using case crossover techniques.

More recently Australian studies have focussed on multi-city analyses investigating the effects of air pollution on mortality and hospital admissions. The most recent study has investigated the effect of air pollution in Australian cities (including 1-hour, 4-hour and 8-hour maximum ozone) on children's health (Barnett et al., 2005). This study investigated the effect of ozone on hospital admissions for children (0 years, 1-4 years and 5-14 years) for respiratory causes, asthma and pneumonia and acute bronchitis. The results of this study indicate that the effects of ozone are observed only during the warm months (November to April). The only statistically significant association observed in this study for ozone was for 1-hour maximum ozone and hospital admissions for total respiratory causes in the 1-4 year age group during the warm months. No statistically significant results were observed for either 4-hour or 8-hour maximum ozone and any outcomes included in this study.

The results of the studies investigating the association between ozone and increases in daily mortality have been varied. Only the study in Perth found statistically significant associations between ozone (four hour and eight hour maximum) and cardiovascular mortality. No significant associations were found for one-hour maximum ozone concentrations and cardiovascular mortality. No significant associations were found for all cause or respiratory mortality and any ozone averaging period.

A statistically significant association was found for both one hour and eight-hour maximum ozone concentrations and all cause mortality in Brisbane in people of all ages and over 65 years of age (Simpson et al, 1997). In Sydney there was also a significant association between ozone concentrations and all cause mortality in people over 65 years although these associations did not remain significant after controlling for particles and NO_2 (Morgan et al, 1998a).

The Melbourne study reported statistically significant associations between one-hour and four-hour maximum ozone concentrations and daily mortality (all causes and respiratory disease) in the all ages and 65+ age groups. No statistically significant associations were found for eight-hour maximum ozone and any of the mortality categories studied except for all cause mortality in the 65+ age group and the three-day average eight-hour maximum concentrations. Controlling for particles and CO resulted in some of the relationships observed being lost or becoming marginal. The associations for same day and three-day average four hour and one hour maximum ozone were retained indicating that these effects may be independent of other pollutants. Controlling for NO_2 resulted in the loss of all statistically significant associations reflecting the high degree of correlation between ozone and NO_2 (EPA Victoria, 2000). The effects were stronger during the warm season and in the western suburbs of Melbourne where higher ozone levels are experienced.

Significant associations were also reported between one hour, four hour and eight hour maximum ozone concentrations and hospital admissions for asthma and respiratory causes in Melbourne (EPA Victoria, 2001). The associations were stronger during the warm season and for admissions for children aged between 0 and 14 years for asthma. Significant associations were also found for cardiovascular admissions for people over 65 years and asthma admissions in the all ages group. The observed associations were retained when particles and CO were included in the analysis indicating that the effects of ozone are independent of these pollutants. Controlling for NO_2 resulted in some of the associations being lost or becoming marginal.

In Perth significant associations between ozone (one hour maximum) and asthma admissions for children (0-14 years), one hour and four hour maximum ozone and respiratory admissions and four hour maximum ozone and COPD admissions were reported (WA Department of Environment, 2003). No significant effects were found for eight hour ozone and any health outcome investigated. The effects estimates were similar to those found for Melbourne. The Perth study found a 2-4% increase in hospital admissions for cardiovascular disease was associated with a 10ppb increase in one hour or four hour maximum ozone.

The Brisbane study also reported significant associations between ozone concentrations and hospital admissions for respiratory disease and asthma (all ages) (Petroeschevsky et al, 2001). The association with respiratory admissions remained after controlling for other pollutants. The effect estimates for one hour maximum ozone were greater than those found for eight hour ozone.

No significant associations were found for ozone and hospital admissions for any outcomes in Sydney (Morgan et al, 1998b).

Three panel studies have also been conducted investigating the effect of ozone on children (Jalaludin et al, 2000 and 2004; Rutherford et al, 2000). In a panel study of 125 children with wheeze, a significant association was found between one hour maximum (0.012-0.04ppm) daytime ambient ozone and decrements in peak expiratory flow (PEF) (Jalaludin et al, 2000). The effect was about three-fold greater in children with asthma. In a further analysis of the same panel of children, no significant associations were found with one hour maximum ozone and respiratory symptoms (such as wheeze, wet cough, dry cough), medication usage or doctors visits for asthma (Jalaludin et al, 2004).

Rutherford et al (2000) examined the associations between both one and eight hour average daytime ozone, reporting a significant association between eight hour maximum ozone concentrations (0.022-0.027ppm) and reduced PEF in asthmatics allergic to pollen or fungal spores.

2.5.3 Summary of Australian Epidemiological studies

Studies conducted in Australia have shown that ozone is associated with increases in daily mortality, hospital admissions and decrements in lung function. Adverse health effects have been observed with 1-hour, 4-hour and 8-hour maximum ozone concentrations. The most consistent finding is for increases with hospital admissions for children with asthma and other respiratory diseases.

Panel studies have shown that exposure to ozone is linked to decrements in lung function in asthmatic children.

Care must be taken when interpreting the overall health risk associated with the differing averaging periods. Though for some health outcomes the magnitude of the associations between eight hour average ozone and both mortality and hospital admissions were higher than either one hour or four hour averaging times, the eight hour maximum concentrations are lower than one hour or four hour concentrations, hence the overall risk associated with a one unit change of ozone (ie 1 ppb) may be higher for a one hour maximum concentration than that attributable to eight hour maximum concentrations. Determining the relative importance of ozone averaging periods in terms of risk to public health requires a quantitative risk assessment. This will allow for consideration of both the strength of the effects for different averaging periods and the differences in ozone concentrations in the various averaging times.

2.6 SUMMARY

The adverse respiratory effects seen in controlled exposure studies are confirmed by epidemiological studies. The health effects include increases in daily mortality, hospital admissions and emergency department attendances, exacerbation of asthma, reductions in lung function, increases in airway inflammation and respiratory symptoms.

The controlled exposure studies indicate that responses are observed with exposures of between one and eight hours. The results of epidemiological studies have found adverse health effects associated with one hour, four hour and eight hour maximum daily ozone concentrations. These effects are generally observed at concentrations lower than those used in controlled exposure studies and may reflect the inclusion of the most sensitive individuals in the epidemiological studies or the impact of exposure to other pollutants that may increase the impact of ozone on the health of the population.

Controlled exposure studies have revealed that there is a large range of variability in response across healthy individuals, that the primary influence on response to ozone is concentration and that response to constant exposure to ozone over hours, increases with up to five to six hours of exposure, after which the response appears to level off.

Epidemiological studies conducted in Australia have found that exposure to ozone at one hour, four hour and eight hour maximum averages are associated with a range of health outcomes. However, findings of studies investigating both hospital admissions and mortality have shown significant variability in the strength and significance of the association across cities. For some studies, the effect of ozone appears to be removed or weakened when other pollutants such as nitrogen dioxide and particles are included.

Both the controlled exposure and epidemiological studies indicate that asthmatic children are the most susceptible group to the effects of ozone. This is reflected in the results of epidemiological studies conducted in Australia. Other susceptible groups include people with respiratory disease (including COPD), outdoor workers and athletes.

The results of the controlled exposure studies focussed on healthy exercising individuals indicate a LOAEL of 0.12ppm and a NOAEL of 0.10ppm (based on a group mean reduction in lung function) for a one to three hour ozone exposure. Those studies that have reported health effects for longer exposure periods of 6.6 to 8 hours indicate a LOAEL of 0.08ppm and a NOAEL of 0.04ppm. In considering these values in the process for setting standards for ozone, it should be noted that these effect levels are based on a group mean response for healthy individuals and that these studies indicate large variability in individual response. The same LOAEL and NOAEL may not apply to sensitive groups. The results of the epidemiological studies indicate that effects have been observed in the community below these levels.

3 WORLDWIDE SITUATION

3.1 OZONE LEVELS OVERSEAS

Ambient levels of ozone in Australia are low relative to many other parts of the world, including the United States and Europe. For example, in approximately 100 metropolitan areas in the United States, ozone levels exceed their eight hour ozone standard of 0.08ppm more than three times per year on average[4]. By way of comparison, in Australia, the more stringent four hour ozone standard of 0.08ppm is exceeded very rarely anywhere other than in the Sydney Greater Metropolitan Region.

In the United States and Europe, the sources of ozone pollution in any one state or country include not only NO_x and VOC emissions from within that state/country, but also pollution which has travelled across borders from other jurisdictions. By contrast, in Australia, the ozone levels in the major urban airsheds are generally more directly related to precursor emissions within those airsheds.

3.2 OZONE STANDARDS OVERSEAS

In reviewing Australia's ozone standards, it is useful to look at ozone standards from other countries, particularly those at similar stages of social and economic development. It is important to note that from one country to another, ozone standards are set in different ways and may operate slightly differently. The table of standards set out below (Table 1) and accompanying text seeks to make clear a number of differences underlying the standards.

This chapter draws attention to three key aspects of overseas ozone standards:

- the rationale for the averaging periods of overseas standards
- ways in which health and achievability are taken into account in overseas standard setting
- ways in which ozone impacts on vegetation are taken into account.

This latter point is of interest given that the vegetation effects of ozone have been paid more attention in some overseas jurisdictions than in Australia.

[4] Speech of the USEPA Administrator, 'The Clean Air Rules of 2004: The Next Chapter in America's Commitment to Clean Air', 14/04/2004.

Table 2: Australian and Overseas Ozone Standards

	1 hour average (ppm)	**4 hour average** (ppm)	**8 hour average** (ppm)
Australia (AAQ NEPM), 1998	0.10 (exceedance allowed on one day a year - to be achieved by 2008)	0.08 (exceedance allowed on one day a year - to be achieved by 2008)	
New Zealand, 2004	150 µg/m³ (0.07ppm)		
WHO Guidelines for Air Quality, 1999; WHO Air Quality Guidelines for Europe, 2000			120 µg/m³ (0.06ppm)[5] (replaces one hour guideline from 1987 of 0.075 - 0.10ppm)
US National Standards	0.12 (does not apply once standard has been attained)		0.08 (three year average of the annual 3rd highest maximum eight hour concentration at each monitoring site - currently being implemented)
California, 2005[6]	0.09		0.070
Canada, 2000			0.065 (three year average of the annual 4th highest daily maximum eight hour concentration - to be achieved by 2010)
EU, 2002	180µg/m³ (0.09ppm) (information threshold [7]) 240µg/m³ (0.12ppm) (alert threshold[8])		120µg/m³ (0.06ppm) (maximum daily eight hour mean): – target value for 2010 for the protection of human health – not to be exceeded on more than 25 days per calendar year averaged over three years 120µg/m3 (0.06ppm) (maximum daily eight hour mean within a calendar year - long term objective[9])
UK, 1997 and 2000			0.05 (10 exceedances allowed per year at each measuring site - to be achieved by 31 December 2005)

[5] For comparing standards, the conversion 100µg/m³ = 0.050ppm (which applies at 20°C) has been used in the table, except for New Zealand where the standard is specified at 0°C and the appropriate conversion is 100µg/m³ = 0.0467ppm.

[6] The new Californian 8 hour standard was announced on 28 April 2005. This follows on from a report prepared for the California Air Resources Board in December 2000 which concluded that significant harmful health effects may occur among both children and adults when outdoor ozone concentrations are at or near the current standard.

[7] The 'information threshold' is a level above which there is a risk to human health from brief exposure for particularly sensitive sections of the population and at which up-to-date information is necessary (Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air).

[8] The 'alert threshold' is a level beyond which there is a risk to human health from brief exposure for the general population and at which immediate steps shall be taken by the Member States re providing information to the public (Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air).

[9] This objective is to be attained in the long term, save where not achievable through proportionate measures, with the aim of providing effective protection of human health. Community progress towards attaining the long-term objective shall be subject to successive reviews, using the year 2020 as a benchmark (Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air).

3.3 RATIONALE FOR AVERAGING PERIODS OF OVERSEAS STANDARDS

An overview of ozone standards indicates that an eight hour averaging period has been adopted by a number of overseas jurisdictions in their ozone standards. Jurisdictions with an eight hour standard include Canada, the UK, the US, the EU and the WHO. Europe also has population information/warning thresholds for one hour average levels. New Zealand has a stand-alone one hour standard. In April 2005. California announced its decision to adopt an eight hour standard in addition to maintaining its one hour standard. Of those jurisdictions examined, Australia is the only one to have a four hour ozone standard.

3.3.1 New Zealand

In 2004, the New Zealand government set a one hour ozone standard of 150 μg/m^3 or 0.07ppm that aims to provide a reasonable level of protection for human health. It represents a risk-based approach and aims to prevent effects on respiratory function in vulnerable sub-groups of the population. The standard is to be used as the basis for airshed planning, and regional councils with air pollution that exceeds the standard are expected to comply by 2013 (New Zealand Ministry for the Environment 'Proposed National Environmental Standards for Air Quality: Resource Management Act Section 32 Analysis of the Costs and Benefits', May 2004 p22).

3.3.2 World Health Organisation

The WHO, in its most recent Air Quality Guidelines for Europe, adopted an eight hour standard in place of a one hour standard. It explained this change as based on research indicating that prolonged exposure to ozone is a more significant public health risk[10]. In 2003, a WHO Working Group Report reiterated that an eight hour averaging period was more relevant than a one hour averaging period for the protection of human health[11]. This is due to the increasing health impacts of ozone with exposure over multiple hours.

In replacing its one hour guideline (0.075 - 0.10ppm) with an eight hour guideline in 1999/2000, the WHO noted that the eight hour guideline (0.06ppm) would generally protect against acute exposures in the range of 0.075 - 0.10ppm[12].

Following the *Systematic Review of Health Aspects of Air Quality in Europe*, the WHO concluded that recent epidemiological studies had strengthened the evidence about short-term effects of ozone on mortality and morbidity and the new evidence warranted an update of its Air Quality Guidelines on ozone. The Systematic Review focussed on Europe but the assessment will be generalised to other regions of the world and the revised Air Quality Guidelines are due to be published by the end of 2005[13].

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[10] Air Quality Guidelines, WHO, 1999, Chapter 3.1 and Air Quality Guidelines for Europe, 2000, Chapter 7.2. Both sets of guidelines state that 'the health problems of greatest concern (increased hospital admissions, exacerbations of asthma, inflammatory changes in the lung, and structural alterations in the lung) are more appropriately addressed by a guideline value which limits average daily exposure, and consequently inhaled dose and dose rate, rather than one designed to cover the rare short-duration deteriorations in air quality that may be associated with unusual meteorological conditions'.

[11] 2003 WHO Working Group Report, '*Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide*', p 43.

[12] Air Quality Guidelines for Europe, 2000, Chapter 7.2.

[13] WHO Health Aspects of Air Pollution: Results from the WHO project "Systematic review of health aspects of air pollution in Europe", June 2004 p20.

3.3.3 United States

In 1997, the USEPA introduced an eight hour standard of 0.8ppm. The existing one hour standard of 0.12ppm will be phased out as counties reach attainment with that standard. In explaining the move from a one hour to an eight hour standard, the USEPA has stated:

> although 1-3 and 6-8 hour ozone exposures can be addressed through one hour or eight hour standards, the eight hour standard is more directly associated with the health effects of most concern cited in recent 6-8 hour exposure studies. These studies were conducted at more typical exercise levels and at lower exposure levels (0.08ppm) than the one hour studies[14].

The decision was informed by a quantitative risk assessment. The US ozone standards are currently under review. A draft criteria document has been released (available at <www.ncea.epa.gov>) which reviews recent studies of health effects of ozone for different time periods and examines ozone trends and patterns in the US.

3.3.4 California

In its recent review of ozone standards, the Californian EPA has recommended standards for both one and eight hour averages based on both the evidence from the studies examining the concentrations of ozone at which adverse health effects have been observed and on the existing relation between one and eight hour averages at existing monitoring sites[15].

As part of the review, an analysis was done of the relationship between high one hour and high eight hour ozone averages. This found that in California, different regions exhibit varying relationships between the one and eight hour average concentrations. Some areas exhibit narrow high ozone peaks while others exhibit wide afternoon peak concentrations. Since many areas in the state experience broad peaks and since a large number of Californian residents spend multi-hour periods outdoors working or exercising, the Californian EPA therefore considers that, in addition to the one hour standard, an eight hour standard is required to protect the public from single and multi-hour concentrations of concern[16].

The Californian EPA recommendations for revision of the Californian ozone standard were issued in March 2005 as a Staff Report *Review of the California Ambient Air Quality Standard for Ozone* following public consultation and peer review. The Air Resources Board agreed to the recommendations on 28 April 2005[17].

3.3.5 European Union

The EU based its long-term ozone objective and shorter-term target value on the WHO eight hour guideline. However, it also adopted one hour community information thresholds on the basis that an eight hour period is too long for triggering an information release, especially as the daily ozone peak typically occurs in the afternoon, ie information warnings based on eight hour averages would be delivered too late to avoid adverse health consequences[18].

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[14] USEPA Fact Sheet: EPA's Revised Ozone Standard, July 17, 1997 - <http://www.epa.gov/ttn/oarpg/t1/fact_sheets/o3fact.pdf>.

[15] Review of the California Ambient Air Quality Standard for Ozone, March 2005.

[16] Ibid. Vol 3: 11-20.

[17] <www.arb.ca.gov/research/aaqs/ozone-rs/ozone-rs.htm>

[18] EU Ozone Position Paper, p 81.

As indicated earlier, in 1998 when the Ambient Air Quality NEPM was made, the National Health and Medical Research Council had existing ozone guidelines of one and four hours and these guidelines were adopted as the NEPM ozone standards. At the time of setting the standards, several stakeholders suggested that an eight hour standard would be preferable to a four hour standard. The NEPM project team noted in response that days with high eight hour ozone levels also have high four hour ozone levels.

3.4 WAYS IN WHICH HEALTH AND ACHIEVABILITY ARE TAKEN INTO ACCOUNT IN STANDARD-SETTING

As already outlined, standards under the Ambient Air Quality NEPM are not only based on health protection but also take achievability into account. Thus, the NEPM standard-setting process includes an analysis of the costs and benefits of meeting air quality standards. In some cases, such as ozone, the standards are set at levels where some health impacts might be expected and a single exceedance of those levels is allowed.

3.4.1 United States

In the United States, the Clean Air Act authorises the USEPA to make standards, the attainment of which is requisite to protect the public health. The USEPA has interpreted the Act as not permitting the EPA to take factors such as cost or attainability into account in setting air quality standards. A number of judicial decisions have supported this interpretation[19]. The US standard setting process therefore focuses almost entirely on assessing what level of pollution poses an acceptable level of risk to the health of the public[20].

Under the Clean Air Act, the states are required to prepare and submit State Implementation Plans to the USEPA for approval, setting strategies and timeframes for compliance with the air quality standards. The EPA anticipates that feasibility and costs will be taken into consideration in the preparation of these plans[21].

3.4.2 California

California's air quality standard-setting process does not include any explicit consideration of achievability. The Californian EPA's review of ozone standards did not include an 'achievability' analysis and the Californian EPA Review Report indicates that the economic impact of measures to meet the ozone standard will be considered if and when specific control measures are proposed[22]. The Review Report indicates that measures to meet air quality standards typically involve emission limitations for stationary sources, mobile sources and consumer products[23].

3.4.3 Canada

Canada's Ministers for the Environment have described the Canada Wide Standard for ozone as representing a balance between the desire to achieve the best health and environmental protection possible in the relative near-term and the feasibility and costs of reducing the

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[19] See discussion and case citations in '*National Ambient Air Quality Standards for Ozone; Final Rule – Federal Regulation*', Federal Register, Vol 62, No 138, Fri July 18, 1997, p 38855-38896, Part IVa.

[20] Nonetheless, the US standards are less health-protective than Australian ambient air quality standards.

[21] Sunstein, C. '*Risk and Reason – Safety, Law and the Environment*', Cambridge University Press, Cambridge UK, 2002, p 236.

[22] *Review of the California Ambient Air Quality Standard for Ozone*, Vol 1:1-6.

[23] Ibid. Vol 1: 2-12.

pollutant emissions that contribute to elevated levels of ozone in the ambient air[24]. This would appear to be a similar approach to standard setting as was used for the Ambient Air Quality NEPM.

