EXPOSURE ASSESSMENT OF TRAFFIC-RELATED PM_{10} POLLUTION IN OUTDOOR PLAY AREAS OF EARLY CHILDHOOD CENTRES

MARK LYNE

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MARK LYNE

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Mark Lyne

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This study received approval from the Ministry of Education, the licensing body for early childhood centres.

Advice was sought and provided by the University of Auckland Human Participants Ethics Committee that the study did not require ethical approval.

ABSTRACT

AIM

This thesis seeks to assess the exposure of children in outdoor play areas of early childhood centres in Auckland City to traffic-related PM_{10} pollution.

BACKGROUND

An estimated 400 premature deaths occur each year in New Zealand due to motor vehicle emissions. In addition to premature deaths, acute and chronic health effects including asthma, chronic obstructive pulmonary disease (COPD), heart disease and bronchitis, as well as increased hospitalisations and restricted activity days (sick days) are also associated with vehicle emissions. Epidemiological studies have shown that respiratory diseases such as asthma can be exacerbated by increases in the concentration of particulates of less than 10 microns in diameter (PM_{10}) from motor vehicle emissions. Significant positive associations have been found between proximity to heavily travelled roads and increased childhood respiratory disease symptoms including hospitalisations for childhood asthma. In spite of this evidence, many early childhood centres in Auckland are located adjacent to busy roads. Children at these early childhood centres spend much of their time playing in the outdoor areas of these centres with the potential for particulates from motor vehicle emissions to exacerbate symptoms in those children already suffering from respiratory disease and asthma.

RATIONALE

Very little research has been carried out either in New Zealand or internationally on the air quality of outdoor play areas of early childhood centres in relation to motor vehicle emissions and childhood respiratory disease and asthma. The extent of monitoring is also limited and the amount of exposure data available in New Zealand relatively sparse, particularly in comparison with Europe.

METHODS

Levels of traffic-related PM_{10} in the outdoor play areas of early childhood centres were measured in centres located adjacent to busy roads and in centres away from a quiet road or adjacent to a very quiet road for comparison.

RESULTS

Two of five early childhood centres located alongside busy roads had PM_{10} levels that exceeded the World Health Organization (WHO) guideline value. While PM_{10} levels monitored at the other three centres located alongside busy roads did not exceed the WHO guideline value, results were often only marginally within this guideline value. In contrast, PM_{10} levels monitored at two centres located away from a quiet road and one centre located adjacent to a very quiet road were well within the WHO guideline value.

CONCLUSION

This pilot study provides preliminary evidence that children attending early childhood centres located alongside busy roads have greater exposure to traffic-related PM_{10} pollution than those attending early childhood centres located away from a quiet road or adjacent to a very quiet road.

IMPLICATIONS

If the link between PM_{10} exposure and health effects is causal, as suggested by epidemiological studies, then children attending early childhood centres proximal to busy roads are at a greater risk of respiratory illness than children attending early childhood centres adjacent to quiet roads. Further work is required to confirm the findings in this small sample of air quality around early childhood centres in a larger sample, and possibly to undertake an epidemiological study to confirm the link to health effects. Drawing on the precautionary principle, prudent territorial local authorities should be encouraged to introduce regulations ensuring that any new early childhood centres are located at a specified distance from major roads, and that information for parents, ongoing PM_{10} monitoring and processes for issuing PM_{10} advisories when limits are exceeded are available in existing early childhood centres that are adjacent to busy roads.

ABBREVIATIONS

AQGs	Air Quality Guidelines
BAM	Beta attenuation monitor
CAFE	Clean Air For Europe
CAMP	Childhood Asthma Management Programme
CI	Confidence interval
COAD	Chronic obstructive airways disease
COMEAP	UK Committee on the Medical Aspects of Air Pollutants
COPD	Chronic obstructive pulmonary disease
CORD	Chronic obstructive respiratory disease
DEP	Diesel exhaust particulate
EBD	Environmental burden of disease
ECPERS	Early Childhood Physical Environment Rating Scale
EPIs	Environmental Performance Indicators
EU	European Union
FEV	Forced expiratory volume
GIS	Geographic information system
IT	Interim targets
LRS	Lower respiratory tract
MED	Ministry of Economic Development
MfE	Ministry for the Environment
MMEF	Maximum mid-expiratory flow rate
MRR	Mortality rate ratio
NES	National environmental standards