3.4.4 European Union

The EU based its long-term ozone objective[25] on the WHO Ozone Health Guideline, which was set purely with regard to health considerations[26]. However, the process for setting the EU ozone target value, which is to be achieved by 2010 and which is expected to drive policy, took achievability considerations into account[27]. The target was set at the level of the WHO guideline level, to maintain a benchmark based purely on health protection, but also includes 20 allowable exceedances per year.

3.4.5 United Kingdom

The UK has a similar approach to incorporating health and achievability considerations in its standard setting process. That is, the UK sets standards for minimum or zero risk levels of pollutants purely with regard to scientific and medical evidence on the effects on health or, in the appropriate context, on the wider environment[28]. However, UK air quality objectives (as opposed to standards) are set taking into account economic efficiency, practicability, technical feasibility and timescales[29]. Accordingly, the objective for ozone indicates that the ozone standard level of 0.05ppm may be exceeded up to 10 times per year at each monitoring station.

3.5 STANDARDS FOR VEGETATION PROTECTION

Although the current NEPM aims to protect public health, ozone also affects vegetation and ecosystems. A number of overseas jurisdictions have therefore set ozone standards specifically for the protection of vegetation. Some others have considered vegetation impacts in the process of setting their health-based standards.

The USEPA set a 'secondary' ozone standard to protect against the adverse impacts of ozone on vegetation. The purpose of secondary standards under the Clean Air Act is to protect the public welfare. The secondary ozone standard was set at the same level as the primary health protection standard.

In proposing its secondary standard, the USEPA noted that exposures to ozone have been associated with a wide range of vegetation effects such as visible foliar injury, growth reductions and yield loss in annual crops, growth reductions in tree seedlings and mature trees, and effects that can have impacts at the forest stand and ecosystem level[30].

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[24] Canadian Council of Ministers of the Environment, '*Canada-Wide Standards for Particulate Matter and Ozone*, June 5-6, 2000, Quebec City, p 3.

[25] The 'long term objective' means an ozone concentration in the ambient air below which, according to current scientific knowledge, direct adverse effects on human health and/or the environment as a whole are unlikely (Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air).

[26] EU Ozone Position Paper, p 56, 69-71.

[27] EU Ozone Position Paper, p 69-71.

[28] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, 2000, p 29-30.

[29] Ibid.

[30] '*National Ambient Air Quality Standards for Ozone; Final Rule – Federal Regulation*', Federal Register, Vol 62, No 138, Fri July 18, 1997, p 38855-38896, Pt III.

In addition, the USEPA noted that:

- ozone concentrations of more than or equal to 0.10ppm can be phytotoxic to a large number of plant species, and can produce acute foliar injury responses and reduced crop yield and biomass production
- ozone concentrations within the range of 0.05 to 0.10ppm have the potential over a longer duration of creating chronic stress on vegetation that can result in reduced plant growth and yield, shifts in competitive advantages in mixed populations, decreased vigour leading to diminished resistance to pest and pathogens, and injury from other environmental stresses31.

The EU set a long-term objective and target value (to be met by 2010) for the protection of vegetation. It took the WHO guideline values for vegetation protection (see below) as its starting point and ultimately adopted the crop protection guideline as its guideline value. A less stringent value was adopted for the target value.

The California Clean Air Act allows welfare effects of air pollution to be taken into account in the setting of air quality standards. In the current review of the Californian ozone standards, the Californian EPA has assessed the impacts of ozone on agriculture[32]. However, its recommended ozone standards are based primarily on health protection[33].

The Canadian ozone standards are based solely on the protection of human health. Protection of vegetation was not considered as part of the standard setting process[34].

The ozone standards in the Ambient Air Quality NEPM are also based solely on the protection of human health and not the protection of vegetation. It is acknowledged in the NEPM Revised Impact Statement that ozone can impact on vegetation, however, as high ozone levels are an urban issue in Australia, significant economic damage to commercial crops is unlikely. However market gardens, domestic vegetables and ornamentals may be affected[35].

The 2001 *Australia State of the Environment Report* suggested that the significance of ozone for Australian agriculture and native vegetation could be increasing with growing evidence that precursor emissions from major urban regions are leading to high ozone in regional and rural Australia[36]. However, there is little information available on the effects of ozone on Australian vegetation.

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[31] Ibid.

[32] Review of the California Ambient Air Quality Standard for Ozone, Vol 2 Ch 8.

[33] Ibid, Vol 2 Ch 8.

[34] Canadian Council of Ministers of the Environment, 'Canada-Wide Standards for Particulate Matter and Ozone", June 5-6, 2000, Quebec City, p 3.

[35] NEPM Impact Statement, p 81.

[36] Australian State of the Environment Committee, 2001. *Australia State of the Environment 2001 (Atmosphere Theme Report)*, Independent Report to the Commonwealth Minister for the Environment and Heritage, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.

Table 3: Overseas Standards for Vegetation Protection

Country	Vegetation Protection Standard
USA	0.08ppm (three year average of the annual 3rd highest maximum eight hour concentration at each monitoring site - currently being implemented)
WHO Crops (yield) Forests Semi-natural vegetation Crops (visible injury)	 AOT40[37] - 3ppm.h (3 months) AOT40 - 10ppm.h (6 months) AOT40 - 3ppm.h (3 months) AOT40 - 0.2ppm.h/0.5ppm.h (5 days) – humid conditions/dry conditions
EU	AOT40 - 18000µg/m^{3}h (9ppm.h): - May to July, averaged over 5 years; - target value for 2010 the protection of vegetation AOT40 - 6000µg/m^{3}h (3ppm.h) - May to July; - long-term objective, using the year 2020 as a benchmark.

3.6 CLIMATE CHANGE AND OZONE

The impact of climate change on air quality is an emerging issue worldwide. It is the subject of current research in a number of jurisdictions, including examination of how to effectively integrate climate change and air pollution policies[38]. The linkages are particularly relevant for ozone. Climate change influences ozone concentrations and the frequency of ozone episodes through changes in the atmosphere. Ozone also has an impact on climate change because it is a greenhouse gas itself. A recent European Environment Agency report suggests that increasing background ozone concentrations in Europe are affecting climate change[39].

The most recent assessment of climate change in Australia[40], indicates that annual average temperatures in Australia are projected to increase by 0.4 to 2.0 degrees Celsius by 2030 relative to 1990. The number of days over 35 degrees Celsius may increase by 10-100%.

In addition to raw temperature trends, other more complex meteorological patterns such as trends of winds and pressure system movements should also be considered in assessing the potential effects of climate change on ozone.

It is likely that higher average daily temperatures will lead to increased evaporative emissions of ozone precursors (such as auto fuels) and increased rates of ozone production, which could make ozone episodes in parts of Australia more common and more intense.

There is still uncertainty about the implications of climate change for air quality and health, and how to best incorporate climate change and associated air pollution health impacts in determining the adequacy or achievability of air quality standards. However, there is a need to ensure that ozone reduction strategies remain effective as the impact of climate change emerges, and that the linkages between climate change and ozone are examined in developing emission reduction policies and considering their cost effectiveness.

[37] AOT40 is accumulated exposure over a threshold of 40ppb. The AOT40 is calculated as the sum of the differences between the hourly ozone concentrations in ppb and 40ppb for each hour when the concentration exceeds 40ppb, using sunlight hours only.

[38] For example: European Environment Agency *Air pollution and climate change policies in Europe: exploring linkages and the added value of an integrated approach*, Technical report No 5 2004, Copenhagen, 2004.

[39] Ibid p2

[40] Pittock, *Climate Change: An Australian Guide to the Science and Potential Impacts*, 2003

4 WHAT WE KNOW ABOUT OZONE IN AUSTRALIA

4.1 WHAT IS OZONE

Ozone (O_3) is a secondary air pollutant formed by reactions of the primary pollutants, oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. These primary pollutants arise mainly from motor vehicle emissions, stationary combustion sources and industrial and domestic use of solvents and coatings. In addition to these anthropogenic sources, natural sources can also contribute significantly to ambient ozone levels.

4.2 WHAT WE KNOW ABOUT OZONE FORMATION IN AUSTRALIA

Ozone has been monitored in most major cities since the late 1970s. Peak ozone levels have decreased significantly over that period although in recent years the trends are not as apparent in most jurisdictions. There is significant year-to-year variability in peak ozone levels due to variability in meteorology.

Exceedances of the current ozone standards are occasionally observed in most major Australian cities, with more frequent exceedances observed in Sydney[41]. Tables 3 to 8 show the maximum and 90th percentile one hour and four hour ozone levels for all NEPM sites for 2003 as reported to NEPC and Table 9 lists Sydney's exceedances for the past 10 years.

Table 4: Ozone Levels in New South Wales 2003

Region site	**1 hr Max ppm**	**1 hr 90th percentile**	**4hr Max ppm**	**4 hr 90th percentile**
Sydney				
Rozelle	0.083	0.037	0.070	0.034
Chullora	0.084	0.040	0.077	0.037
Woolooware	0.106	0.037	0.089	0.035
Blacktown	0.181	0.050	0.157	0.045
St Marys	0.093	0.052	0.091	0.046
Richmond	0.148	0.053	0.138	0.048
Liverpool	0.151	0.045	0.132	0.040
Bringelly	0.155	0.056	0.133	0.050
Oakdale	0.102	0.054	0.089	0.048
Illawarra				
Wollongong	0.097	0.040	0.080	0.037
Kembla Grange	0.113	0.038	0.107	0.036
Albion Park	0.130	0.040	0.111	0.037
Lower Hunter				
Wallsend	0.077	0.042	0.059	0.039
Newcastle	0.079	0.039	0.061	0.038
Regional				
Bathurst	0.056	0.042	0.053	0.040

[41] The particular features of the topography and meteorology of the Sydney basin contribute to the higher levels of ozone in Sydney.

Table 5: Ozone Levels in Queensland 2003

Region site	**1 hr** **Max ppm**	**1 hr** **90th percentile**	**4hr** **Max ppm**	**4 hr** **90th percentile**
South-East Qld				
Mountain Creek	0.060	0.035	0.057	0.033
Deception Bay	0.095	0.043	0.076	0.040
Rocklea	0.065	0.046	0.059	0.042
Springwood	0.047	0.034	0.042	0.030
Flinders View	0.087	0.048	0.080	0.044
Gladstone				
Targinie	0.045	0.031	0.041	0.028

Table 6: Ozone Levels in Victoria 2003

Region site	**1 hr** **Max ppm**	**1 hr** **90th percentile**	**4hr** **Max ppm**	**4 hr** **90th percentile**
Port Phillip				
Alphington	0.102	0.041	0.090	0.038
Footscray	0.105	0.041	0.094	0.038
Melton	0.112	0.046	0.099	0.042
Brighton	0.109	0.046	0.102	0.042
Dandenong	0.098	0.044	0.093	0.040
Mooroolbark	0.098	0.047	0.090	0.044
Craigieburn	0.068	0.050	0.065	0.046
Pakenham	0.071	0.036	0.066	0.032
Pt Cook	0.094	0.041	0.093	0.038
Geelong South	0.081	0.033	0.072	0.029
Pt Henry	0.095	0.041	0.083	0.037
Latrobe Valley				
Traralgon	0.077	0.037	0.067	0.035
Moe	0.083	0.043	0.072	0.038

Table 7: Ozone Levels in South Australia 2003

Region site	**1 hr** **Max ppm**	**1 hr** **90th percentile**	**4hr** **Max ppm**	**4 hr** **90th percentile**
Adelaide				
Gawler	0.078	0.042	0.069	0.039
Elizabeth	0.077	0.042	0.063	0.040
Northfield	0.068	0.030	0.061	0.042
Netley	0.069	0.039	0.060	0.037
Kensington	0.074	0.042	0.071	0.040
Pt Pirie	0.073	0.039	0.048	0.035

Table 8: Ozone Levels in Western Australia 2003

Region site	**1 hr Max ppm**	**1 hr 90th percentile**	**4hr Max ppm**	**4 hr 90th percentile**
Perth				
Caversham	0.083	0.044	0.069	0.039
Quinns Rocks	0.086	0.045	0.071	0.040
Rockingham	0.064	0.039	0.059	0.037
Rolling Green	0.087	0.049	0.075	0.043
South Lake	0.071	0.041	0.063	0.037
Swanbourne	0.082	0.041	0.066	0.037

Table 9: Ozone Levels in the Australian Capital Territory 2003

Region site	**1 hr Max ppm**	**1 hr 90th percentile**	**4hr Max ppm**	**4 hr 90th percentile**
Canberra				
Monash	0.102	0.045	0.082	0.043

Table 10: Number of Exceedance Days in Sydney

Year	**1 hour ozone standard**	**4 hour ozone standard**
1994	13	16
1995	0	1
1996	1	2
1997	16	21
1998	13	16
1999	9	9
2000	6	12
2001	19	21
2002	9	15
2003	7	9

Ozone formation is dependent on a number of factors including concentration and ratios of precursors (VOCs and NO_x), temperature, wind speed, UV radiation and atmospheric mixing (USEPA, 1996a). In some urban areas in the US, a linear increase in maximum ozone concentration and maximum temperatures above 30°C has been observed (USEPA, 1996a). The slope is steeper in areas with a high level of anthropogenic activity, eg New York or Detroit, than in areas with a smaller contribution from anthropogenic sources such as Billings Montana. Similar temperature dependence would be expected to occur in major Australian cities. Data for Melbourne clearly shows temperature dependence with no significant ozone formation at temperatures below 25°C. Low wind speeds and high UV radiation are other critical factors that lead to elevated ozone levels.

Ambient ozone concentrations, unlike primary pollutants, are higher away from the source of emissions of precursors due to the photochemical reactions that form ozone. Ozone concentrations vary in complex ways because of this photochemistry, because of its rapid destruction by NO, the effects of differing VOC to NO_x ratios and regional transport of both ozone and its precursors. In urban areas, ozone shows a diurnal pattern following the pattern of solar radiation. Ozone concentrations are higher during spring, summer and early autumn.

The trans-boundary transport of ozone in the US and Europe has a major influence on ozone formation patterns leading to, in addition to short-term peaks, longer periods of elevated ozone levels than observed in Australian cities (USEPA, 1996a and b; European Commission, 1999). Because of the relative isolation of Australia and the relatively large distances between the major airsheds, long-range (or trans-boundary) transport is not a serious issue in Australia. The transport that is important is that within airsheds, such as the Sydney Greater Metropolitan Region, which includes the Sydney, Illawarra and Lower Hunter regions.

To assist in the review of appropriate averaging times for ozone in the Ambient Air Quality NEPM, an analysis of ozone formation patterns in Sydney, Melbourne, Brisbane, Adelaide and Perth for the period 1998 to 2001 (Adelaide 2002-2003) was undertaken (Hibberd, 2004). The analysis considered the patterns, peak times, and durations of the periods with elevated ozone concentrations. The results of this analysis showed that ozone formation patterns in Australian cities are complex and vary significantly from site to site within a city although similar patterns are observed in most cities.

Figure 1 shows examples of the types of patterns of ozone observed on days with moderate to high ozone concentrations. The timing and concentrations vary from site to site and city to city but several types of patterns could be identified:

a) a triangular pattern with an approximately linear increase until mid-afternoon followed by a linear decrease to zero by late evening, a very common pattern

b) a rapid increase then plateauing with elevated levels persisting for five to 10 hours

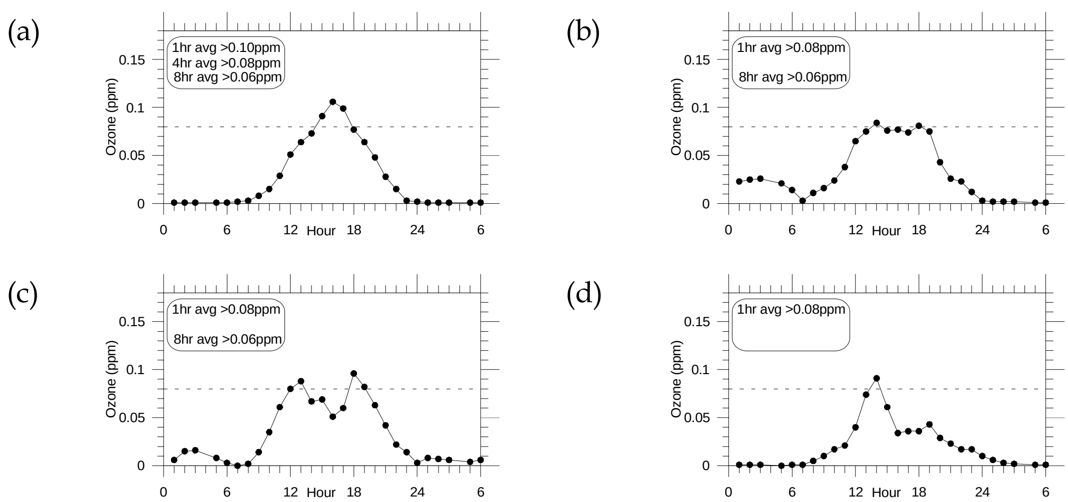
c) multiple peaks

d) a brief period of one to three hours with concentrations elevated well above those existing during the rest of the day

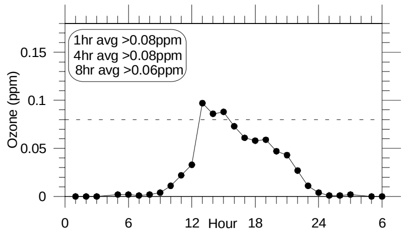
e,f) rapid changes (increases or decreases) in concentration from one hour to the next.

Figures 1(a) and 1(b) illustrate the triangular and square wave exposure profiles referred to in Chapter 2.

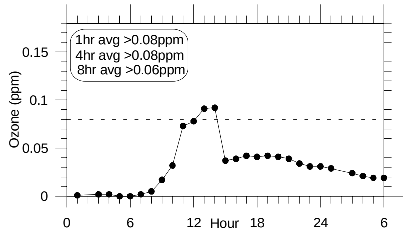
Figure 1: Examples of the Types of Patterns of Ozone Concentrations observed on Moderate to High Ozone Event Days in Australian Cities.



(e)



(f)



The reasons for the formation of these various patterns are complex and include the movement of air masses in an airshed. For example, the arrival of a sea breeze can bring cleaner air into a region and cause a rapid decrease in concentrations. Alternatively a sea breeze may increase concentrations by bringing in polluted air that had earlier been carried offshore during the morning. Several jurisdictions have active research programs directed at understanding the reasons for the various patterns but these are not further discussed here.

Figure 2: Time of Day of Elevated Ozone Concentrations (one hour average greater than 0.06ppm) on a State-by-State Basis for the NEPM Sites analysed in the Ozone Data Analysis Report

(Note that the data presented here for Victoria only include the six sites in the Port Phillip Control Region)

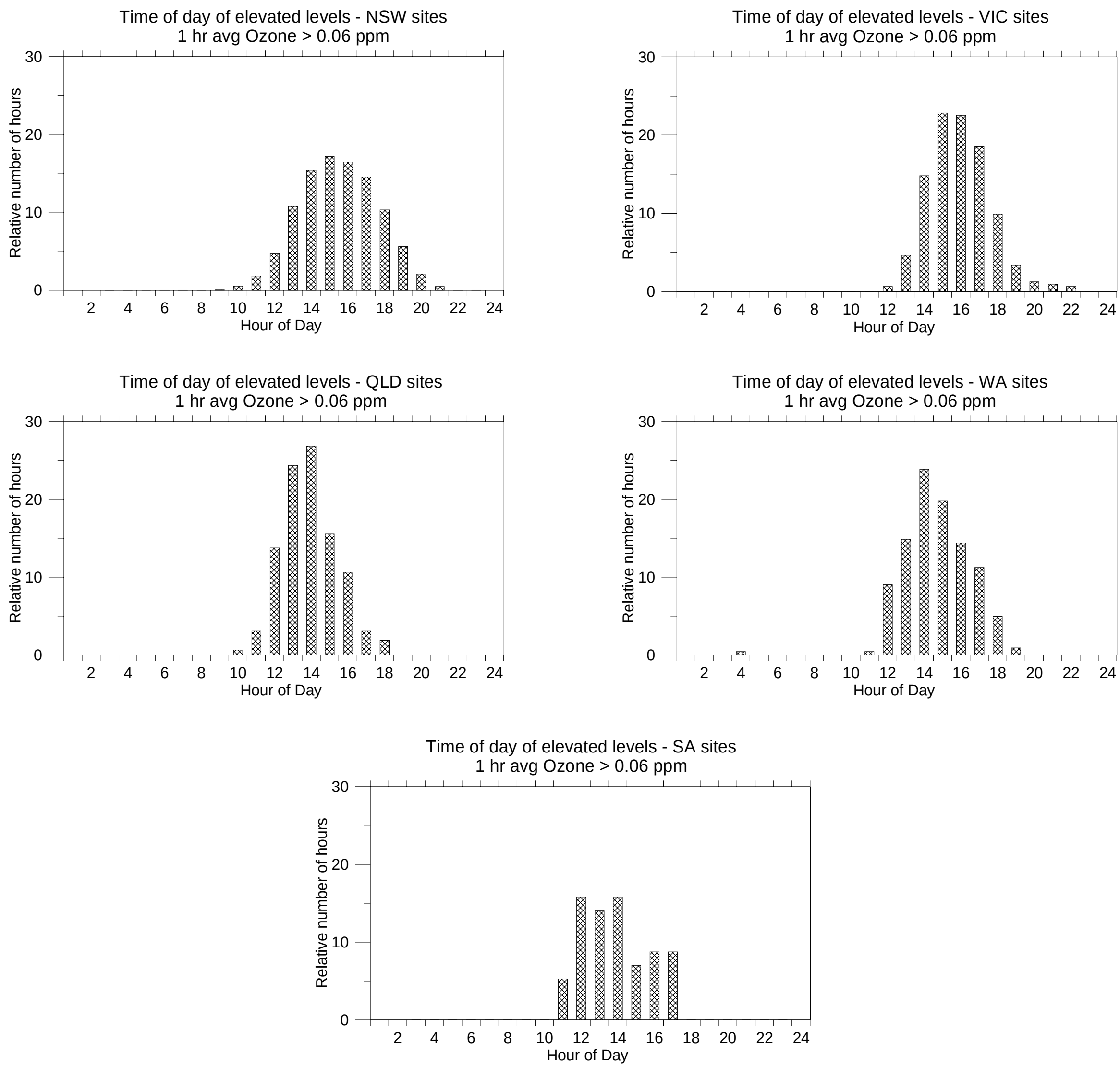
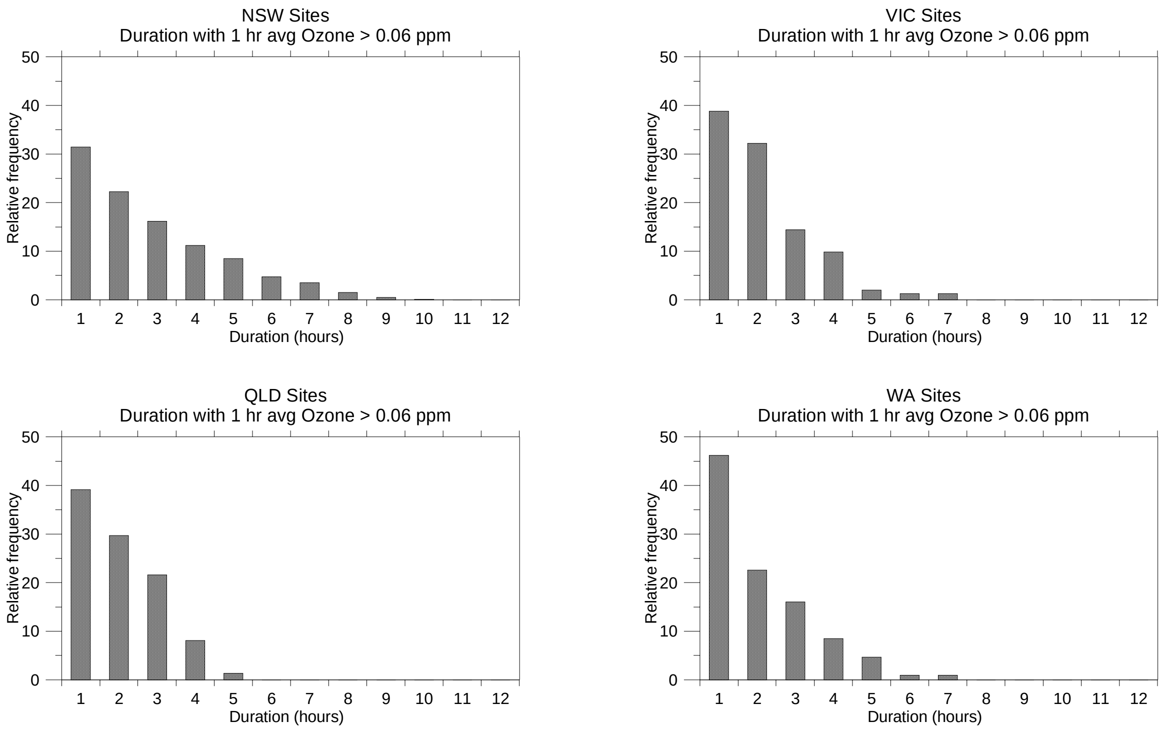


Figure 2 shows the times at which the highest ozone concentrations occur. This analysis shows the time of day when one hour average ozone concentrations exceeded 0.06ppm. This value was selected to provide data from all states for their highest ozone concentrations, because most sites rarely exceed the current NEPM ozone standard. The figures show combined results from selected NEPM sites in each state[42] - nine in NSW, six in Victoria, three in Queensland, three in Western Australia, and four in South Australia. Ozone is not routinely monitored in Tasmania and the Northern Territory because screening, applied in accordance with the NEPM, indicates that monitoring is not required.

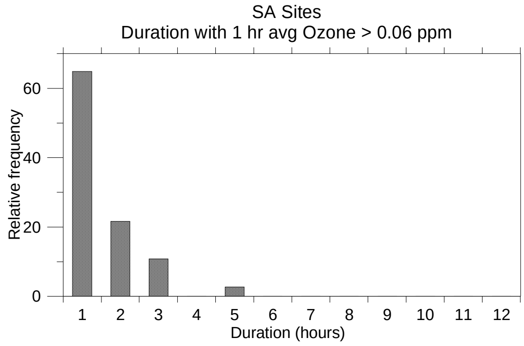
Generally peak ozone concentrations were found in mid to late afternoons during the warmer months. Particular features of the times at which elevated concentrations occur in each state are:

- NSW - the most frequent peak times are between 14:00 and 16:00, although the peak occurs earlier (13:00) near the coast and later (18:00) in the far west
- Victoria - the metropolitan peaks occur between 15:00 and 16:00
- Queensland – these sites show the most frequent peaks between 12:00 and 14:00
- Western Australia - the most frequent peak times are 14:00 to 15:00
- South Australia - these sites show the most frequent peaks between 12:00 and 14:00.

Figure 3: Duration of Elevated Ozone Concentrations (one hour average greater than 0.06ppm) on a State-by-State Basis for the NEPM Sites analysed in the Ozone Data Analysis Report



[42] The NEPM sites in each State used in this analysis were: NSW - Blacktown, Bringelly, Lidcombe, Liverpool, Oakdale, Richmond, Rozelle, St Marys, and Woolooware; VIC - Alphington, Footscray, Pt Cook, Brighton, Dandenong and Geelong South; QLD - Springwood, Deception Bay, and Rocklea; WA - Caversham, South Lake, and Swanbourne; SA - Netley, Kensington, Northfield, and Elizabeth.



The same ozone data were also analysed to determine the duration of periods when the one hour average concentration exceeded 0.06ppm (Figure 3). Comparisons between States are difficult because of the large differences in exposure levels at different sites. However, Figure 3 shows that typically:

- 30–50% of the durations are one hour
- 20–30% of the durations are two hours
- 10–20% of the durations are three hours
- about 10% of the durations are four hours
- up to 20% of the durations are five hours or longer
- the longest durations are nine hours in New South Wales, seven hours in Victoria and Western Australia and five hours in Queensland and South Australia.

4.3 BACKGROUND OZONE CONCENTRATIONS

Ozone is present in the atmosphere even in the absence of human activities. This is sometimes termed 'natural background' ozone and is often treated as though it were present at a constant level. This greatly oversimplifies the situation.

Firstly, ozone forms from a range of natural sources including:

- in situ production of ozone from biogenic VOCs from eucalypt forests, wetlands and swamps and NO_x from soils and lightning
- downward mixing of stratospheric ozone (under certain meteorological conditions, so-called tropopause folding events)
- ozone formation arising from emissions of precursors from bushfires (large quantities of VOCs and NO_x are released).

'Natural' ozone production is usually limited due to low natural NO_x levels so that there is often an excess of VOCs in background air. These can produce ozone by reacting with anthropogenic NO_x releases from power stations or NO_x plumes downwind of urban areas. Thus it is not just 'background ozone' but also 'background ozone precursors' that need to be taken into account.

Secondly, ozone formation and destruction processes vary with location, time of day and meteorological conditions so that 'background' levels vary. This is particularly so within the first few tens of metres above the ground. At night the destruction of ozone through contact with surfaces and reaction with nitric oxide usually reduces levels to near zero and produces a strong diurnal variation that is not apparent at a height of say 100 metres above ground. Indeed one cause of rapid increases in morning ozone concentrations is mixing down of air from above the nocturnal inversion. Thus standard monitoring station measurements do not reflect the 'background' ozone that is available to be mixed into near-surface air once the nocturnal inversion breaks down after sunrise.

It follows that accurate modelling of the varying 'background' ozone concentrations involves chemistry and dynamics that can be as complex as modelling urban airshed ozone. Advanced ozone modelling attempts to account for all these factors.

Many approaches have been used to estimate background concentrations including:

- monitoring data from remote locations
- estimates of ozone concentrations in the absence of any anthropogenic sources
- modelling estimates of concentrations from 'pre-industrial' times
- the ozone concentration that needs to be added to model results for an airshed to match measured concentrations
- estimating background concentrations from monitoring data in urban areas by selecting sites or times when anthropogenic contributions are expected to be small.

The first three of these are easily understood as an 'undisturbed' background level but it is less clear how this should be applied in an urban setting, particularly because of the diurnal and day-to-day variation. The fourth is really only relevant for modelling and may include components to account for inadequacies of the model. The fifth represents values on a 'clean' day but may not represent the 'background' contribution on a more polluted day.

The Californian EPA has moved away from 'natural' background as a definition to 'policy relevant' background. The reason for this is that there may be some non-natural background that cannot be controlled and therefore needs to be considered in a policy context. In the US, long-range (trans-boundary) ozone transport from other states or countries is a significant contributor to background ozone concentrations. This is not an issue in Australia.

Estimates of background ozone levels in urban centres in Australia are usually between 0.02 and 0.034ppm, and occasionally up to 0.04ppm. These have been determined through a range of methodologies including analyses of monitoring data and modelling estimates. The 5th percentile of monitored ozone levels between 09:00 and 16:00 during summer months at NEPM monitoring sites generates estimates of 0.015-0.020ppm, and the 80th percentile produces estimates of 0.025-0.035ppm. The temperature dependence of ozone formation in Melbourne also indicates that at temperatures below 15^{o}C, ozone concentrations are in the range of 0.02 to 0.03ppm.

There is some evidence emerging that background ozone concentrations are increasing at 0.1 - 1% per year, possibly due to human-induced changes in the chemistry of the troposphere, which needs to be taken into account when modelling future ozone trends[43].

On any given day, background ozone concentrations during mid-morning to early evening can usually be considered to be constant (although under some circumstances such as bushfires higher one hour peaks may be observed). This means that on any given day the relative contribution of background to total ozone concentrations will be greater for an eight hour

[43] Galbally IE et al *Trends in near-surace ozone at Cape Grim and in the Southern Hemisphere*, Paper presented at the 17th International Clean Air and Environment Conference, Hobart, 3-6 May 2005

average than a one hour average. This can make the achievability of health-based eight hour standards more difficult (see Chapter 5).

4.4 Past, Current and Predicted Trends in relation to Ozone Levels and Precursors to Ozone Formation

There are numerous factors that contribute to ozone levels including background levels, the volume of precursor emissions, NO_x to VOCs ratios and meteorological conditions.

The impact of year-to-year changes in meteorology on observed changes in ozone levels, particularly on the highest percentiles, is significant.

For this reason, it is difficult to discern trends in ozone levels related to the level of precursor emissions. Another factor that can make identification of trends difficult is the lack of consistency in the coverage of monitoring stations. The most precise way to analyse trends is to compare data collected from a single site over time.

The 2001 *Australia State of the Environment Report* presented ozone monitoring data from jurisdictions from 1979. The report found that there had been a steady decline in the maximum value of hourly ozone concentrations in the biggest cities of Australia since the 1980s, however no similar decline had occurred in maximum value of four hour concentrations.

The *State of the Air Report*, which examined national ambient air quality from 1991 to 2001, performed a site-specific trend analysis for ozone for 26 sites around Australia without adjusting for the influence of meteorology. The analysis was performed for daily maximum and 2nd highest one hour concentrations as well as for the 99th, 98th, 95th, 90th, 75th and 50th percentiles. Trends were generally found not to be statistically significant.

For New South Wales, 11 sites were examined and although the direction of the trend or tendency was upward for most indicators, this was only considered statistically significant at the low percentile levels, in particular at the 50th percentile level. Analysis results for four sites in Victoria showed a downward tendency or trend in general with higher statistical significance at the lower percentile levels. Analysis for three Queensland sites showed a downward tendency, while there was an upward tendency at one site for most indicators. In South Australia, two sites were analysed and an upward tendency was found at one site and a downward tendency at the other (noting that trend periods ended at 1996 and 1993 respectively for these South Australian sites). In Western Australia, trend analysis at three sites showed an upward tendency, which was statistically significant at low percentile levels at one site.

A trend analysis was also conducted for daily maximum four hour ozone, with similar results.

Past and current trends suggest that Melbourne, Perth, Brisbane and Adelaide are close to meeting or are meeting current ozone standards. Sydney however often records more than five exceedance days per year and has recorded up to 12 days with exceedances of the four hour standard.

Future trends in ozone levels have been modelled for most major Australian cities. In general, peak ozone levels are not expected to decrease in Sydney. In other cities peak ozone levels are predicted to stay relatively constant with minor downward trends in some locations, eg Melbourne and Perth. The major sources of the precursors to ozone formation are motor vehicles, especially for NO_x. Although new motor vehicle design rules will result in a decrease in NO_x and VOCs from this source, the predicted increase in vehicle kilometres travelled and in number of vehicles on the road largely offsets the gains made by these rules' emission controls. Emissions of VOCs and NO_x from individual industries are expected to decrease with improvements in process technologies and practices but growth in overall activity may offset these individual reductions.

4.5 EXPOSURE OF THE POPULATION TO OZONE

4.5.1 Adequacy of the Network in Representing Australian Population Exposure

It could be considered that the network is adequate if monitoring is conducted at a sufficient number of sites to allow determination of exposure of all sectors of the community. This could be achieved by a combination of measurements at sites exposed to Generally Representative Upper Bound (GRUB) concentrations, population-average sites, non-NEPM sites and dispersion modelling to deduce the concentrations away from monitoring sites.

Ozone is called a secondary pollutant because it is not discharged directly from emission sources but is formed in the atmosphere by the reaction of the primary pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Natural biological activity releases these VOC and NO_x precursors, resulting in non-trivial background ozone concentrations in many areas of the country. Nevertheless, the highest concentrations of ozone precursors are generated by motor vehicles and industrial activities in the airsheds of Australia's most heavily populated cities.

Within those airsheds, ozone formation is a gradual process that occurs as the reacting precursors are transported by wind across the region. The location, spatial extent and duration of peak ozone concentrations are determined each day by the physical location, diurnal activity pattern of precursor sources and the day's meteorological conditions. Unlike pollutants such as carbon monoxide and sulfur dioxide, the higher concentrations of ozone are not experienced at or adjacent to the area in which the causal emissions are discharged. In order to properly characterise ozone exposure of the community, the monitoring networks need to account for this phenomenon.

In most cities, monitoring sites tend to be located strategically in areas of relatively high population density to assess community exposure, as embodied in the GRUB concept of a monitoring site. Whilst monitoring for ozone in these areas provides the most representative information on community ozone exposure on a population basis, it does not necessarily discover the maximum concentrations. Due to the characteristics of ozone formation, these highest levels are likely to occur at or beyond the urban fringe where currently only a small proportion of the community resides. Monitoring in those locations is generally undertaken by jurisdictions and is important for several reasons. These are to determine the magnitude of ozone formation and to improve understanding of the contributing factors, and hence improve management strategies. It is also important because, as the cities grow in future decades, the proportion of the population represented by those 'fringe' sites will increase.

The greatest community exposure to ozone, and thus its routine measurement, occurs in the regions of the capital cities of Brisbane, Melbourne, Adelaide, Perth, Canberra and Sydney. They are the sites of not only the greatest number of people exposed, but also the highest concentrations experienced and the longest duration of photochemical smog episodes. Ozone is also monitored for NEPM purposes in the Illawarra and Lower Hunter regions of New South Wales, Latrobe Valley and Geelong region of Victoria, Gladstone in Queensland and the North

Coast sub-region of Queensland. Jurisdictions also conduct ozone monitoring at non-NEPM sites.

Campaign monitoring has been conducted in some non-capital cities to investigate whether there is a minimum population above which the emissions of VOCs and NO_x (which are generally population–dependent in the absence of major point sources) are large enough to generate ozone at levels close to the NEPM standards.

Monitoring Plans

Each jurisdiction has prepared a monitoring plan endorsed by NEPC, based on the protocol requiring measurements to be conducted in regions of population 25,000 and above, unless otherwise screened out because pollutant levels are reasonably expected to be consistently lower than the standards. The monitoring plans and annual reports of measurements can be viewed on the website relating to the Ambient Air Quality NEPM <www.ephc.gov.au/nepms/air/air_nepm.html>. These monitoring plans detail the logic behind the location of measurement sites to achieve the broadest representation of community exposure to air pollution. The development of sites for ozone generally was scenario based for the individual ozone-prone airsheds, from knowledge of the interaction between ozone precursor emission sources and meteorology in those regions. There appears to be little need to measure ozone in every urban centre less than 100,000 in population in order to characterise the exposure of rural city populations. This can be done by comparison with similar locations of known exposure. Some jurisdictions have included campaign monitoring to add to the knowledge base and improve the predictive capacity of the regional airshed models.

A description of ozone monitoring sites in Australia is included in Appendix 2.

In summary, the networks of ozone monitors have been established to ensure their results closely represent the exposure of the general population. Most sites can be classified as GRUB sites in terms of the NEPM technical paper, meaning that they are generally representative of community exposure at the upper range of concentrations likely to be encountered. Additional measurement is undertaken at population-average sites. The validated modelling shows that in cities where measurement is not routinely conducted, the exposure of their populations can be derived reasonably from comparison with cities of similar size and climate.

4.6 TIME ACTIVITY STUDY

As discussed in Chapter 2, the health effects attributable to exposure to ozone are dependent on concentration, duration of exposure and level of activity. Ozone levels indoors are generally low due to the fact that there are few indoor sources and, being a reactive gas, ozone reacts quickly with furnishings and surfaces in the home. Small amounts of ozone may be generated by photocopiers and certain electrical equipment. Industrial processes such as electric welding may result in increased occupational exposures. The main source of ozone indoors is the penetration of outdoor levels. The use of air conditioning significantly reduces the penetration of ozone indoors.

Given that the main source of exposure to ozone is related to ambient levels, an understanding of the amount of time spent outdoors and the level of activity undertaken is important to understand the potential health effects that may arise due to exposure to ozone.

To gain a better understanding of the time-activity patterns of the Australian population to inform the review of ozone standards, EPHC commissioned a study in 2002 to determine how much time people spend outdoors and the types of activity that are undertaken. The study was conducted in early September 2002 (the cool season) and in February 2003 (the warm season) in an attempt to ascertain differences in people's behaviour in the different climatic conditions. The results of the study are available at <www.ephc.gov.au>.