OR	Odds ratio
P	Probability
PAH	Polynuclear aromatic hydrocarbons
PEF	Peak expiratory flow
PM	Particulate matter
PM_{10}	Particulate matter of less than 10 microns in diameter
$PM_{2.5}$	Particulate matter of less than 2.5 microns in diameter
RMA	Resource Management Act 1991
SUV	Sport utility vehicle
TEOM	Tapered element oscillating microbalance monitor
TSP	Total suspended particulate
USEPA	US Environmental Protection Agency
WHO	World Health Organization
WoF	Warrant of fitness
cm	Centimetre
m	Metre
m/s	Metres per second
$\mu g/m^3$	Micrograms per cubic metre
µm	Micron
ml	Millilitre
ml/s	Millilitres per second
mm	Millimetre
nm	Nanometre

1: INTRODUCTION

An estimated 400 premature deaths occur each year in New Zealand due to motor vehicle emissions.[1] This compares with approximately 500 people dying from road traffic crashes.[1] On a regional basis most of the increased mortality due to vehicle emissions (64%) occurs in the Auckland region.[1]

In addition to premature deaths, acute and chronic health effects including asthma, chronic obstructive pulmonary disease (COPD), heart disease and bronchitis, as well as increased hospitalisations and restricted activity days (sick days) are also associated with exposure to vehicle emissions.[2] In Auckland in 2003, there were an estimated 280 hospitalisations per year and 750,000 restricted activity days resulting from air pollution caused by motor vehicles.[2]

There is good epidemiological evidence that respiratory diseases such as asthma can be exacerbated by increases in the concentration of particulates of less than 10 microns in diameter (PM_{10}) from motor vehicle emissions.[3]

Research in the United States has found an increase in respiratory illnesses and in illness-related school absenteeism in school children due to increases in PM_{10} pollution.[4] Other overseas studies have found significant positive associations between proximity to heavily travelled roads and increased childhood respiratory disease symptoms including hospitalisations for childhood asthma.[5, 6, 7, 8, 9]

In spite of this evidence, many early childhood centres in Auckland are located adjacent to busy roads. Children at these early childhood centres spend much of their time playing in the outdoor areas of these centres with the potential for particulates from motor vehicle emissions to exacerbate symptoms in those children already suffering from respiratory disease and asthma.[4, 5, 6, 7, 8, 9]

Very little research has been carried out either in New Zealand or internationally on the air quality of outdoor play areas of early childhood centres in relation to motor vehicle emissions and its relationship to childhood respiratory disease and asthma. The extent of monitoring is also limited and the amount of exposure data available in New Zealand relatively sparse, particularly in comparison with Europe.[1]

This thesis therefore aims to address this gap. It seeks to measure levels of traffic-related PM_{10} pollution in the outdoor play areas of early childhood centres located adjacent to busy roads and in centres located away from a quiet road or adjacent to a very quiet road for comparison.

In the first section, the nature of particulate matter and its sources are explained; respiratory disease and asthma and the health effects of particulate matter are detailed; children as a susceptible population group are discussed; and early childhood centres, their licensing requirements and their role in youth development are explored.

This section is followed by a literature review that provides evidence from relevant international, national and regional studies demonstrating significant positive associations between traffic-related PM_{10} levels and adverse health effects, in particular with children's health effects.

In the next sections, relevant air quality guidelines and standards are discussed and current results and recent trends of ambient background PM_{10} levels in Auckland presented. Air quality monitoring and the various techniques available as well as air quality modelling as a possible alternative to monitoring are explored. The sampling methodology is detailed and the early childhood centres monitored are described in relation to surrounding roads and traffic counts. The chosen monitoring method is also explained.