The study focussed on age groups known to be more susceptible to the effects of air pollution – children, people 65 years and older and people with existing diseases (such as asthma, COPD or cardiovascular disease) that may make them more susceptible to the effects of air pollution. Outdoor workers are another potentially vulnerable group due to the extended periods of time they spend outdoors, however they were not specifically assessed in this study.

The study found that there were subtle differences in the activity patterns of the people surveyed between the warm and cool seasons. The reported time spent outdoors in winter and summer showed a clear pattern of increased time spent outdoors in summer before 9am and between 3pm and 9pm. The period in the middle of the day, between 9am and 3pm, showed significantly less time outdoors in summer than in winter. Time spent outdoors breathing heavily as a result of either work or exercise showed a similar pattern with a significant increase in time early in the day (before 9am) and late in the day in summer. Significantly fewer children were reported to be 'very active' or doing organised sports in the summer compared with winter. For children aged five to 14 years, the peak time for outdoor activities was mid afternoon corresponding to after school activities.

On average people were found to spend approximately two to three hours per day outdoors (approximately 12% of the day). The time spent outdoors was slightly higher in summer than in winter but the time of day that people were outdoors differed.

The level of activity outdoors decreased with increasing age, with children being the most active group. People 60 years and over were more active in the mornings and became less active later in the day. Children and adults with asthma and other respiratory conditions were just as active as those not reporting these conditions.

As discussed in Chapter 4, the patterns of ozone formation are complex but generally peak mid to late afternoon. The Time Activity Study indicates that this is potentially a peak exposure period for school aged children (5-14 years) who engage in after school activities at this time.

4.7 Current Management Approaches to Reducing Precursors in order to Reduce Ozone Levels

Strategies implemented across Australia involve reduction of both nitrogen oxides and VOCs, but the relative emphasis on each precursor class may differ between jurisdictions primarily due to differences in the relative sensitivity to each precursor class of ozone formation and removal. There are also differences in the particular VOC species involved due to differences in industrial emissions and variations in petrol composition.

The relationship between VOCs, nitrogen oxide, nitrogen dioxide and ozone concentrations in air is complex, such that tangible reductions in both precursors together could yield little or no reduction in ozone. Some combinations of NO_x and VOC reduction could actually increase ozone levels. Initially, ozone control strategies concentrated on reducing VOC emissions while additional research was conducted in a number of the capital city airsheds to determine the most appropriate mix of strategies, given the complementary need to control nitrogen oxide emission to reduce ambient levels of nitrogen dioxide in its own right.

Essentially the strategies are designed to reduce emissions from industry, motor vehicles and domestic/commercial sources, through a mixture of legislative and financial instruments and programs seeking to change behaviour, such as encouraging alternatives to private vehicle travel.

In all major urban airsheds in Australia the single largest contributor to the criteria pollutants and thus to ozone formation is motor vehicle use. Australian Design Rules (ADRs) establish limits for evaporative and exhaust emissions from new vehicles on a national basis. The most recent ADRs apply Euro 4 Standards for light vehicles from mid 2008 and Euro 5 standards for heavy vehicles from 2010. They will enable the introduction of new technologies that achieve significantly lower exhaust emissions as well as fuel economy improvement.

Individual jurisdictions are responsible for in-service vehicle emission control, and implement programs addressing this to varying degrees. Smoky vehicle legislation is common, targeting vehicles that emit excessive smoke, which can also be accompanied by excessive VOC emissions. The Diesel NEPM has led to implementation of programs that reduce VOCs as well as diesel particulates. Non-legislative programs aimed at reducing use of vehicles include Travel Smart and support for alternatives to private vehicle use such as cycling, walking or 'park and ride' programs, in which the public are encouraged to park their motor vehicles at suburban stations near home and commute to CBDs by public transport.

VOC emissions from petrol are also addressed by legislation or formal agreements to reduce volatility in summer months. Stage 1 vapour recovery systems collect vapours at petrol depots and from retail petrol station underground storage tanks and return them via the road tankers to recovery systems at the terminals. Stage 2 recovery systems are currently being trialled and would lead to greater reductions if implemented.

Most jurisdictions have environment protection legislation that provides for licensing of major industries and that also sets maximum concentration limits for certain air pollutants. Licences may impose additional conditions that regulate operational practices and discharges. Solvent composition, fuel type, process and control equipment and process discharges are often regulated to reduce the emission of VOCs and NO_x.

In recent years load based licensing has been introduced in several jurisdictions, to link licence fees to the quantity of pollutants discharged thus providing a financial incentive for licensees to achieve discharges below the required minimum performance.

Small commercial and industrial sources of VOC emissions are generally addressed by implementation of industry-specific or chemical-specific codes of practice or guidelines.

The domestic sector is less regulated, although it is also a significant contributor to VOC emissions. Household sources include petrol lawnmowers, garden tools, solvents and paints and solid wood heaters. For example, in combination these 'area sources' are responsible for 42% of anthropogenic VOC emissions in the Greater Metropolitan Region of New South Wales.

Appendix 3 details the ozone management strategies being undertaken in five Australian states.

5 ASSESSING THE IMPACTS OF CHANGES TO OZONE STANDARDS

The NEPC Acts establish a framework for the development of National Environment Protection Measures. The Acts provide that prior to making a NEPM, NEPC must prepare an impact statement that must include:

- the environmental reason for the proposed NEPM
- an identification and assessment of the economic and social impact on the community (including industry) of making the proposed NEPM
- an analysis of alternative means of addressing the environmental concerns in question.

Although the NEPC Acts do not refer specifically to 'achievability', the social and economic impacts of a NEPM relate to achievability issues. Achievability is partly a function of technical feasibility and partly a function of the cost that a society is prepared to bear to bring about an environmental change.

The Ambient Air Quality NEPM and its supporting documentation make clear that the NEPM standards are based on health protection but also take achievability into account. The Ambient Air Quality NEPM standard-setting process included an analysis of the health impacts of the criteria pollutants and of the costs and benefits of meeting the air quality standards.

This chapter provides an overview of some of the achievability issues that will need to be considered in the review of the ozone standard and some of the approaches that could be taken to assessing the achievability of any proposed changes to the NEPM ozone standards.

5.1 ACHIEVABILITY AND AIR QUALITY STANDARDS

Achievability can be taken into account in standard setting in determining:

- the level at which a standard is set
- the number of exceedances of the standard level allowed, if any
- the time period within which a standard is to be achieved.

The current NEPM ozone standards incorporated achievability considerations in the following ways:

- they were set at slightly less stringent levels than those recommended by health experts involved in the NEPM development process
- exceedance of the standards on one day per year is allowed
- jurisdictions were given 10 years (to 2008) to bring their ozone levels into compliance with the standards.

A number of other countries that also take achievability into account in their standard setting processes have done this primarily through allowing a significant number of exceedances. For example, the EU standards are set at levels where no or minimal effects on human health are likely to occur, but allow 25 exceedance days per year. The EU explained its rationale for this approach as based on the transparency of having a standard level based purely on health protection to act as a benchmark and ultimate goal (see Chapter 3).

5.2 METHODS OF ANALYSING ACHIEVABILITY

The achievability of current or future ozone standards can be analysed in a number of ways. Examining background levels gives a sense of the very minimum ozone levels we could expect to achieve. Analysing past and current ozone levels and trends gives an indication of how close we are to achieving a particular ozone standard. However, this does not take into account significant changes which may occur in precursor emissions (due to, for example, changed patterns of consumption and production, new technologies or policy interventions) or changes in meteorological conditions due to climate change. The year-to-year variability in meteorological conditions further confounds this type of analysis.

To determine the extent to which a reduction in current ozone levels to meet a proposed standard level is achievable may require modelling of the impacts of policy interventions or anticipated technological or behavioural changes on future ozone levels. The costs of the policy interventions that would be required to meet a proposed standard can then be assessed so that a decision can be made regarding whether or not the costs would be acceptable.

Decision-makers should also be provided with information about the social and economic benefits of proposed ozone standards, such as reductions in mortality and hospital admissions, to assist in determining whether proposed standards would benefit society overall.

5.3 CURRENT OZONE LEVELS AND ACHIEVABILITY

As indicated in Chapter 4, given the numerous factors that contribute to ozone levels, it is difficult to discern a uniform trend in ozone levels across Australia, and in some major cities across all sites, with some sites displaying upward trends and others downward trends.

The NEPM annual reports and the *State of the Air Report* indicate that currently Melbourne, Perth, Brisbane and Adelaide are meeting, or are close to meeting, current ozone standards, whereas Sydney often records multiple exceedance days.

At a stricter standard level, such as 0.08ppm for the one hour averaging period, achievability may also becomes a challenge for the other major cities, with exceedance days expected to increase. To illustrate the potential impact of a change in the standard the following table shows the number of exceedance days which would have occurred at a range of sites in Sydney, Melbourne, Brisbane and Perth from 1998 to 2001 if there had been a one hour standard of 0.08ppm and an eight hour standard of 0.06ppm. These were the concentrations and averaging periods recommended by the Technical Review Panel during the development of the NEPM in 1998.

Table 11: Number of Exceedance Days with Stricter Standards

	Number of exceedances one hour ozone of 0.08ppm				**Number of exceedances** eight hour ozone of 0.06ppm			
Site	**1998**	**1999**	**2000**	**2001**	**1998**	**1999**	**2000**	**2001**
Sydney								
Blacktown	10	4	6	16	8	2	7	12
Bringelly	14	11	14	16	10	7	13	15
Earlwood	5	0	3	4	0	1	2	4
Lidcombe	8	4	4	11	7	2	5	8
Liverpool	14	5	8	13	9	1	9	11
Randwick	2	0	2	3	2	1	2	1
Richmond	6	3	4	12	6	5	3	12
St Marys	7	9	10	17	10	4	13	16
Woolooware	3	0	5	5	2	0	3	2
Melbourne								
Alphington	1	0	0	0	1	0	0	0
Box Hill	1	0	0	0	1	0	0	0
Brighton	1	0	0	0	1	1	0	1
Dandenong	2	0	0	0	1	2	0	0
Footscray	2	0	0	0	1	1	0	0
Paisley	4	0	0	0	3	0	0	0
Point Cook	4	1	0	2	2	1	0	3
RMIT	0	0	0	0	0	0	0	0
Brisbane								
Brisbane CBD	1	1	2	1	0	0	1	0
Deception Bay	0	1	0	0	0	1	0	1
Eagle Farm	1	2	2	0	0	1	2	1
Flinders View	5	5	2	0	0	1	1	1
Mt Warren Park	1	1	2	0	0	0	0	1
North Maclean	4	0	2	2	2	0	1	1
Rocklea	3	3	1	3	1	2	1	0
Perth								
Caversham	5	5	1	3	3	3	0	2
Quinns Rocks	0	2	0	0	2	0	2	1
Swanbourne	1	2	0	0	1	1	2	1

5.4 BACKGROUND LEVELS AND ACHIEVABILITY

Jurisdictions are not able to control all sources of ozone in order to eliminate exceedances. Background concentrations of ozone have an impact on the ability to comply with the standards. They may also limit the potential improvements to air quality resulting from control programs. The discussion in Chapter 4 indicates that average background ozone can vary according to location, time of day and weather. Given that background ozone levels in urban centres in Australia have been estimated between 0.02 and 0.03ppm and occasionally up to 0.04ppm, this would make it challenging for a number of Australian cities to meet a stricter standard with a longer averaging period.

Since background ozone concentrations during mid-morning to early evening are usually constant, on any given day the relative contribution of background to total ozone concentrations will be greater for an eight hour average than a one hour average. This can make the achievability of an eight hour standard more difficult than a one hour standard.

5.5 OZONE MODELLING

Ozone modelling can tell us the impact of new technologies, projected behavioural changes (eg increased vehicle kilometres travelled (VKT)) and policy interventions on ozone precursors under a range of meteorological scenarios.

Modelling is a complex process taking into account a range of factors including:

- what we know about the chemistry of ozone formation
- what we know about the sources of ozone precursors
- variability associated with local climatic conditions and contributions from biogenic sources.

New South Wales, Victorian, Queensland and Western Australian environment agencies have models that are used for projecting future ozone levels. Other jurisdictions do not have routine modelling capacity.

The CSIRO has developed Photochemical Air Quality Modelling Systems for the Perth, Melbourne, Sydney and Brisbane airsheds. The systems typically use a comprehensive emissions inventory of NO_x, CO and VOC, and meteorological data sets for a number of case study days.

Comprehensive modelling was conducted for Melbourne as part of the development of the Air Quality Improvement Plan for the Port Phillip Region. Some modelling has also been undertaken by the CSIRO for the Adelaide airshed using a simplified population based emissions inventory.

A number of jurisdictions have done significant modelling exercises, for example to project the impact of new vehicle emissions technologies on ozone levels. These modelling projects could be useful to inform the issue of the achievability of the current ozone standards or of a new ozone standard as they estimate the impact of significant reductions in precursor emissions on ozone levels.

In the case of New South Wales, modelling exercises to date suggest that very large reductions in precursor emissions would be required to meet the current ozone one hour goal. Modelling completed to inform the Motor Vehicle Environment Committee Vehicle Emissions and Fuel Standards Review looked at the impact of both currently mandated vehicle emissions standards (Euro-II and Euro-III) and possible emission standards (Euro-IV and Euro-V).

This work shows that implementation of Euro-II and Euro-III motor vehicle emission limits is not sufficient to meet the current goal. Even with a greater than 30% reduction in NO_x for the Sydney airshed (due to Euro-II and Euro-III), a 40% reduction in anthropogenic ROC emissions would be unlikely to be sufficient to achieve compliance with the current goal. Moreover, this modelling work shows that halving the current emissions of NO_x and VOC would not be sufficient to meet a one hour goal of 0.08ppm.

For those airsheds which do not look like they are likely to meet a proposed standard (based on past and present levels), modelling the impacts of potential policy interventions could be an important process for determining whether the improvements required by a proposed standard are achievable.

In the cost-benefit analysis for the 1998 Ambient Air Quality NEPM, a short-cut was used in place of modelling, ie an assumption was made that an x% reduction in NO_x or ROCs would result in an x% reduction in ozone.

For the review of the NEPM there will need to be consideration of whether the accuracy of a modelling exercise to inform the review would be sufficiently beneficial to warrant the time and expense.

5.5.1 Impact of vehicle replacement rate

When the National Environment Protection Council adopted the current ozone standards in 1998, it identified the slow motor vehicle replacement rate in Australia as one of the key reasons why more stringent standards would not be achievable within 10 years[44]. The estimated replacement rate of 17 years for full turnover of the vehicle fleet meant that the impact of tighter fuel standards and vehicle emission controls would be slow to take effect. This is still likely to be an issue affecting achievability which will need to be considered in the review.

5.6 ASSESSMENT OF COSTS AND BENEFITS

Cost-benefit analysis is one method of measuring and comparing the various benefits and costs arising from a policy change. It is a complex process that requires a range of assumptions to be made along the way. However, it can provide useful information to policy makers about the costs and benefits associated with policy options and point out some of the deficiencies or weaknesses in data or measurement associated with an issue[45].

A cost-benefit analysis of proposed air quality standards could involve the following steps:

1. modelling changes in ambient air quality resulting from reductions in pollutant emissions
2. estimating avoided health effects (some work is currently underway at a national and state level to cost the health impacts of air pollution, including ozone, which should be available for use in a future analysis)
3. estimating avoided non-health, ecological and other social impacts
4. estimating costs of emission reduction
5. economic valuation of avoided health and non-health effects
6. balancing costs and benefits[46].

5.6.1 Estimating Costs of Emission Reduction

One important decision that needs to be made in estimating the costs of emission reduction is what pollution abatement measures should be costed. The best approach here may be to select a number of potential policy responses and assess the relative cost-effectiveness of these

[44] Revised Impact Statement for the Ambient Air Quality NEPM, June 1998, p82

[45] The Standard Setting Working Group established by the Environment Protection and Heritage Standing Committee will be considering approaches to cost benefit analysis in standard setting in more detail. Their work will inform the review of the Ambient Air Quality NEPM.

[46] These are the steps recommended by a Canadian Expert Panel appointed to review the socio-economic analysis conducted in the development of the Canadian standards for particles and ozone (Report of an Expert Panel to Review the Socio-Economic Models and Related Components Supporting the Development of Canada-Wide Standards for Particulate Matter and Ozone, to the Royal Society of Canada, The Royal Society of Canada, Ottawa, June 2001).

responses in obtaining a selected level of reduction. The most cost effective policies would then be included in the cost-benefit analysis.

In addition to deciding how to calculate the direct costs of emission reductions, decisions also need to be made about whether to consider behavioural or market changes within the sector or industry being directly affected by abatement measures, and whether to consider flow-on effects to other sectors or industries.

A Canadian Experts Group on cost-benefit analysis has pointed out that direct cost estimates generally overstate the true social cost of regulatory change because they ignore behavioural changes that can generate cost savings. They also ignore the potential that sometimes exists for firms to pass some of the costs of regulatory changes on to customers through increased product prices.

5.7 NATIONAL APPROACH VS AIRSHED APPROACH

A further important issue is how to break down the costs and benefits of reducing ambient ozone levels geographically. One option is to compare costs and benefits across the nation as a whole. Each jurisdiction is ultimately separately responsible for its own compliance with the NEPM standards and each airshed is likely to require somewhat different policy responses. For example, Sydney is likely to require much more stringent measures to meet any tighter standards than the other capital cities.

It may be more useful to break down the costs and benefits to each jurisdiction. The scale of the abatement task is one factor here, but the costs of least-cost abatement would also be expected to differ between jurisdictions. Similarly, health costs and benefits may differ with significant jurisdictional differences in ozone levels and size of exposed populations.

5.8 MULTI-POLLUTANT APPROACH

Exposure to ozone can occur at the same time as exposure to other pollutants and the sources of the pollutants are often the same. For example ozone and particles share many common precursors, such as motor vehicles. The recent review of Air Quality Management in the United States by the National Research Council (2004) recommended that a multi–pollutant approach is more effective than a single pollutant approach when addressing multiple emissions from common mobile and stationary sources.

The approach focuses on achieving the most cost effective mix of emission reductions of key pollutants from any one source rather than separately responding to different pollutants. This approach should enhance the ability of agencies to maximise the cost effectiveness of their overall air pollution control strategies (National Research Council (2004) p130ff, p270). A multi–pollutant approach may be more effective than considering the costs and benefits of ozone independently of other pollutants.

6 KEY ISSUES

6.1 BACKGROUND TO THE CURRENT OZONE STANDARD

The current ozone standards in the Ambient Air Quality NEPM are based on the protection of human health and apply at locations that are generally representative of population exposure. The standards do not apply at peak sites. The current standards are 0.10ppm for a one hour average and 0.08ppm for a four hour average which are to be achieved by 2008 with one exceedance day allowed per year.

During the development of the Ambient Air Quality NEPM, the Streeton Review recommended a tighter one hour standard (0.09ppm) and an eight hour standard (0.05ppm) for inclusion in the NEPM. The technical review panel for the development of the NEPM also recommended a tighter one hour standard (0.08ppm) and an eight hour standard (0.06ppm). In adopting the current standards, the National Environment Protection Council recognised that the more stringent recommended standards may not have been achievable within the 10 year period set for compliance with the NEPM goals.

The National Environment Protection Council adopted the four hour NHMRC goal of 0.08ppm for inclusion in the NEPM instead of the eight hour standard recommended by the Streeton Review and technical review panel. The Council was of the view that the four hour standard would be more achievable within the 10 year timeframe while still providing health protection from the adverse effects associated with exposure to ozone.

Given the concerns raised during the development of the NEPM about the potential health effects associated with exposure to ozone, it was agreed by the National Environment Protection Council that a review of the practicability of setting a long-term goal (>10 years) of achieving a one hour ozone standard of 0.08ppm was to commence in 2003 ahead of the full review of the NEPM scheduled to commence in 2005.

It was envisaged that further information would be available from monitoring data in the intervening period that would facilitate an assessment of the achievability of the more stringent health-based standard.

6.2 FACTORS RELEVANT TO THE OZONE STANDARD

As outlined in the previous chapters, the setting of air quality standards for ozone and assessing the achievability of any changes to the standards requires consideration of a range of factors including health impacts, current and predicted ozone levels, background concentrations, and the costs and benefits of management strategies that must be applied to reduce levels of ozone. As ozone is a secondary pollutant, controls must be applied to the precursors of ozone, mainly VOCs and NO_x, to reduce ambient ozone levels. The photochemistry leading to the formation of ozone is complex and is strongly influenced by meteorology and the management of ozone control strategies can vary from city to city.

In addition to ozone arising from anthropogenic sources, natural sources of ozone precursors lead to the formation of 'background' ozone that can be a significant portion of the ambient levels and limit the ability to reduce levels of ozone to those that are unlikely to produce health effects in sensitive individuals.

6.3 FACTORS RELEVANT TO SETTING THE AVERAGING PERIOD

Health based ambient air quality standards (concentration and averaging time) are set with a view to restricting the exposure of members of the community to air pollutants such as ozone. The impact on people exposed depends on both the duration of exposure and the concentration levels. Common exposure periods that are examined in controlled exposure studies investigating the health impacts of ozone are one to three hours and six to eight hours. Health impacts associated with these exposure periods could potentially be addressed through standards with a range of averaging periods, eg it may be that a one hour standard would protect against eight hour exposures, so long as compliance with the one hour standard kept eight hour average levels below levels at which health effects of concern would be expected. This depends on the situation in any particular location, which can be determined through analysis of monitoring data. Epidemiological studies in Australia have shown adverse effects are linked with exposure to ozone at one, four and eight hours.

Although there is not necessarily a uniform approach for setting averaging periods for air quality standards, certain key jurisdictions have provided some explanation for how they selected averaging times for their ozone standards (as outlined in Chapter 3). From those overseas jurisdictions examined, it would appear that averaging periods have been selected based on the review of health studies combined with consideration of exposure periods that pose the most significant health risks in their jurisdictions.

The WHO indicated, as the basis for its decision to replace a one hour ozone guideline with an eight hour guideline, that:

> the health problems of greatest concern are more appropriately addressed by a guideline value which limits daily exposure rather than one designed to cover the rare short-duration deteriorations in air quality that may be associated with unusual meteorological conditions[47].

The Californian EPA has adopted ozone standards for both one and eight hour averages:

> based on both the evidence from the studies examining the concentration of ozone at which adverse health effects have been observed and on the existing relation between one and eight hour averages at existing monitoring sites. … The recommended averaging times, one and eight hours, are based on common exposure patterns, and both are needed to address the non-linear aspects of the exposure duration. As such these averaging times address the influence of both dose-rate and exposure duration on induced responses. Staff recognize that in some areas of the state one of the two recommended standards may be more controlling than the other[48].

6.4 ISSUES EMERGING SINCE 1997/98

The Woolcock Report indicated that internationally the implementation of eight hour standards had gained in prominence since the development of the NEPM, in recognition of the cumulative effects of ozone on lung function and respiratory systems. A number of major overseas reviews of the health impacts of ozone have been undertaken or are underway, including a meta-analysis by WHO in 2004. As a result of the strengthening evidence about the health impacts of ozone, several overseas jurisdictions have reviewed, or are currently reviewing, their ozone standards. There is a growing body of data suggesting a link between daily mortality and ozone concentrations during the warmer months. While not all studies support this finding, the evidence has strengthened since 1997-98. In Australia a number of studies have been

[47] WHO Regional Office for Europe *Air Quality Guidelines for Europe* 2000, Ch 7.2
[48] Review of the California Ambient Air Quality Standard for Ozone, March 2005 part 11-21

undertaken since 1997/98 that are relevant to the ozone review, such as the Time Activity Study completed in 2003 and a number of health studies are discussed in chapter 2.

The monitoring data reported under the NEPM since 1998 have been used in this preliminary work for the ozone review to assess current levels and analyse typical exposure patterns in Australia's major urban airsheds. In order to consider whether tighter standards may be becoming more achievable, the monitoring data have also been used to examine whether the standards recommended by the technical review panel in 1998 would have been met had they been adopted.

6.5 HEALTH IMPACTS

The results of epidemiological studies indicate that there may be no threshold for the adverse health effects that have been linked with exposure to ozone. Studies conducted in Australia and overseas have found that adverse health effects such as increases in mortality, hospital admissions, emergency department visits, increases in respiratory symptoms, decreases in lung function and exacerbation of asthma are associated with exposure to ozone over a range of averaging times. The international studies have focussed on maximum one hour and eight hour ozone concentrations. In Australia, in addition to one hour and eight hour averages, maximum four hour ozone concentrations have also been associated with increases in mortality and hospital admissions.

Controlled exposure studies have found that for young healthy individuals, reductions in lung function and increases in respiratory symptoms are associated with exposure to ozone for periods ranging from one hour to 6.6 hours. The Lowest Observed Adverse Effects Level (LOAEL) for this group has been identified at 0.12ppm for exposure to ozone of one to three hours and 0.08ppm for exposure of six to eight hours. As these levels apply to healthy individuals, the LOAELs for sensitive individuals such as asthmatics or children are expected to be lower. For a 1-3 hour exposure a NOAEL of 0.10ppm can be assumed and for a 6-8 hour exposure a NOAEL of 0.04ppm can be assumed. The identification of a NOAEL is suggestive of a threshold for these exposures.

6.6 BACKGROUND OZONE LEVELS

From the previous chapters it is clear that there is still considerable debate over what constitutes 'background' ozone. In Australia there is no agreed definition of what is meant by 'background' ozone levels. The definition of background is critical to the assessment of the achievability of a tighter (0.08ppm) one hour ozone standard, changes to the four hour standard, or a health-based eight hour standard consistent with international guidelines/standards.

Estimates of background provided to the review team by jurisdictions range from 0.02 to 0.04ppm irrespective of averaging period. What this means is that for longer averaging periods (eg eight hours), the relative contribution of background to ambient levels is greater than for the shorter averaging periods (one hour), making the achievability of health-based standards more difficult for an eight hour averaging period.

6.7 EXPOSURE PATTERNS

As described in Chapter 4, analysis of ozone exposure patterns in the major urban centres indicates that Australian cities do not experience a single typical pattern of ozone formation. There can be frequent periods of one to three hours where concentrations are much higher than the rest of the day, and days when there is a rapid increase in concentration and then elevated concentrations that persist for eight to ten hours. There are also circumstances where multiple short-term (eg one hour) peaks are observed within a day. However, the majority of ozone peaks are less than six hours in duration and occur in mid to late afternoon in the warmer months. Sydney generally experiences the ozone peaks of longest duration.

The duration of ozone peaks in Australian cities is relevant to the selection of averaging periods for health-based ozone standards as this is related to the exposure of the Australian population to elevated levels of ozone. The Time Activity Study indicates that people are outdoors (and potentially exposed to ozone) on average for two to three hours per day. This, combined with the analysis of the duration of ozone peaks, suggests that most population groups may not be exposed for extended periods (eight hours or longer) to ozone in Australian cities. Outdoor workers, children and recreational/professional athletes may be exposed for longer periods and form a small but potentially vulnerable group to the effects of ozone.

6.8 OVERSEAS VS AUSTRALIAN SITUATION

The European and North American jurisdictions examined as part of this review have all established an eight hour standard for ozone, either as a single standard or in combination with a one hour standard. The primary reason for the adoption of an eight hour standard is to protect against the cumulative health effects of ozone. These jurisdictions may not be directly comparable to Australia in terms of exposure of the population to ozone. In the US and Europe, long-range trans-boundary transport of ozone is a significant problem and leads to prolonged (eight hours and longer) elevated levels of ozone. Due to the longer exposure periods, the population health effects associated with longer exposures are potentially more significant in these locations. However, differences in ozone duration patterns between the US/Europe and Australia do not mean that health impacts for individuals from the US/Europe and Australia will differ, when exposures of similar durations are compared.

Australian cities tend not to experience the multi-day events with continuing high levels of ozone that occur overseas. However, extreme events such as bushfires or stagnant meteorological conditions can impact on ozone formation patterns. Of the major Australian cities, only Sydney experiences occasional multi-day events. In the future the impact of climate change may influence the frequency and intensity of ozone episodes.

One implication of this analysis is that short-term peaks (eg one hour) may be as significant if not more so than eight hour peaks in terms of exposure and potential health effects in Australia.

Although the results of Australian epidemiological studies indicate that adverse health effects are associated with one hour, four hour and eight hour daily maximum ozone levels, the relative public health importance of the different averaging periods requires a risk assessment to be undertaken.

In agreeing to the commencement of preliminary work for the review of the ozone standards, NEPC requested that the appropriate averaging periods for the ozone standards be considered. While the averaging periods cannot be considered in isolation from the levels to which they apply, the final levels for the standards will be determined as part of the full review of the Ambient Air Quality NEPM.

6.9 ACHIEVABILITY

In 1998, achievability was an important consideration for National Environment Protection Council in determining both the levels and the averaging periods for the standards. One of the issues for consideration in the current review of the standards will be how achievable is a possible change to a longer averaging period such as eight hours, and how achievable is a change to a stricter level such as 0.08ppm for one hour.

Sydney, Melbourne, Perth, Brisbane and Adelaide are the Australian cities with the meteorology, population, size and degree of urbanisation for significant ozone formation. Monitoring data indicate that Melbourne, Perth, Brisbane and Adelaide are currently meeting or are close to meeting the standards and goals in the NEPM. Sydney however regularly records more than five exceedance days per year. This is partly due to the topography of the Sydney basin.

Jurisdictions have a range of strategies in place to reduce emissions of ozone precursors (nitrogen oxides and VOCs) from industry, motor vehicles and domestic/commercial sources. Despite the effectiveness of emission reduction strategies, in a number of cities the predicted growth in population and in motor vehicle use and ownership, and increased industrial and residential development is likely to offset some of the gains from ozone reduction strategies, including significantly lower emissions from vehicles and stricter fuel quality standards. This is likely to be a particular concern for Sydney as it continues to expand. This situation is further complicated by the complexity of the ozone production process so that in some cases reducing NO emissions in urban areas may actually have the perverse effect of increasing ozone formation (Stedman, CSIRO).

Modelling for ozone is complex and predicted trends in ozone levels vary in the major urban airsheds. In general, ozone levels are expected to stay relatively constant with some minor downward trends in locations such as Melbourne.

Data analysed for this review indicates that for some of the major urban airsheds, meeting an eight hour standard consistent with overseas guidelines/standards of 0.06ppm would be more difficult to achieve than a one hour standard of 0.08ppm. However other cities would find it more difficult to meet the tighter one hour standard. In order to meet stricter standards, or in Sydney's case to meet current standards, some significant policy changes may be required to reduce precursor emissions.

The costs and benefits of these policy changes need to be assessed before any changes to the standard are made. In many cases the most cost effective strategies have already been adopted, so the challenge is in identifying further options that are socially and economically viable. Future technological change is likely to continue to assist in reducing emissions although it is difficult to quantify potential impacts. Consideration of costs and benefits are a requirement of the National Environment Protection Council Acts. One key factor in this assessment is the contribution of background levels to any proposed standards. It may be for the longer averaging periods that background would make a major contribution to the health-based level, making such a standard a major challenge to meet for some cities.

6.10 KEY ISSUES FOR COMMENT

This paper has outlined some of the issues to be considered in commencing the review of the ozone standards, particularly those associated with averaging periods for the standards. Your views are sought on issues that should form part of the deliberations for the full review of the standards. Key issues where your input is sought include:

6.10.1 Health Impacts

- What health outcomes (eg lung function, mortality) should be used as a basis for setting ozone standards?
- To what extent should standards take account of the most sensitive individuals in the community?
- What does the health data suggest about the appropriate averaging periods for ozone standards?

6.10.2 Background Ozone

- What is the most appropriate definition of background ozone in a policy context?
- What is the best approach for estimating background ozone levels?
- How should background ozone be taken into account in the standard setting process?

6.10.3 Exposure Patterns

- What does the analysis of Australian ozone monitoring data suggest about averaging periods for ozone standards?
- Do we need the same averaging periods as those used overseas, taking into account exposure in Australia?
- How important is time-activity data for setting standards for ozone?

6.10.4 Achievability

- To what extent should achievability be considered in setting standards for health protection?
- How should achievability be taken into account in the setting of the standard?

6.10.5 Overall

- In light of all the information presented, what do you consider are the most appropriate averaging period(s) for ozone standards in Australia?
- How should climate change be taken into account in the setting of the standards?
- Are there any other issues that need to be considered in setting ozone standards in Australia?

7 WHERE TO FROM HERE

7.1 CALL FOR SUBMISSIONS

The National Environment Protection Council is seeking input from organisations and individuals with an interest in the management of ozone in ambient air. Input from the public will ensure that the Council is well informed on community views and will also assist the Council to prepare for the full review of the ozone standards in the forthcoming review of the Ambient Air Quality NEPM.

You are invited to:

- express your views on the issues outlined in the paper, particularly those listed in Chapter 6
- identify any other issues that you consider should be taken into account in reviewing the ozone standards
- make available any information that you consider pertinent to the review of the ozone standards.

Written submissions should be sent to:
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The closing date for submissions is **Friday 15 July 2005**.

7.2 GUIDE TO MAKING A SUBMISSION

Please include the following information along with your comments or suggestions.

7.2.1 Name and Contact Details

- Your name
- Your address
- A telephone number
- Your company or organisation (where applicable); and
- Your email address (if you have one).

This will allow us to contact you if we have any questions.

7.2.2 Confidentiality

All submissions are public documents unless clearly marked "confidential" and may be made available to other interested parties, subject to Freedom of Information Act provisions.

7.2.3 Format of Submission

An electronic form for lodging comments is available. The form can be emailed to you by the NEPC Service Corporation or downloaded from the EPHC website <www.ephc.gov.au>. This form can be filled out and submitted electronically. It is preferable for submissions to be made using this form.

If you wish to provide your comments in another format, submissions can be:

- emailed to mgilbey@ephc.gov.au
- on a 3.5 inch floppy disk or CD Rom, or
- in hardcopy.

Hardcopy submissions should be unbound to facilitate photocopying. Electronic submissions should be provided in Microsoft Word.

7.3 THE NEXT STEPS

The comments received on the Issues Paper will be analysed and a report prepared for consideration by the National Environment Protection Council. The report will provide input to further work on ozone that will be undertaken as part of the full review of the Ambient Air Quality NEPM scheduled to commence this year.

GLOSSARY

Airshed	An airshed is a part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions
All cause mortality	Deaths due to all causes (except accidents)
Ambient	In the air as it exists in our breathing zone under usual circumstances
Anthropogenic	Having genesis with the human race
Asthma	Chronic disorder of the airways that causes them to narrow too easily and too much in response to a wide range of stimuli
Biogenic	Originating from living organisms
Bronchial hyper-responsiveness	Abnormality of the bronchial tube that makes it narrow too easily and too much in response to various stimuli
Cardiovascular disease	Heart disease
Chronic obstructive pulmonary disease	A group of diseases characterised by an irreversible reduction in expiratory airflow
Controlled exposure study	A study carried out in a controlled environment that measures response to a series of known exposures to the substance of interest
Diurnal pattern	A pattern relating to each day
Dose-response relationship	A relationship in which a change in amount, intensity or duration of exposure is associated with a change, either an increase or a decrease, in risk of a specified outcome
Effective dose	The simple product of concentration, ventilation rate and duration of response
Epidemiological study	A study of the distribution and determinants of disease in populations
Exceedance	An exceedance occurs when the concentration of a pollutant is measured and found to be above the level specified in the air quality standard in the Ambient Air Quality NEPM

Group mean difference	An average difference observed in health response between different exposures for a study group
Health effect	An adverse health outcome associated with exposure to an air pollutant
Lag 1	Previous day exposure
LOAEL	Lowest observed adverse effect level – refers to the lowest concentration or amount of a substance, found by experiment or observation, that causes adverse alterations of morphology, functional capacity, growth, development or life span of target organisms.
Long-term exposure	Months to years in duration
Neural response	A response driven by the nervous system
NOAEL	No observed adverse effect level – refers to the highest dose of a substance at which no toxic (ie adverse) effects are observed
Panel study	Well-defined group of subjects followed over time to measure the relation between an exposure (eg pollution level) and an outcome (eg symptom or lung function)
Photochemical oxidants	Technical term for the type of smog seen in Australia. Photochemical oxidants are formed when sunlight falls on a mixture of chemicals in the air. Ozone is one of the main photochemical oxidants found in this type of smog. Ozone is measured as the marker of photochemical oxidants.
Respiratory disease	Diseases such as asthma, chronic bronchitis, emphysema or serious allergies
Short-term exposure	Hours in duration

ACRONYMS AND ABBREVIATIONS

APHEA	Air Pollution and Health European Approach
ADR	Australian Design Rule
CI	Confidence interval
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EPHC	Environment Protection and Heritage Council
EU	European Union
FEV_1	Forced Expiratory Volume in one second
GRUB	Generally representative upper bound (generally representative of community exposure at the upper range of concentrations likely to be encountered)
LOAEL	Lowest observed adverse effect level
MVEC	Motor Vehicle Environment Committee
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NMMAPS	National Mortality and Morbidity Air Pollution Study (USA)
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NOAEL	No observed adverse effect level
O_3	Ozone
PEF	Peak Expiratory Flow
PEFR	Peak Expiratory Flow Rate
PM_{10}	Particles with an equivalent aerodynamic diameter less than or equal to 10 micrometres
ppb	A measure of gas in parts per billion
ppm	A measure of gas in parts per million

ROC	Reactive organic compound
SO_2	Sulfur dioxide
TAPM	The Air Pollution Model
TSP	Total suspended particulates
UK	United Kingdom
US	United States of America
USEPA	United States Environmental Protection Agency
UV	Ultra-violet
VKT	Vehicle kilometres travelled
VOC	Volatile organic compound
WHO	World Health Organisation

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APPENDIX 1 – HEALTH EFFECTS OF OZONE

Characteristics of study types used to understand health effects of ozone, Mechanisms of Action, Potential for Adaptation, Susceptibility, Review of Key International Studies and Summary of Australian Studies

This Appendix provides a more detailed discussion than provided in Chapter 2 about the characteristics of study types used to understand health effects of ozone, mechanisms of action, potential for adaptation following repeated exposure to ozone, the factors that may affect susceptibility to ozone and some more detailed reviews of the key international studies that provide evidence about the health effects attributable to ozone.

The Appendix includes the results of the Australian health studies discussed in Chapter 2 in tabulated form, including ozone levels relevant to the studies. It also includes an example of a dose response curve for FEV_1 to demonstrate an approach to reporting the health risk from exposure to ozone at the population level.

Characteristics of study types used to understand the health effects of ozone

Controlled Exposure Studies

The main outcomes used to determine adverse health effects in controlled exposure studies include changes in lung function (eg decrements in forced expiratory volume (FEV_1)), cellular and biochemical indicators of pulmonary inflammation (eg eosinophil and neutrophil concentrations in sputum), respiratory symptoms (eg increased cough, shortness of breath and chest pain on deep breath) and changes in bronchial responsiveness.

Many studies include healthy subjects in the 18-35 year age range and include an exercise component to simulate likely exposure conditions for one of the potentially highest exposure population – healthy workers carrying out high levels of activity. One limitation of these studies is that individuals are generally exposed to a constant level for the entire exposure period. This controlled exposure scenario may be quite different to what might be expected in real life situations where a range of concentrations would generally be experienced over an eight hour time period. It is likely that the response in the experimental setting will differ from that experienced in real world exposure conditions (USEPA, 1996).

Another limitation of controlled exposure studies is that the most sensitive individuals (eg people with severe asthma, people with existing chronic obstructive pulmonary disease (COPD) or heart disease) are generally excluded, limiting the generalisability of findings to the broader population.

Epidemiological Studies

Epidemiological studies conducted in various parts of the world have shown links between exposure to ozone and adverse health effects such as premature mortality, emergency department visits and hospitalisations, reductions in lung function and increases in respiratory symptoms. In general the effects are greater during the warmer months than for other times of the year. Like controlled exposure studies, there are some limitations in utilising results from epidemiological studies. These include issues around exposure assessment and controls for covariates and confounders. However, one key advantage of epidemiological studies is that they measure the health response of the broad population, including the most susceptible groups, to the effects of ozone.