Results of PM_{10} monitoring are then presented for each centre in comparison to the World Health Organization (WHO) annual guideline value. Weekly measured PM_{10} levels for each of the centres are also presented as two separate time analyses for comparison (weeks 1-4 and 5-8).

Key findings are discussed in detail and their implications are explored. Finally, conclusions from the thesis are presented together with recommendations for monitoring, and possible areas for further research.

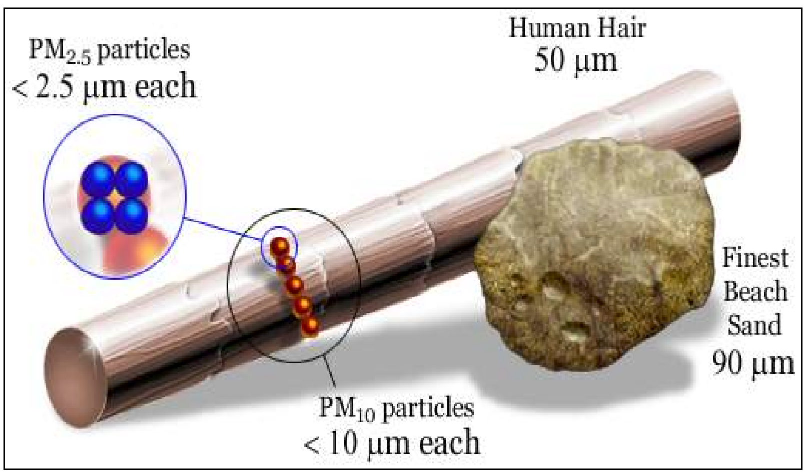
2: BACKGROUND

PARTICULATE MATTER

What is Particulate Matter?

Particulate matter can exist in a variety of different sizes and chemical compositions. The focus in New Zealand has been the PM_{10} size fraction, *i.e.* particles less than 10 microns in diameter. In much the same way, the majority of health effects studies regarding particulates both in New Zealand and world wide have also focused on measurements of PM_{10}.

Figure 1: Comparison of size of particles to a strand of hair and beach sand [10]



The larger particles of up to 100µm in diameter are comparable to the thickness of a human hair (Figure 1). These larger particles of up to 100µm in diameter are of negligible health significance since they rapidly settle out of the air, and although it is possible to inhale them, they do not generally penetrate beyond the nose and mouth as the natural human defence mechanisms such as mucus secretions capture and dispose of them.[10]

It is the particles of up to 10μm in diameter that are of most health significance, since these manage to bypass the natural human defence mechanisms, are inhaled into the lungs and pass deep into the respiratory tract to the alveoli.[10]

The PM_{10} size fraction is often referred to as coarse and fine particles. Initially this was proposed so as to characterise the particles based upon their source, *i.e.* coarse particles being formed through abrasive type mechanisms and fine particles being formed through chemical reactions and combustion processes. More recently, however, these terms are used to characterise the particles by their size, *i.e.* less than 2.5 microns (fine) and between 2.5 and 10 microns (coarse).[10]

Table 1: Particle definitions [11]

Nanoparticles	Particles smaller than 50nm (nanometres) in diameter (0.05μm [microns]).
Ultrafine particles	Particles smaller than 100nm in diameter (0.1μm).
Fine particles	Particles in the fine mode (Figure 4) or those in the $PM_{2.5}$ fraction. The two may differ.
$PM_{2.5}$	Mass concentration of particles passing a size-selective inlet designed to exclude particles greater than 2.5μm aerodynamic diameter, *i.e.* those smaller than 2.5μm.
Coarse particles	Either particles in the caurse mode (Figure 4) or in the $PM_{2.5\text{-}10}$ fraction. The two may differ.
$PM_{2.5\text{-}10}$	Particles measured by mass, determined by the difference between PM_{10} and $PM_{2.5}$.
PM_{10}	Particles measured by mass passing a size-selective inlet designed to exclude particles greater than 10μm aerodynamic diameter, *i.e.* those smaller than 10μm.

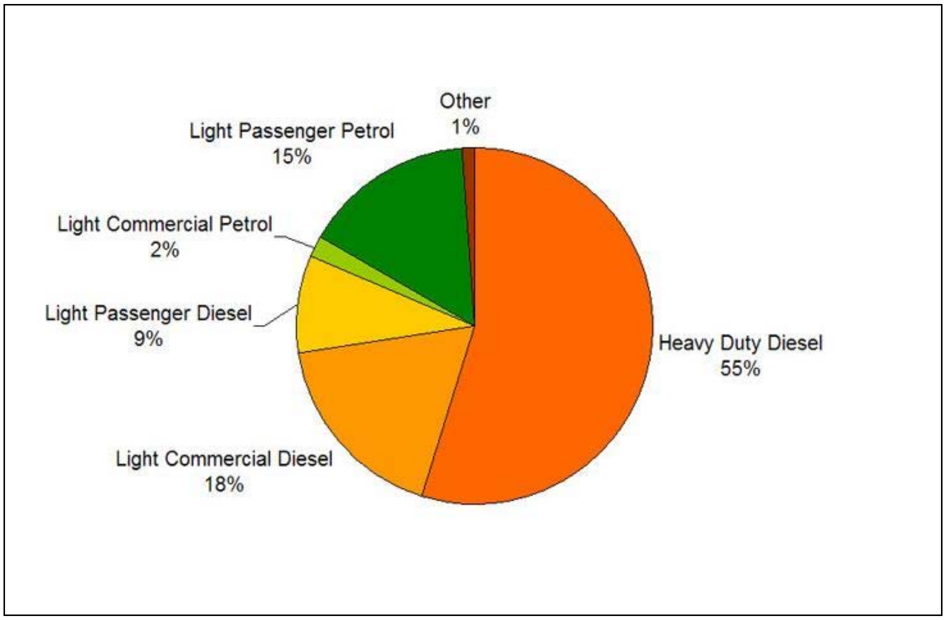
The behaviour of particles in the atmosphere and within the human respiratory system is largely determined by their physical properties, which are in turn dependent upon particle size.

Sources and Composition

PM_{10} may be emitted from a number of sources, some of which are natural such as volcanoes and dust storms, while many others that are more widespread and more important to public health include power plants and other industrial processes, domestic coal and wood burning waste incinerators and vehicular traffic.[12] The majority of these man-made sources are concentrated in specific areas which mostly tend to be urbanised areas of high populations.

In New Zealand, there are four main source categories from which PM_{10} originates; road vehicles, domestic emissions, industrial emissions, and natural sources (*e.g.* sea spray).[1] These occur in different proportions in different and diverse regions across the country. For example, domestic heating which utilises the burning of coal and wood is the main source of PM_{10} in the South Island and of particular concern during the winter months. In other areas such as Taranaki, the main source of PM_{10} is caused by westerly winds which bring sea spray inland as fine salt particles. In Auckland, vehicle emissions are the main source of PM_{10}. These may be broken down by vehicle type (Figure 2).

Figure 2: Contribution to PM_{10} emissions by vehicle type [13]



Airborne particulate matter presents a much greater problem than most other air common pollutants due to its complexity. Not only does it consist of particles of a wide range in size, but also many different chemical substances.[11]

Both the chemical composition and the size of particles can provide significant insights into their various sources, which also determine their behaviour and outcome, and subsequently their effects on human health.

An important distinction between primary and secondary atmospheric particles is that primary particles are emitted directly from combustion sources, such as road vehicles, whereas secondary particles are not emitted directly from a source, but are formed as a result of chemical reactions in the atmosphere.