Mechanisms of action

Ozone is a highly reactive gas and powerful oxidant with a short half-life. The mode of breathing (whether nasal or oral) has little effect on uptake, suggesting that ozone is removed equally by both mouth and nose.

Recent research indicates that the switch from nasal to oral breathing coupled with increases in respiratory flow associated with exercise causes a shift in the ozone dose distribution. This means that under these circumstances ozone penetrates deeper into the lung, increasing the potential of damage to bronchiolar and alveolar tissues (USEPA, 2005).

In addition, there are considerable inter-individual differences in the absorbed fraction of ozone (ranging from 0.25-0.97) that are critical for understanding ozone dose-response relationships (USEPA, 2005).

Both neural and inflammatory responses to ozone have been identified, though their interactions and associated response times are complex and not completely understood. A comprehensive review of recent findings on mechanisms of action can be found in Chapter 6 of the USEPA Review (2005).

Potential for Adaptation

Numerous studies have observed a dampening or attenuation of some adverse health effects (eg reduction in FEV_1) following repeated short-term ozone exposures (ranging from two to 6.6 hours) over days (Gong et al, 1997b; Folinsbee et al, 1994; Christian et al, 1998). In these studies, no increase in adverse health affects was observed following between two and four days of repeated exposure. This finding has typically been observed in studies of healthy individuals and individuals with mild asthma and suggests that the lack of adverse change in some health effect measures following repeated ozone exposure is suggestive of adaptation to repeated ozone exposure.

However, in contrast to this, there is evidence that some health effect measures such as small airway dysfunction and some measures of airway inflammation persist or even increase with repeated ozone exposure (Frank et al, 2001; Jorres et al, 2000). The long-term health impact of these persistent measures of response is not well understood.

Further, baseline lung function appears to decrease with repeated ozone exposure and attenuation of both lung function and symptom responses to a fixed ozone concentration does not necessarily alter the response to a subsequent exposure to higher or lower ozone concentration. The individual variability in response to ozone also indicates that any adaptation observed is not consistent across all individuals within a study.

Recent dosimetry studies continually exposing subjects to either ozone or nitrogen dioxide or sulfur dioxide for two hours, indicate that continuous ozone exposure lowered the uptake of ozone, whereas prior continuous exposure to nitrogen dioxide or sulfur dioxide increased capacity for ozone absorption. The reason provided for this is that continuous exposure to ozone depletes the compounds that are oxidised by ozone, hence reducing ozone uptake (USEPA AX4-7).

Susceptible Groups

There are a number of factors that influence an individual's reaction to ozone. These include potential for high exposure and individual susceptibility, including the presence of a pre-existing condition.

High Exposure

Higher exposures are most likely to occur for individuals spending significant amounts of time outdoors and for those who participate in outdoor activities that increase breathing rate, eg outdoor workers, children, recreational and professional athletes.

Individual Susceptibility

The literature suggests that there is an intrinsic genetic variability to ozone and that there are individuals who are 'ozone responders'. Large differences, in the order of ten to one hundred fold, in the same health outcome measure in response to the same ozone exposure across individuals have been reported in controlled exposure studies (Woolcock, 2003; Californian EPA, 2004). Studies have also indicated that individuals who respond with one health outcome measure may not respond in other ways.

Other influences on response to ozone such as age, gender and ethnicity have been investigated by a range of controlled exposure and epidemiological studies. Of these only age appears to influence response. Controlled exposure studies indicate that children and young adults appear to have similar responses to ozone, with a lessening of response with increasing age (Hazucha et al; McDonnell et al, 1997) up to approximately 55 years (Gong et al, 1997a). Epidemiological evidence indicates associations between ozone and respiratory health endpoints for all ages, though associations are generally strongest in children.

Pre-Existing Conditions

Asthma

Though the controlled exposure studies do not provide strong evidence of a difference in magnitude of response for individuals with asthma, this group already have a compromised respiratory system and hence the overall impact of ozone exposure is likely to be higher. In addition, many of the controlled exposure studies with subjects with asthma provide little information on the severity of asthma in individuals, and for those where this information is provided, subjects with mild-moderate asthma are typically included.

Some studies do indicate that individuals with asthma experience a more vigorous ozone induced inflammatory response in both the upper and lower airways than individuals without asthma (Scannell et al, 1996; McBride et al, 1994). This inflammatory response may explain the epidemiological evidence that indicates statistically significant associations between ozone and asthma hospitalisations, emergency department visits and individual measures such as lung function and respiratory symptoms in individuals with asthma.

As demonstrated in healthy subjects, subjects with asthma also adapt to repeated ozone exposures (Gong et al, 1997b).

Chronic Obstructive Pulmonary Disease (COPD)

Controlled exposure studies with COPD subjects have all included ozone exposures higher than current standards (eg one hour maximum ozone of 0.12ppm – Linn et al, 1982, four hour exposure to 0.24ppm – Gong et al 1997a) and, even at these higher exposures, individuals with COPD are unlikely to experience marked respiratory effects as a result of ozone exposure.

Some epidemiological studies (eg Anderson et al, 1997) have reported associations between ozone and hospital admissions for COPD.

Although there is not consistent evidence from controlled exposure studies to indicate that individuals with asthma or COPD, as a sensitive subgroup, may experience decreases in lung function (ie observed response has been similar in individuals with asthma and without), it is important to consider the magnitude of changes in individuals with pre-existing impaired respiratory function. A comparable change in lung function is likely to have a greater impact on the health status of an individual with a pre-existing respiratory disease such as asthma, chronic bronchitis, emphysema or serious allergies, than on a healthy individual with normal lung function and reserve capacity (USEPA, 1996b).

Controlled Exposure Studies

One to Three Hour Ozone Exposures

Exposures to 0.12ppm ozone for one to three hours with moderate exercise have been reported to be associated with reductions in lung function for some healthy subjects (Horstman et al, 1990; Folinsbee et al, 1988; McDonnell et al, 1995; Adams, 2002). For example, statistically significant ($p<0.05$) though small average reductions in lung function for the whole study group (in the order of 3-5% measured as FEV_1) have been observed following approximately three hours of exposure to ozone as low as 0.12ppm (eg Horstman et al, 1990). The study by Horstman et al (1990) exposed 22 healthy non-smoking male volunteers aged 18-35 years for 6.6 hours of ozone exposures at 0.0, 0.08, 0.10 and 0.12ppm on different days. Exposures included six 50-minute exercise periods. The presence of ozone was identified through odour, but subjects and investigators were blinded to the actual exposure concentrations greater than zero. The responses to the varying ozone exposures for a range of lung function measures, respiratory symptoms and airway reactivity were assessed. A large variability in magnitude of responses between individuals was observed, consistent with a number of other studies (Folinsbee et al, 1988; McDonnell et al, 1983; Ultman et al, 2004).

Though a number of studies have included exposures less than 0.12ppm, there are no studies that indicate significant changes in group mean differences to ozone concentrations below this level although some individuals did respond to concentrations lower than 0.12ppm (Californian EPA, 2004). For example, Horstman et al (1990) and McDonnell et al (1991) reported no statistically significant change in group mean FEV_1 after a one hour exposure to 0.10ppm.

Based on the group mean response, these findings indicate a LOAEL for the health outcomes investigated in these studies of 0.12ppm for an exposure to ozone of one to three hours in healthy, moderate to heavy exercising individuals and a NOAEL of 0.10ppm. As the LOAEL represents the level at which a statistically significant mean reduction in lung function was observed, it could be expected that sensitive individuals would respond to lower levels of ozone. Controlled exposure studies have consistently reported significant variability in individual response to ozone. For example, Horstman et al (1990) reported individual FEV_1 responses to ozone in normal subjects ranging from +7.0 to -25.9% at 0.08ppm and from +2.8 to -38.9% at 0.12ppm.

Six to Eight Hour Ozone Exposures

Several controlled exposure studies in healthy non-smoking adults investigating exposure durations of six to eight hours for a range of exposure levels (including exposures potentially experienced by the community eg 0.08, 0.10 and 0.12ppm) indicate statistically significant lung function responses to 0.08ppm ozone (the lowest concentration evaluated) after moderate exertion (Horstman et al, 1990; McDonnell et al, 1991, 1995; Adams, 2002). These studies also indicate an increasing response after the third hour of exposure.

The study by McDonnell et al (1995) exposed 68 healthy non-smoking adults aged 18 to 34 years to two or more 6.6 hour ozone exposures of combinations of 0.0, 0.08, 0.10 or 0.12ppm. During the exposure period, five hours of exercise were undertaken by participants and lung function was measured before exposure and following each hour of exposure. The proportion of subjects experiencing a 10% decrement in FEV_1 at each exposure time and concentration was investigated.

Though average changes observed after exposures to 0.08ppm ozone are typically mild or small (for example Horstman et al (1990) reported a significant reduction in FEV_1 of 7% and Adams (2002) reported a significant reduction in FEV_1 of 6.4%), responses of some sensitive individuals are sufficiently severe and prolonged to be considered adverse. McDonnell et al (1995) report that after 6.6 hours of exposure to 0.08ppm ozone, 30% of participants experienced a 10% decrement in FEV_1.

Adams' (2002) study of 30 healthy adults with exposure over a period of 6.6 hours to doses of fresh air, 0.04, 0.08 and 0.12ppm also found a significant mean increase in measures of pain on deep inspiration and total symptoms scores following 6.6 hours of 0.12ppm and a significant mean increase in total symptoms scores (not pain on deep inspiration) following 6.6 hours of 0.08ppm. This study utilised a different dosing method (face-mask exposure) for exposing subjects compared to previous studies (chamber exposure), though a subsequent comparative study by Adams (2003) did not find any significant difference between responses for the two different dosing methods used.

The concept of **"**effective dose**"** is critical for understanding a health response to ozone. Controlled exposure studies have indicated that effective dose for ozone is a function of ozone concentration, ventilation and duration of exposure. Ozone concentration is the primary influence, followed by ventilation and then duration of exposure. Controlled exposure studies have also indicated that the higher the ozone concentration, the more rapid the adverse health effects become apparent.

Results from numerous controlled exposure studies indicate that the response to ozone exposure is not a linear function of concentration. For example, McDonnell et al (1991) report a curvilinear response as a function of exposure duration and McDonnell et al (1995) present a dose-response model indicating that the averaging time that best describes response is a function of concentration and will be longer for low concentrations and shorter for high concentrations.

Hazucha et al (1992) explored the relationships between ozone concentration and duration of exposure further by exposing two groups of subjects to two patterns of ozone exposure - a steady state profile (eight hours at 0.12ppm) and a triangular profile (increased linearly from 0 to 0.24ppm over the first four hours and then decreased back to zero in the last four hours). The two exposure profiles induced similar exposure doses in the first four hours of exposure, resulting in lung function and symptom responses of a similar magnitude. However, during the second four hours of exposure, the lung function changes were considerably larger for the triangular exposure profile compared with the steady state profile.

Epidemiological Studies

Epidemiological studies provide information about the impacts of ozone exposure on the range of susceptible populations and for a range of exposure conditions that reflect real exposures. As well as providing information on the impacts on symptoms and lung function, epidemiological studies also provide valuable information on the impacts of ozone exposure on mortality, emergency department visits and hospitalisations. Some epidemiological studies can also provide valuable information on the adverse health effects of longer-term exposures to ozone (eg months or years).

Epidemiological studies conducted in various parts of the world have consistently shown links between exposure to ozone and adverse health effects such as premature mortality, emergency department visits and hospitalisations, reductions in lung function and increases in respiratory symptoms. In general the effects are greater during the summer than for other times of the year. Like controlled exposure studies, there are some limitations in utilising results from epidemiological studies. These include issues around exposure assessment and controls for covariates and confounders. However, one key advantage of epidemiological studies is that they measure the health response of the broad population, including the most susceptible groups, to the effects of ozone.

The most common averaging period for ozone concentrations used in epidemiological studies is the daily one hour maximum. Approximately 70% of the studies published in the literature used one hour maximum values, 20% used eight hour maximum average and 25% used 24 hour averages. The Australian studies have also included analysis of four hour maximum ozone concentrations. The relative importance of the averaging periods in the risk posed to the health of the population is difficult to determine and requires a quantitative risk assessment. The effect estimates for each period are similar, however there is much greater variability in one hour ozone concentrations than four hour or eight hour concentrations.

Mortality Studies

The findings of studies investigating the association between ozone and increases in daily mortality have been variable although a large number of recent studies provide an increasing body of information that links exposure to ozone (especially in the warm months) with increases in daily mortality for all causes, respiratory and cardiovascular causes.

The APHEA studies have found that increases in daily all cause mortality are associated with daily one hour maximum and eight hour (9am - 5pm) ozone concentrations in several European cities (Gryparis et al, 2004; Anderson et al, 1996). The study by Anderson et al (1996) found that eight hour ozone concentrations were associated with increases in all cause, respiratory and cardiovascular mortality in London. The associations with all cause and cardiovascular mortality were significant in the warm season but not in the cool season. The association with respiratory mortality was similar in both seasons. Gryparis et al (2004), as part of the APHEA2 project, found that for the warm season an increase of 0.005ppm in daily one hour maximum ozone concentrations was associated with a 0.33% (95% CI, 0.17-0.52) increase in all cause mortality, 0.45% (95% CI, 0.22-0.69) increase in cardiovascular deaths and 1.13% (95% CI, 0.62-1.48) in respiratory deaths. The corresponding figures for eight hour ozone were similar to those found for one hour ozone. The associations with all cause mortality were independent of SO_2 and PM_{10} but were somewhat confounded by NO_2 and CO. Individual city estimates showed significant variability for both all cause and cardiovascular deaths. For cardiovascular mortality, larger effects were observed in the southern European cities included in the APHEA2 project. No effects were observed during the cool months.

Kinney and Ozkaynak also found that one hour and eight hour maximum ozone concentrations were associated with increases in daily mortality, however this relationship was not significant when particles were accounted for in the analysis (Kinney and Ozkaynak, 1991, 1992). This finding is consistent with other studies where there is a high correlation between particles and ozone.

As part of the National Mortality and Morbidity Air Pollution Study (NMMAPS) in the US, the association between 24 hour average ozone concentrations and increases in daily mortality was investigated in the 90 largest US cities (Samet et al, 2000; Dominici et al, 2003). The results of this study found a 0.4% increase in mortality per 10ppb increase in 24 hour average ozone during the warm season. The results obtained during the cool season were negative (-0.5%) and statistically significant.

Other studies from various parts of the world have also found significant positive associations between ozone in the warm season and increases in mortality. These include analyses of Netherlands data (Hoek et al, 2000, 2003), Australia (EPA Victoria, 2000; Simpson et al, 1997; Morgan et al, 1998; WA Department of Environment, 2003), Montreal Canada (Goldberg and Burnett, 2003) and Vancouver Canada (Vedal et al, 2003). All these studies found stronger associations in the warm season than in the cool season.

From an analysis of the international literature, the Californian EPA estimate that the median effect estimate for one hour maximum ozone is 3% per 0.04ppm change in one hour ozone (Californian EPA, 2004). Using the data from European cities, Anderson et al (2004) report an effect estimate of 0.6% per 0.04ppm change in eight hour ozone.

Hospital Admissions and Emergency Department Visit Studies

The most significant consistent short-term health effects observed in epidemiological studies with exposure to ozone are increased hospital admissions and emergency department visits due to respiratory causes. These health effects can include respiratory infections such as pneumonia, asthma attacks and exacerbation of other respiratory diseases such as COPD. These effects are observed for people with asthma and other impaired respiratory symptoms. There is no evidence that healthy individuals are affected by ambient ozone to such an extent that it results in admission to hospital or treatment at an emergency department of a hospital (USEPA, 1996b). Although some studies have reported associations between ozone and increases in hospital admissions for cardiovascular causes, these studies are limited and the results are variable (Californian EPA, 2004b).

The largest studies investigating the association between ozone and daily increases in hospital admissions have been conducted in Canada (Burnett et al, 1997a) and Europe (Anderson et al, 1997). Both studies reported significant ozone effects and hospitalisations for respiratory causes. The Burnett et al (1997a) study of 16 Canadian cities reported significant positive associations between daily one hour ozone concentrations (lag 1) and hospital admissions for respiratory causes in spring and summer. Smaller effects were observed in autumn and no association was observed in winter. Though other averaging periods were examined (24 hour mean, 8am to 8pm mean, and daily eight hour maximum), the strongest association was observed for the daily one hour maximum.

The Anderson et al (1997) study conducted as part of the APHEA1 study examined the association between daily ozone concentrations and hospital admissions for respiratory causes in six European cities – Amsterdam, Barcelona, London, Milan, Paris and Rotterdam. The strongest and most consistent associations were found for hospital admissions for COPD.

Effects were observed in full year analyses but were stronger during the warm months. Analysis was also conducted for black smoke, TSP, SO_2 and NO_2 but the most consistent and significant findings were for ozone.

There are many other studies from around the world that also provide substantial evidence for ozone effects on respiratory hospitalisations (Burnett et al, 1999, 2001; Lin et al, 2003; Moolgavkar et al, 1997; Petroechevsky et al, 2001; EPA Victoria, 2001; WA Department of Environment, 2003; Morgan et al, 1998b; Schouten et al, 1996; Sheppard et al, 1999) and emergency department visits for asthma and other respiratory causes (Cassino et al, 1999; Delfino et al, 1998, 1997; Hernadez-Guarduno, 1997; Jaffe et al, 2003; Jones et al, 1995; Lin et al, 1999; Martins et al, 2002; Stieb et al, 1996; Tenias et al, 1998, 2002; Tobias et al, 1999; Tolbert et al, 2000; White et al, 1994; Romieu et al, 1995; Weisel et al, 1995).

Several studies have been published in the last decade examining the association between ozone and emergency department visits for asthma and other respiratory causes (Cassino et al, 1999; Delfino et al, 1998, 1997; Hernadez-Guarduno, 1997; Jaffe et al, 2003; Jones et al, 1995; Lin et al, 1999; Martins et al, 2002; Stieb et al, 1996; Tenias et al, 1998, 2002; Tobias et al, 1999; Tolbert et al, 2000; White et al, 1994; Romieu et al, 1995 and Weisel et al, 1995). Many of these studies have investigated the impact of ozone on emergency department attendances for asthma.

The studies examining the association between ozone and emergency department visits for asthma and respiratory disease in children have found consistent significant effects (Stieb et al, 1996; Jaffe et al, 2002; Tolbert et al, 2000; Linn et al, 1999; Martins et al, 2002). The study by Stieb et al (1996), found that there was an elevated risk at one hour maximum ozone concentrations greater than 75ppb but this was not statistically significant. A similar result was found for people older than 15 years but in this age group the results were statistically significant. A study by Linn et al (1999) found that respiratory emergency department attendances for children in Sao Paulo were significantly associated with ozone. A further study in Sao Paulo reported significant positive associations with emergency department visits for respiratory causes in people over 65 years of age (Martins et al, 2002).

Several studies have investigated the concentration response function for the association between ozone and emergency department visits. These studies give some insight into the ozone concentrations that may be of concern. Stieb et al (1996) found an increased risk of emergency room visits in adults exposed to one hour ozone concentrations above 75ppb (maximum 160ppb). Emergency department visits for childhood asthma in summer in Atlanta indicated a significantly elevated risk at one hour ozone concentrations above 110ppb (maximum 160ppb) (White et al, 1994). Weisel et al (1995) reported significant effects for one hour summertime ozone concentrations and emergency room visits for asthma above 60ppb (maximum 160ppb). Romieu et al (1995) reported an association between emergency room visits for childhood asthma and one hour ozone concentrations in Mexico City. The strongest associations were observed when consecutive days had ozone concentrations above 110ppb. Tolbert et al (2001) reported an association between paediatric emergency room visits for asthma and ozone in Atlanta with elevated risks becoming apparent at eight hour ozone concentrations greater than 70ppb. The effects became statistically significant when eight hour concentrations were between 100ppb and 113ppb.