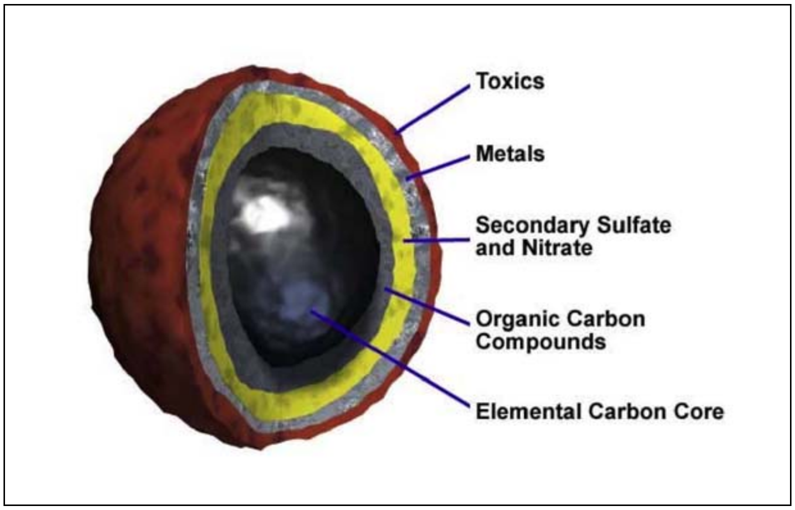
Airborne particles contain both major and minor components (Table 2).

Table 2: Major and minor components of airborne particles [11]

- *Sulphate*
  Mainly arising as a secondary compound from atmospheric oxidation of sulphur dioxide.
- *Nitrate*
  Generally present as ammonium nitrate formed from the neutralisation of nitric acid vapour.
- *Ammonium*
  Generally present in the form of ammonium sulphate or ammonium nitrate.
- *Sodium and chloride*
  Present in sea salt.
- *Elemental carbon*
  Present as black graphitic carbon formed from the combustion of fossil fuels, particularly motor vehicles.
- *Organic carbon*
  Present directly as a result of motor vehicles or secondary from the oxidation of volatile organic compounds, also present as a result of motor vehicles.
- *Mineral compounds*
  Aluminium, iron, calcium and silicon present in coarse dusts.
- *Water*
  Water may be taken up by water soluble compounds of airborne particles.
- *Trace metals*
  Lead, cadmium, nickel, mercury, manganese, and zinc may be present as impurities or additives in fuel.
- *Trace organic compounds*
  Generally arising as a direct result of fuel combustion and include hydrocarbons, heterocyclics and oxygenates.

Diesel exhaust particulate (DEP) is responsible for up to 90% of the airborne PM_{10} in most of the world's largest cities.[14] 18,000 different high molecular weight organic compounds have been identified in the carbonaceous cores of diesel exhaust particulate (Figure 3).

Figure 3: Diesel exhaust particle [15]



There are three main components of diesel exhaust particulate;

1. Carbonaceous soot that is created during combustion,
2. Heavy hydrocarbons that condense or adsorb onto the particle,
3. Sulphates/bound water.

Primary particulates consist of small spheres of graphitic carbon and are formed by the thermal decomposition of the fuel during the diffusion burning phase of combustion. The rapid polymerisation of consequential unsaturates, including acetylene, at reasonably high temperatures in oxygen-deficient conditions also leads to their formation.[16]

The primary particulates collect and link into clusters and chains that cause soot to take on its fluffy characteristic appearance. The majority of the soot is ultimately burned off during the later fraction of the expansion stroke; in the case of a modern diesel vehicle, 90% of the soot formed during this phase is burned off.[16]

However, this oxidation of soot is much slower than the process of soot formation and greatly dependent on the availability of very high temperatures and a plentiful oxygen supply. Oxygen-deficient conditions or a reduced combustion period causes a reduction in the rate of soot oxidation, which results in an increased emission rate.

Apart from soot itself, most of the diesel exhaust particulates consist of heavy hydrocarbons condensed or adsorbed onto the soot. This is commonly known as the soluble organic fraction and originates in part from unburned fuel, lubricating oil, and as a result of other compounds formed during the combustion process. Each of these sources varies between the diesel vehicle itself, the fuel quality and mode of engine operation.

Particulates emitted as a result of all types of combustion, *e.g.* domestic fires, motor vehicles, etc. contain a soluble organic fraction that includes polynuclear aromatic hydrocarbons (PAH), PAH derivatives, aldehydes and other oxygenated hydrocarbons, many of which are known or suspected carcinogens and/or toxic contaminants.

Formation

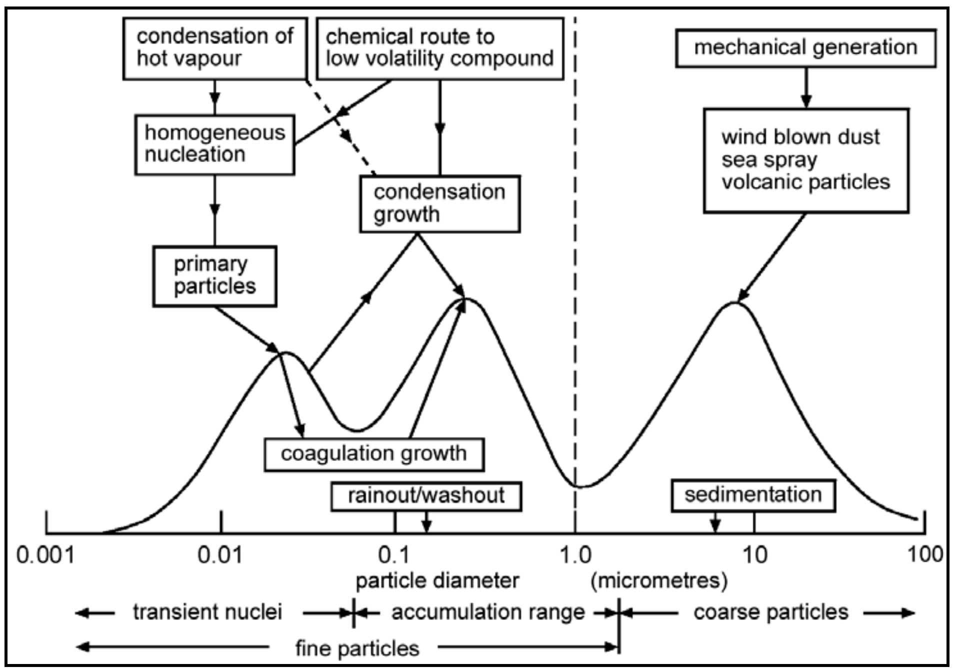
Fine particles are formed during the process of nucleation in which molecules of corresponding substances combine to form a condensation nucleus. This grows due to the combination or coagulation of existing particles together with the condensation of other gases on the nuclei of the particles.

In comparison to fine particles, coarse particles in their formation also include many natural sources such as pollens, spores and sea spray.

Smaller particles are those which are recently nucleated and may be as small as 1-2nm in diameter. They contain only tens of molecules.

Figure 4 indicates in schematic form a typical size distribution of airborne particles. Sizes range across several orders of magnitude.

Figure 4: Schematic diagram of the size distribution of airborne particles [11]



RESPIRATORY DISEASE AND ASTHMA

There have been significant advances in knowledge regarding the effects of air pollutants on human health in the past few years. The general public, especially patients with upper or lower respiratory symptoms, are aware from media reports that adverse respiratory effects can occur from air pollution.[17]

The Auckland region has a much higher rate of asthma and chronic obstructive pulmonary disease (COPD) than other countries across Europe and the US, in which the majority of air quality guidelines and standards have been developed to protect human health. Overall, New Zealand has an asthma rate which is one of the highest in the world and the fifth highest rate of COPD.[18]

Not only is the prevalence of asthma high but also the number of severe cases in New Zealand is high relative to the rest of the world.[19]