Panel and Field Studies

In addition to broad population studies examining the association between increases in daily mortality, hospital admissions and emergency department visits, a number of studies have also examined the effects of exposure to ozone on people in high exposure groups such as children on summer camps (Kinney et al, 1996), hikers (Korrick et al, 1998) and outdoor workers (Brauer et al, 1996). These studies have focussed on individuals with asthma and usually involve small groups of subjects. The common health outcomes used in these studies include lung function, respiratory symptoms and asthma medication usage. The value of these types of studies is that they provide information on exposure-response at an individual level and allow for control of individual level factors that may influence the health outcome of interest.

A large body of literature (reviewed by the USEPA, 1996) from past clinical and field studies demonstrates reversible decrements in lung function following ozone exposure. In the past decade only a few studies have provided new insights regarding these effects. In the study by Brauer et al (1996), statistically significant changes in measures of lung function were reported with one hour maximum ozone concentration. Lung function was measured in a group of 58 berry pickers (10-69 years) before and after outdoor summer work shifts in the Fraser Valley in British Columbia. Work shifts averaged 11 hours in duration. Significant decrements in lung function were found at the end of the shift and the following morning. The ozone effects remained significant when data were restricted to daily one hour maximum ozone concentrations less than 40ppb.

A study conducted in Alpine California found no significant effects on morning or evening peak expiratory flow rate (PEFR) among 22 individuals with asthma aged 9-46 years even though daily 12 hour ozone concentrations ranged from 34 -103ppb. Personal exposure was measured in this study by the use of passive ozone samplers. The negative findings in this study may be related to the small sample size and imprecision in personal sampling (Delfino et al, 1997b). A further study conducted in Moline Illinois found significant associations between morning and evening PEFR and ozone in a study of 40 individuals with asthma (Ross et al, 2002) although some questions have been raised about the statistical analyses used in this study.

A study by Gent et al (2003) investigated daily respiratory symptoms in 271 asthmatic children in New England over a six month period. Significant effects were found with both one hour and eight hour ozone at levels above 52ppb at lag 1 (previous day exposure). A variety of symptoms were investigated including chest tightness and shortness of breath in children who used asthma medication. Of particular importance in this study was the finding that significant associations were observed at one hour maximum ozone concentrations of 43.2ppb and higher and eight hour maximum concentrations of 63.3ppb and higher.

A number of other panel studies have also found significant associations with ozone and respiratory symptoms mainly in asthmatic children (Desqueyroux et al, 2002; Gielen et al, 1997; Gold et al, 1999; Hiltermann et al, 1998; Romieu et al, 1996; Ross et al, 2002). Three studies conducted in Mexico City found significant associations between symptoms (such as cough, phlegm and difficulty breathing) and daily one hour maximum ozone concentrations (Romieu et al, 1996; Romieu et al, 1997; Gold et al, 1999). A study by Gielen et al (1997) of 61 mostly asthmatic children aged 7-13 years in Amsterdam found only limited evidence of an association between symptoms and ozone exposure. Of 14 symptoms analysed only upper respiratory symptoms were associated with ozone concentration.

Tabulated results of Australian Studies

The following tables summarise the outcomes of Australian ozone studies. They were compiled as part of the Woolcock Institute Report (2003)

Table 12: Summary of Australian Panel Studies published up to 2003

Location (study period)	Study details	Averaging period	Ozone levels (ppm)	Outcome factor	Results
Sydney (Jalaludin 2000)	125 children with wheeze followed for 12 months in 1994 with daily asthma diaries	1-h mean of daytime period (6am-9pm)	Mean 1-h maximum of daytime period: 0.012 (maximum=0.04)	Evening peak expiratory flow rate	All children: beta=-0.88 (se=0.42) Children with asthma and positive histamine challenge: beta=-2.61 (se=0.78) *Results from models adjusting for PM_{10} and NO_2.
Brisbane/Ipswich (Rutherford 2000)	About 60 asthmatics recorded PEFR twice a day at two cities (children and adults) in 1994-1995	1-h and 8-h mean of daytime period (10am-6pm)	Mean 1-h maximum: 0.03-0.035 Mean 8-h: 0.022-0.027	Morning PEFR	Single air pollutant models. Eight hour ozone effects on PEFR in allergic asthmatics (allergic to pollen/fungal spore) in spring when ozone levels are high. Effects confounded by fungal spores.
Sydney (Jalaludin, in press, 2003)	125 children with wheeze followed for 12 months in 1994 with daily asthma diaries	1-h mean of daytime period (6am-9pm)	Mean 1-h maximum of daytime period: 0.012 (maximum=0.04)	Evening wheeze Evening dry cough Evening wet cough Asthma medication use Doctor visit for asthma	No association between ambient ozone and any of the outcome factors

Table 13: Summary of outcomes of Australian hospitalisation studies published 1997- 2003

Author, year and city	Type of Hospital Admission	Age	Averaging Period	RR	Unit Increase	Ambient ozone mean(SD)	Adjusted confounders
Petroeschevsky 1987-1994 Brisbane	Total respiratory	All	8 hr	1.023(1.003-1.043)*	1pphm	1.90 pphm for 8 hour (0.17-6.47)	season,flu,day,long term, holiday, temp, humidity, rainfall, age, year, , lag 0-5 days
	Total asthma	All	8 hr	1.090(1.042-1.141)*			
	Total cardiovascular	All	8 hr	0.987(0.971-1.002)			single pollutant model for ozone
	Total respiratory	All	8 hr	1.021(0.998-1.045)			above plus bsp
	Total respiratory	All	8 hr	1.022(1.001-1.043)*			above plus SO2
	Respiratory	15-64	8 hr	1.042(1.004-1.082)*			
	Respiratory	65+	8 hr	1.042(1.001-1.085)*			
	All of above		1 hr max.	"Effects not as great"		2.53 pphm for 1 hour (0.25-10.72)	
Morgan 1990-1994 Sydney	Asthma	1-14	1 hr max.	0.9747(0.9321-1.0192)	28 ppb	Daily 1-h max.: 25 (13) ppb	weather, season, long term trends, day, holidays, single pollutant
	Asthma	15-64	1 hr max.	1.0251(0.9749-1.0779)			
	COPD	65+	1 hr max.	1.0097(0.9602-1.0618)			
	Heart Disease	All	1 hr max.	1.012(0.9897-5.35)			
	Heart Disease	65+	1 hr max.	1.0245(0.9963-1.0535)			
	Heart Disease	<64	1 hr max.	0.9987(0.9508-1.0281)			
	Asthma	1-14	1 hr max.	0.9719(0.9294-1.0163)			above plus particulates and NO2
	COPD	65+	1 hr max.	0.9938(0.9450-1.0450)			
	Heart Disease	65+	1 hr max.	1.0043(0.9766-1.0327)			
EPA Victoria 1994-1997 Melbourne	Respiratory	All	8 hr max.	1.0014 (1.0006-1.0022)*	1ppb	21.79 (8.89) ppb for 8 hour (all year)	weather, season, long term trends, day, holidays, single pollutant
	Respiratory	All	4 hr max.	1.0014 (1.0006-1.0022)*		24.65(9.99) ppb for 4 hour (all year)	
	Respiratory	All	1 hr max.	1.0013 (1.0005-1.0021)*		26.35(11.11) ppb for 1 hour (all year)	
	Respiratory	65+	8 hr max.	1.0014 (0.9998-1.0030)			
	Respiratory	65+	4 hr max.	1.0016 (1.0002-1.0030)*			
	Respiratory	65+	1 hr max.	1.0015 (1.0003-1.0027)*			
	Asthma	0-14	8 hr max.	0.9978(0.9955-1.0002)			
	Asthma	0-14	4 hr max.	0.9985(0.9965-1.0005)			
	Asthma	0-14	1 hr max.	1.0021(0.9992-1.0051)			
	Respiratory	65+	4 hr max.	1.0038 (1.0011-1.0066)*			above plus NO_2
	Respiratory	65+	4 hr max.	1.0094 (0.9996-1.0194)			above plus CO
	Respiratory	All	4 hr max.	1.0090 (0.9990-1.0192)			above plus CO
	see Figure 7.8.1a					25.07(11.13) ppb for 8 hour (warm season) 28.18(13.13) ppb for 4 hour (warm season) 30.35(15.02) ppb for 1 hour (warm season)	
WA Dept of Envir 1992-1997 Perth	Respiratory	All	4 hr max.	1.0016(1.0000-1.0033)*	1ppb	25.9 (6.5) ppb for 8 hour	Case cross-over analyses. Current day with 1 week before and 1 week after. Adjusted for humidity, temperature, day and holidays.
	Respiratory	All	1 hr max.	1.0015(1.0002-1.0028)*		28.8 (7.8) ppb for 4 hour	
	COPD	All	4 hr max.	1.0047(1.0002-1.0092)*		31.6 (10.2) for 1 hour	
	Asthma	0-14	1 hr max.	1.0031(1.0003-1.0058)*			

*= p <0.05

Table 14: Summary of the Australian studies of ambient ozone and mortality published 1997-2003.

Author	Year	City	Type of Mortality	Age	Averaging Period	RR	Unit Increase	Adjusted confounders
Morgan	89-94	Sydney	Total	All	1 hr max.	1.0204 (1.0037-1.0373)*	28ppb	weather, , long term trends, day,
			Respiratory	All	1 hr max.	1.0252(0.9975-1.0538)		holidays, influenza epidemic,
			Cardiovascular	All	1 hr max.	0.9916(0.9284-1.0591)		
				All		1.0169((0.9949-1.0395)		above plus particulates and NO2
				All		1.0229(0.9953-1.0514)		
				All		0.9814(0.9189-1.0482)		
Simpson	91-96	Melbourne	Total	All	1 hr	1.0011(1.0003-1.0019) (all year)	1ug/m3	weather, long term trends, day,
			Total	>65	1 hr	1.0008(1.0002-1.0014) (all year)		season, holidays, influenza
			Respiratory	All	4 hr	1.0027(1.0007-1.0047) (all year)		single model only, no sig. efect in muti-models
			Respiratory	>65	4 hr	1.0029(1.0007-1.0051) (all year)		
			Cardiovascular			no sig effect (all year)		
			Total	All	1 hr	1.0016(1.0006-1.0026) (warm season)		weather, long term trends, day,
			Total	>65	1 hr	1.0010(1.0004-1.0016) (warm season)		season, holidays, influenza
			Respiratory	All	4 hr	1.0035(1.0011-1.0059) (warm season)		single model only, no sig. efect in muti-models
			Respiratory	>65	4 hr	1.0042(1.0016-1.0068) (warm season)		
			Cardiovascular			no sig. effect (warm season)		
Simpson	1987-1993	Brisbane	Total	All	1 hr	1.016(1.006-1.026)*	10ppb	weather, long term trends, day,
			Total	All	8 hr	1.024(1.008-1.040)*		season, holidays, influenza
			Cardiovascular	All	1 hr	1.012(0.994-1.031)		single model only,
			Cardiovascular	All	8 hr	1.020(0.992-1.049)		no interactions between pollutants in multi-pollutant models
			Respiratory	All	1 hr	1.013(0.977-1.050)		
			Respiratory	All	8 hr	1.039(0.980-1.101)		
			Total	>65	1 hr	1.016(1.004-1.028)*	10ppb	
			Total	>65	8 hr	1.024(1.005-1.042)*		
			Cardiovascular	>65	1 hr	1.013(0.993-1.034)		
			Cardiovascular	>65	8 hr	1.019(0.987-1.052)		
			Respiratory	>65	1 hr	1.019(0.982-1.059)		
			Respiratory	>65	8 hr	1.045(0.982-1.112)		
EPA Victoria	1991-1996	Melbourne	Total	All	8 hr max.	1.0023(1.0013-1.0033)*	1ppb= 0.1pphm	weather, season, long term trends, day,
			Total	All	4 hr max.	1.0020(1.0010-1.0030)*		holidays, single pollutant, population
			Total	All	1 hr max.	1.0018(1.0010-1.0026)*		
			Total	65+	8 hr max.	1.0011(1.0001-1.00021)*		
			Total	65+	4 hr max.	1.001(1.0002-1.0018)*		
			Total	65+	1 hr max.	1.0009(1.0003-1.0015)*		
			Respiratory	All	8 hr max.	1.0045(1.0017-1.0073)		
			Respiratory	All	4 hr max.	1.0040(1.0016-1.0064)		
			Respiratory	All	1 hr max.	1.0035(1.0015-1.0055)		
			Respiratory	65+	8 hr max.	1.0051(1.0021-1.0081)		

Author	Year	City	Type of Mortality	Age	Averaging Period	RR	Unit Increase	Adjusted confounders
			Respiratory	65+	4 hr max.	1.0045(1.0021-1.0069)		
			Respiratory	65+	1 hr max.	1.0040(1.0018-1.0062)		
WA Dept of Envir	1992-1997	Perth	Other	All	8 hr max.	0.9998(0.9973-1.0024)	1 ppb	Case cross-over analyses. Current day with 1 week before and 1 week after. Adjusted for humidity, temperature, day and holidays.
					4 hr max.	0.9992(0.9971-1.0013)		
					1 hr max.	0.9994(0.9978-1.0010)		
			Respiratory	All	8 hr max.	1.0071(0.9977-1.0167	1 ppb	
					4 hr max.	1.0035(0.9981-1.0088)		
					1 hr max.	1.0021(0.9978-1.0063)		
			Cardiovascular	All	8 hr max.	1.0042(1.0006-1.0079)	1 ppb	
					4 hr max.	1.0033(1.0003-1.0063)		
					1 hr max.	1.0023(0.9999-1.0046)		

Use of dose response curve to report health risks

The following curve presented in the Woolcock Report (2003) demonstrates the values for duration and concentration of ozone that would be required to prevent 90% of the population from experiencing a 10% decrement in FEV1.

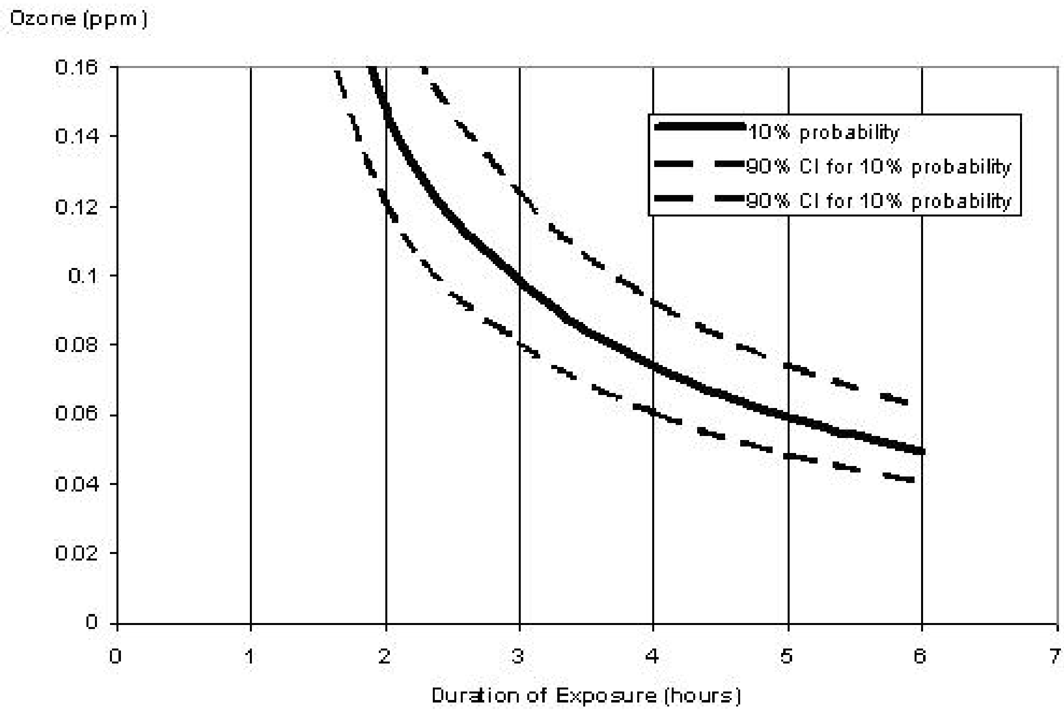

Figure 4: The relationship between duration of exposure and concentration of ozone that would cause 10% of the "population" to experience a 10% decrement in FEV_1. CIs are 90%. Adapted from McDonnell et al. (1995)[20]. The data were derived for exposures in the range 0.08 and 0.12ppm. Hence, values beyond that range represent extrapolation.

Although these data cannot be extrapolated to populations other than the young, healthy, non-smoking white males undertaking moderate exercise, who were participants in the McDonnell et al study, this probably represents a segment of the population which is moderately susceptible to reduced lung function on exposure to ozone. Hence, it would appear to be a reasonable basis for setting exposure limits to reduce the risk of episodes of ventilatory impairment. A regulatory regimen which prevented exceedances of the solid line in the figure would appear to be appropriate. This would entail a two-hour threshold of 0.14ppm, a four-hour threshold of 0.075ppm and/or a six-hour threshold of 0.05ppm (Woolcock, 2003 p37).

APPENDIX 2 – DESCRIPTION OF OZONE MONITORING SITES

In New South Wales, the Sydney region has seven ozone measurement sites from Richmond in the north-west to Macarthur in the south and Oakdale in the west. All of these are long–term trend sites that will measure ozone for at least 10 years. Ozone is measured at two sites in the Lower Hunter region and the Illawarra region has three sites. Campaign monitoring has been undertaken in Bathurst to characterise inland cities and verify the screening criteria. The NEPM Monitoring plan is currently under review. The classification of the exposed population represented by the monitoring sites is detailed in Appendix B of the monitoring plan.

Victoria has eight regions identified for NEPM purposes, the most populous being the Port Phillip region containing Melbourne and Geelong. There are nine ozone measurement sites in that region, classified as either GRUB or population-average sites. The Latrobe Valley has two sites, also classified as GRUB or population-average sites.

Ozone monitoring in Queensland is concentrated in the SE Queensland Region, which itself has been divided into four sub-regions in consideration of the interaction between the topography and meteorology in the area. The Brisbane sub-region has three GRUB sites representative of average population exposure, the North Coast sub-region has one GRUB site for ozone measurement, and the Ipswich sub-region has one ozone monitor classified as a GRUB site. In the Gladstone Region, the Targinnie site is also a GRUB site, but at some distance from Gladstone itself, has low population density. Nevertheless, exposure in the region can more confidently be characterised by siting the instrument at this distance downwind from precursor sources, where it is more likely to detect ozone near its maximum concentrations.

In Western Australia the highest potential for community ozone exposure is in the Perth region. Ozone measurement is conducted at six sites across the region from Quinns Rock in the north to Rockingham in the south. These sites generally can be described as GRUB sites, and therefore are closely representative of community exposure. The Rolling Green site in the northeast is located in a rural area and is located to monitor the extent of ozone formation with prolonged reaction time, to help in understanding the regional scale picture.

The South Australian ozone-monitoring network is focussed on the Adelaide metropolitan region with five sites that can be classed as GRUB sites. As for the other major cities, the sites were chosen to monitor the formation of ozone across the region based on knowledge of the precursor sources, population distribution, and regional topography and meteorology. The Gawler site at the northern end of the region serves the double purpose of monitoring for potential maxima after long reaction time and is in an area of future population growth.

The monitoring station in Canberra is located at Monash, a residential suburb in southern Canberra in the central part of the Tuggeranong Valley where concentrations were considered likely to be in the upper range of exposure.

The exposure of populations in Hobart and Darwin to ground level ozone is not currently measured, but based on the factors that govern ozone formation and the results of monitoring elsewhere, the maximum concentrations are likely to be well below the NEPM standards.

APPENDIX 3 - APPROACHES TO THE MANAGEMENT OF OZONE

NEW SOUTH WALES

OZONE MANAGEMENT IN THE SYDNEY GREATER METROPOLITAN REGION

The Metropolitan Air Quality Study (MAQS), which ran from 1992 to 1994, was undertaken for the purpose of developing a detailed understanding of regional air pollution across the Sydney, Illawarra and lower Hunter regions. The study provided improved understanding of the process of ozone formation across the region. In the 1970s and 1980s ozone control strategies concentrated on reducing VOC emissions. The results of air chemistry studies undertaken as part of MAQS identified that while measures to reduce NO_x emissions should be pursued, continuation of measures to reduce VOCs was also needed.

Recent air quality modelling undertaken by CSIRO suggests that while ozone levels in the Sydney GMR are influenced by changes in both NO_x and VOC emissions, ozone levels are more sensitive to changes in VOC than NO_x emissions.

The CSIRO work involved a sensitivity analysis in which the response of peak one-hour and four-hour ozone to changes in anthropogenic emissions of NO_x and VOCs over a three-day period in 1997 was modelled. This analysis suggests that peak ozone concentrations within the Sydney photochemical plume are more sensitive to VOC reduction than to moderate levels of NO_x reduction. The VOC sensitivity was enhanced for the last day of the three-day event, the day of highest ozone concentration [49].

Ozone Management Framework

'Action for Air', the NSW Government's Air Quality Management Plan for Sydney, the Lower Hunter and the Illawarra sets out a program of measures which target the pollutants of most concern in the region - including ozone. The Plan covers strategies designed to reduce emissions from industry, motor vehicles and domestic/commercial sources. It also supports reduction in private vehicle travel. Complementing 'Action for Air' are the Government's transport policies that include plans for improvements to the region's public transport services.

Key mechanisms for managing ozone in the Sydney GMR or, more specifically, the precursor emissions to its formation, include the following.

Motor Vehicle and Fuel Related Strategies

Stage 1 vapour recovery at service stations and bulk terminals in Sydney

Stage 1 vapour recovery systems are in place in service stations and bulk terminals across Sydney. These systems collect vapours that would otherwise be released at loading terminals and from underground storage tanks at service stations when they are being filled from road tankers and return them to the road tankers. It is estimated these systems can reduce evaporative emissions associated with filling underground storage tanks by 95%.

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[49] Report for the NSW EPA, *The impact of changes in RVP of petrol or blended fuels on photochemical smog in the Sydney Greater Metropolitan Region*, (Unpublished final draft report). Cope M, Lilley B, Azzi M, Carras J and Noonan J, CSIRO, 2003, p 32.

Low volatility petrol
In November 2004, a regulation to reduce petrol volatility in the summer months came into effect. Previously, a Memorandum of Understanding between the NSW EPA and the oil industry was in place for the voluntary supply of low volatility petrol in summer.

National fuel and emissions standards
It is expected that the new national vehicle emissions and fuel standards will achieve significant emission reductions. For example, in Sydney by 2020, emissions of VOCs from the motor vehicle fleet are forecast to fall by 40% and NO_x by 55%.

NSW cleaner vehicles action plan
The traditionally slow turnover of the Australian vehicle fleet has been a limiting factor to the realisation of the air quality benefits from cleaner vehicle technology. To address this, the NSW Government has introduced a plan to encourage carmakers to sell and consumers to purchase the most environmentally-advanced new cars and light trucks. It does this by recognising and rewarding environmentally-friendly purchases and greening the Government's own fleet.

Actions include:

- Clean car benchmarks - environmental performance benchmarks for new light vehicles to identify the cleanest cars available and a rating system for trucks and buses;
- Greener NSW Government fleet program – this requires government agencies to establish fleet improvement plans with targets for reductions in fuel consumption and greenhouse gas, and includes a ban on the purchase of V8 vehicles on Government contract;
- Voluntary clean fleet program – this program encourages the adoption of environmentally-friendly practices by large vehicle fleets and includes voluntary maintenance programs, purchasing cleaner vehicles and maintaining and operating fleets in an environmentally-friendly manner.

Licensed Industry

Industrial emissions are a relatively small proportion of total emissions of VOCs and NO_x in the Sydney region, at 14% and 18% respectively. The situation changes somewhat when considering the GMR, with industry responsible for 60% of NO_x and 14% VOC emissions (NSW EPA 2002).

Controls on emissions to air from industrial sources are in place under NSW Department of Environment and Conservation licensing arrangements for activities listed in Schedule 1 of the Protection of the Environment Operations Act 1997. The Clean Air (Plant and Equipment Regulation) 1997 sets maximum concentration limits for certain air pollutants and DEC licences set additional conditions. This Regulation is currently under review and a revised Regulation is scheduled for implementation in 2005.

In recent years load based licensing has been introduced, which links licence fees to the amount of pollutants discharged thus providing a financial incentive for licensees to achieve discharges below the required minimum performance.

Small Industrial, Commercial and Domestic Sources

Trends in population growth and economic development are expected to increase the significance of small commercial and domestic sources of emissions as a proportion of total emissions, particularly VOCs. These industries are generally service oriented and include, for example, surface coating, mobile asphalt plants, service stations, printers and dry cleaners. The Clean Air (Plant and Equipment) Regulation 1997 sets maximum limits for smoke, soot and particles from these types of activities.

The domestic sector is also a significant contributor to VOC emissions. Household sources include petrol lawnmowers, garden tools, solvents and paints and solid wood heaters.

In combination these 'area sources' are responsible for 42% of VOC emissions in the GMR.

Cleaner industries program

The Cleaner Industries Program is focused on reducing emissions from commercial and other business premises, through partnerships with industries and peak bodies to promote cleaner production to industry members. The program also involves other Government agencies and local councils, which have a role as industry educators.

Examples of initiatives under the program with a focus on reducing emissions to air, include:

- printing industry – production of a guide to reduce use of solvents;
- furniture industry – environmental information incorporated into industry manual on safety and environment;
- composites – reducing use of styrene;
- dry cleaners – reducing emissions of PERC (tetrachloroethylene).

Clean air fund

The Clean Air Fund has been established with funding of close to $5 million from the NSW Environmental Trust. The fund provides funding for programs to reduce air pollution from light industrial, commercial and domestic activities. It includes:

- the Local Air Improvement Program established to assist councils in dealing with local sources of air emissions through emission reduction projects. Funding has been available to NSW councils for projects that concentrate on reducing emissions of NO_x, VOCs and particles from non-licensed activities;
- stage 2 vapour recovery systems are being trialled at council refuelling depots in the Sydney GMR. The purpose of the trial is to assess the cost effectiveness of Stage 2 vapour recovery in terms of reducing evaporative emissions at service stations. Stage 2 vapour recovery systems collect vapours from car petrol tanks during refuelling;
- promotion of the supply and uptake of cleaner small appliances - this initiative will develop voluntary measures to increase the supply and purchase of low emission small engines, eg lawn mowers, whipper snippers and outboard engines.

VICTORIA

In Victoria the primary legislation that guides the approach to protection of the environment and EPA's environmental systems and practices is the *Environment Protection Act (1970).* The Act allows for the development of a range of instruments that guide the protection of Victoria's air environment. This Act established the Environment Protection Authority (EPA) and defines its powers, duties and functions. The Act's provisions include statutory powers, instruments and measures to:

- manage environmental quality;
- establish environmental standards and criteria;

- regulate emissions, discharges and wastes;
- prevent and clean up pollution.

Some of the most important instruments for environmental management include state environment protection policies (SEPPs), waste management policies, regulations, works approvals, licences and pollution abatement notices.

SEPPs establish a statutory framework for protecting the environment. SEPPs are declared by the Governor in Council, on the recommendation of EPA. These policies:

- identify the beneficial uses of the environment (including particular segments such as the air environment, or a particular water body or catchment) that are to be protected;
- establish environmental indicators and associated environmental quality objectives to establish if the environment is being protected;
- define programs for attainment of these objectives so that identified beneficial uses are adequately protected.

Attainment programs usually specify a range of approaches, measures and instruments for policy implementation, and usually require the compliance and cooperation of government agencies, industry and the community to manage sources of pollution, reduce environmental impacts and improve environmental quality.

SEPPs provide the management approach and technical basis for the application of regulations, works approvals, licences and other statutory measures to manage the environment. The application of these instruments and measures must always be consistent with the requirements of SEPPs.

WHICH SEPPS PROTECT AIR QUALITY?

The air environment in Victoria is currently protected by two SEPPs. These were created in February 1999 by dividing the State Environment Protection Policy (The Air Environment) - made in 1981 and subsequently amended several times - into two policies:

- State Environment Protection Policy (Ambient Air Quality) or SEPP (AAQ);
- State Environment Protection Policy (Air Quality Management) or SEPP (AQM).

The SEPP (AAQ) contains the indicators, standards, goals and monitoring and reporting protocol of the Ambient Air Quality NEPM. The SEPP (AAQ) also includes an ambient air objective for visibility reducing particles.

The SEPP (AQM) sets the framework for managing emissions to the air environment and underwent a major review in 2001. Emissions are managed in such a way as to ensure that the air quality objectives of the SEPP (AAQ) are met. In addition, a philosophy of continuous improvement is also pursued. The Principles of Environmental Protection contained in the *Environment Protection Act 1970* are explicitly stated in the SEPP (AQM) and guide the management of emissions to the air environment in Victoria. The focus is on the application of the wastes hierarchy with avoidance being the primary aim rather than end-of pipe controls.

MANAGEMENT PRACTICES FOR REDUCING OZONE LEVELS

The SEPP (AQM) classifies pollutants into Class 1, 2 and 3 indicators. Pollutants are classified according to their toxicity, odorous properties and persistence in the environment. Ozone is included as an indicator in the SEPP (AAQ). The precursors to ozone production are listed as Class 1 (nitrogen dioxide) and Class 2 and 3 indicators (VOCs).

All generators of Class 1 and 2 indicators must control their emissions by the application of best practice. Best practice involves the application of eco-efficient practices with the use of end-of-pipe controls as the last option to be considered. Avoidance of emissions is the primary aim. Class 3 indicators require control to the maximum extent achievable that goes beyond best practice at individual sites.

Design criteria have been set for nitrogen dioxide and individual VOCs and all applicants for works approval and licences must ensure that emissions of these substances are managed in such a way that the design criteria are not exceeded at ground level after the appropriate level of control has been applied (ie best practice to maximum extent achievable). Design criteria are modelling tools to be used in the design stage of an operation. Large point sources of nitrogen dioxide and many VOCs in Victoria are subject to works approval and licensing. Emission limits are set to ensure that the beneficial uses of the environment, which includes human health, are protected.

The SEPP (AQM) also specifies an intervention level for nitrogen dioxide. An intervention level is a local air quality objective that can be used to assess the cumulative impacts of emissions in a local area. If an intervention level is exceeded, then a Neighbourhood Environment Improvement Plan may be triggered. The intervention level for nitrogen dioxide is 0.14ppm for a one hour averaging period.

In 2003, the Motor Vehicle Regulations in Victoria were reviewed. These regulations include requirements to reduce fuel volatility during summer to help to reduce ozone levels. Petrol suppliers must ensure that the petrol supplied to consumers does not have:

- for the summer period 2003/04, a monthly volumetric vapour pressure of more than 70kPa or a maximum vapour pressure of more than 72kPa;
- for the summer periods 2004/05, 2005/06 and 2006/07, a monthly volumetric vapour pressure of more than 67kPa or a maximum vapour pressure of more than 69kPa;
- for the summer periods during and beyond 2007/08, a monthly volumetric vapour pressure of more than 62kPa or a maximum vapour pressure of more than 64kPa.

EPA Victoria is also developing an Air Quality Improvement Plan that will ensure that the requirements of SEPPs are met through a range of actions to reduce emissions of ozone precursors and ambient ozone levels in the Port Phillip Airshed (Melbourne and Geelong).

QUEENSLAND

Ozone is formed in the atmosphere from oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) through a series of photochemical reactions. Ozone formation can therefore be managed by reducing emissions of NO_x and VOCs.

In south-east Queensland (SEQ), the only part of Queensland where elevated levels of ozone have been found, ozone formation is managed through the combined outcomes of a range of legislation, strategies and programs aimed at reducing emissions of NO_x and VOCs in the region. These have been collected and prioritized under a strategic plan entitled 'South East Queensland Regional Air Quality Strategy' 1999 (SEQRAQS). The main components of SEQRAQS that contribute to improved management of ozone levels are summarized below.

MOTOR VEHICLES

National limits are set for emissions of NO_x and VOCs from new vehicles under Australian Design Rules. These limits have featured a series of reductions over the last decade, and further reductions will occur over the next few years. A national process has commenced to develop even more stringent limits for the period beyond 2006. This will result in on-going reductions in emissions from the Queensland vehicle fleet as progressively less polluting vehicles gradually form greater proportions of the fleet due to vehicle write-offs after accidents and retirement of old vehicles.

Queensland Transport operates smoky vehicle and on-road vehicle emission random testing programs to encourage appropriate maintenance standards, and thus lower emissions, including NO_x and VOCs.

Fuel quality specifications under the Environmental Protection Regulations 1998 include a limit of 67kPa on the average Reid vapour pressure of petrol sold in SEQ between 15 November and 15 March. This limits the evaporation of VOCs from storage, distribution and use of petrol during the time of the year when climatic conditions are most conducive to ozone formation. Petrol containing between 9 and 10 percent ethanol is allowed a limit of 74kPa, but any potential effects on ozone formation from additional evaporative emissions are moderated by the relatively low photochemical reactivity of ethanol, and the reduced tailpipe emissions of VOCs and NO_x that result from adding ethanol to petrol.

The Integrated Regional Transport Plan for SEQ includes a range of initiatives aimed at reducing transport demand in SEQ, increasing efficiency across all modes of transport, and increasing the mode share of more sustainable forms of transport (particularly public transport, walking and cycling). Reductions in emissions of NO_x and VOCs will result from the successful implementation of this plan.

COMMERCIAL, INDUSTRIAL AND DOMESTIC SOURCES

Under the *Environmental Protection Act 1994*, 'a person must not carry out an activity that causes, or is likely to cause, environment harm unless the person takes all reasonable and practicable measures to prevent or minimize the harm'. A range of enforcement provisions is available including on-the-spot fines, orders to reduce or stop emissions, and prosecutions.

The general provisions of the Act can be applied to sources of NO_x and VOCs with the aim of achieving best practice environmental management. Medium to large industrial activities are also subject to licensing requirements, which could include conditions of approval aimed at minimizing emissions of NO_x and VOCs.

HAZARD REDUCTION AND ECOLOGICAL BURNING

The organizations responsible for hazard reduction and ecological burning work closely with the Bureau of Meteorology and the Environmental Protection Agency to determine the most appropriate burning methods and the most suitable times for burning. The aim is to ensure that all burning takes place in a way that minimizes the impact of smoke and VOCs on populated areas, including SEQ.

WESTERN AUSTRALIA

In Western Australia, the principal legislation governing the protection of the environment is the *Environmental Protection Act 1986* (the Act). The Act makes provision for the Environmental Protection Authority (EPA) and establishes head powers to provide mechanisms for the development of Environmental Protection Policies (EPPs), the referral and assessment of proposals (Environmental Impact Assessment (EIA)) and the control of pollution as well as enforcement. The EPA is an independent statutory authority that has a policy-making role and responsibility for making and amending regulations. The Chief Executive Officer of the Department of Environment (WA) provides advice to the EPA and administers the pollution control parts of the Act.

The Act requires that licenses be held for industrial or other premises with significant potential for pollution of air, land and water. These licenses are issued with conditions intended to prevent or minimise this potential for pollution and provide the legal powers for controlling the discharge of waste to the environment in a manner consistent with the requirements of any EPPs and the general requirement to prevent pollution. In addition, the Act requires that a works approval be obtained prior to commencing any work or construction on a premise that would cause the premise to have the potential to pollute the environment. Thus, the emission of precursors of photochemical smog (measured as ozone) is regulated by a combination of EIA, EPPs and license conditions as governed by the Act.

The Perth Air Quality Management Plan (AQMP) also has several 'initiatives' that focus on the reduction of NO_x and ROCs (precursors of photochemical smog). These initiatives are Community Education, Cleaner Production, Land Use and Transport Planning, Reduction of Industrial Emissions of NO_x and ROCs and Vehicle Emissions Reduction. Motor vehicles are the largest single source of photochemical smog precursors in Perth and thus a number of key programs within the Perth AQMP focus on the reduction of vehicle use. Western Australia has several community education programs that are aimed at influencing the community's travel behaviour such as TravelSmart to School, TravelSmart Work Place (which include Green Transport Plans), Cycle Instead and Walk There Today.

SOUTH AUSTRALIA

South Australia's management of ozone is focussed on the Adelaide metropolitan region, where the both the total emissions of smog precursors (reactive hydrocarbons and nitrogen oxides), and the region's physical characteristics (topography and meteorology) contribute to photochemical smog formation and growth to significant concentrations in the summer months. The physical sizes and populations of the rural cities in the State are too small to generate ozone precursors in sufficient quantities to result in photochemical smog exposure at levels of concern.

MOTOR VEHICLES

Control strategies are aimed primarily at reduction of hydrocarbon emissions, and secondly at reducing emissions of nitrogen oxides. The largest contributor to both precursors is the motor vehicle, and this source is dealt with on a national basis through Australian Design Rules. Emission limits for hydrocarbons and nitrogen oxides have been increasingly more stringent to address the ozone issue, and harmonisation with international standards is a cornerstone of the Australian legislation. The introduction of Euro 4 emission standards for petrol and light duty diesel passenger vehicles is mooted within this decade.

Management of in-service vehicles is addressed by State legislation. The *Road Traffic Act 1961* includes provisions such as a '10 second smoke rule' applicable to all vehicles. Eliminating visible smoke, which is also associated with incomplete combustion, indirectly reduces the hydrocarbon emissions that contribute to ozone formation. Heavy duty diesel vehicles will be the focus of a proposed emission testing and maintenance program for diesel fleets, funding for which has been sought from the Commonwealth to implement the Diesel NEPM.

Petrol composition is governed not only by the national standards, but also by the Environment Protection (Motor Vehicle Fuels Quality) Policy 2002. Principally aimed at ensuring low overall toxicity of petrol by limiting benzene, aromatics and olefins levels, the Policy also limits petrol volatility to less than 67kPa between 1 November and 31 March each year. The intent is to reduce both tailpipe and evaporative emissions that contribute to increased health risk and formation of ozone.

As well as reducing the emissions per kilometre travelled in the region, there are programs aimed at reducing total motor vehicle transport duty, by encouraging both more efficient use of vehicles and the adoption of alternatives to them. Travel Smart is one program that has produced sustained behaviour change in suburban car use, and the "walking school bus" is growing in popularity along with cycling and a small increase in public transport use.

INDUSTRIAL SOURCES

Industrial emissions are addressed by the *Environment Protection Act 1993* which places a general duty on all persons undertaking any activity to employ all reasonable and practicable means to avoid pollution. It establishes provisions for licensing those activities of environmental significance listed in Schedule 1 to the Act and allows for imposition of conditions of operation to manage their discharges. The Act also provides for the issue of orders to reduce or avoid emissions, and the application of industry specific codes of practice and guidelines.

Hydrocarbon emissions from major industries are addressed through licence conditions that limit solvent composition or discharge concentrations. Nitrogen oxides emissions are managed by imposing more stringent discharge limits for sources in the Adelaide metropolitan region than in rural settings. Hydrocarbon emissions from smaller industries are addressed in generic guidelines and codes of practice, whereas nitrogen oxides are limited by statutory discharge limits.

EMISSION AVOIDANCE

The installation and operating costs of complex control equipment are increasing. That, and the need to achieve better environmental performance will increase the emphasis on avoiding generation of emissions and the acceptance of alternative technologies and practices by industry to manage precursors of ozone.

A Cleaner Industries Program was introduced in 1994 as a non-regulatory approach to encourage government, commercial and industrial enterprises to reduce production costs and discharges to the environment. The focus was on avoiding the generation of wastes and their associated treatment costs, instead of attempting to deal with wastes already created.

This has been successfully transformed into the current Eco-efficiency Program aimed at small to medium enterprises, with participation by local government. Although the main successes have occurred in reducing solid and liquid wastes, reduction of air emissions have primarily related to reactive hydrocarbons. For example, in the surface coating sector this has resulted from the use of low volume/high pressure spray painting equipment, replacing solvent based coatings with water based products, and elimination of solvents by using powder coating systems. Where there is no practicable water-based product, reformulation of solvents is an alternative strategy to reduce the smog creation potential of emissions.