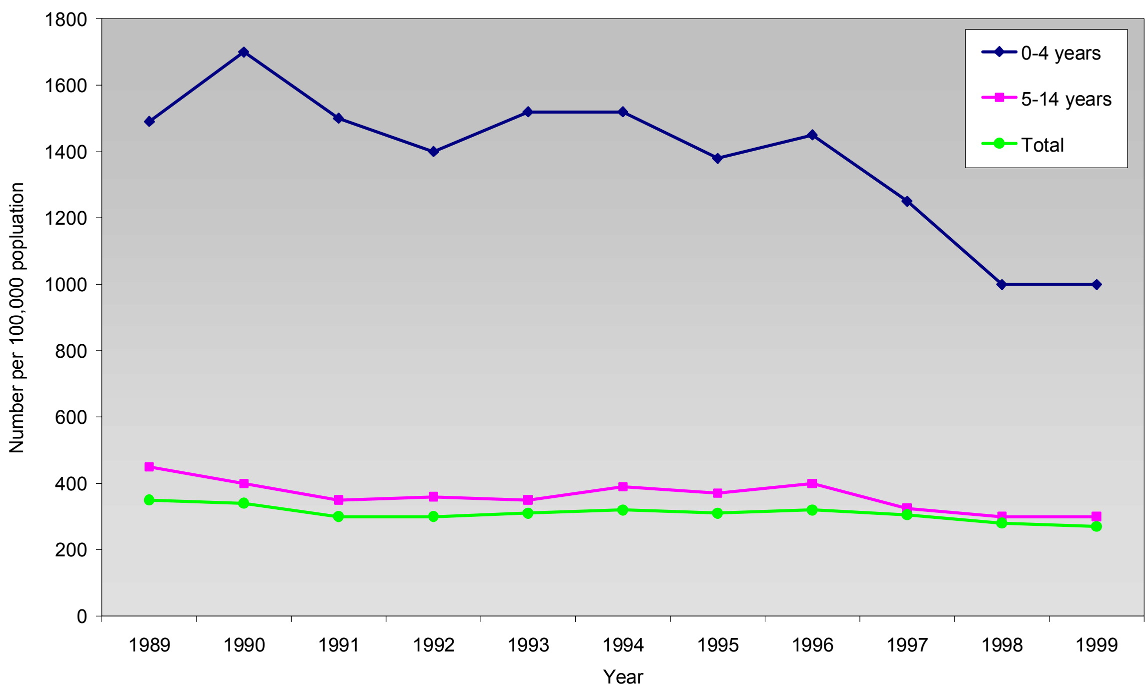
Asthma is a chronic condition, of which the overall incidence in New Zealand is steadily rising.[18] It affects a significant proportion of New Zealanders and consequently is a significant cost to the New Zealand health care system.[19]

Fifteen percent of adults and 20% of children aged 6-14 in New Zealand have asthma.[20] This may be as high as 23% in the 6-7 year age group.[21] Furthermore, 70% of adults and 42% of children who suffer from asthma have symptoms that are not well controlled.[19]

Little statistical data exist in New Zealand with regard to children in the 0-6 year age group. While the New Zealand Health Information Service states that in 1999 there were 247 hospitalisations per 100,000 population for all ages, this overall hospitalisation rate hides a disturbing picture for children. Also in 1999, for children in the 0-4 year age group the hospitalisation rate was 1000 hospitalisations per 100,000 population, which was more than six times the rate for adults aged 15 years and over. The hospitalisation rate in 1999 for children in the 5-14 year age group was 286 per 100,000 population.[22]

Figure 5 presents a breakdown in hospitalisation trends for asthma by age group from 1989-1999. Although hospitalisations for the 0-4 year age group have been reduced from previously higher levels, total hospitalisations for all children under 15 years have remained significantly above comparable international rates.

Figure 5: Hospitalisations for asthma in New Zealand by age group [22]



As well as the significance of health effects, asthma may also be said to be a financial burden to New Zealand due to the large costs to society, which come about as a result of the loss of potential earnings due to absent school days (estimated to be approximately $125 million per year); the loss caused by lower tax revenue caused by those with asthma having a high number of absent days and consequently a reduced number of days in paid, taxable employment; as well as the significant cost to the economy and society as a whole due to lost productivity of adults who are unable to perform their normal paid and unpaid work, some of who are either less productive while at work or who miss working days (estimated loss to GDP of $2 billion).[22]

An international review conducted in 2001 by the Asthma and Respiratory Foundation of New Zealand found that most properly conducted studies show that the world wide prevalence of asthma has increased in children and young adults over the past several decades by as much as 5-6% per year.[23]

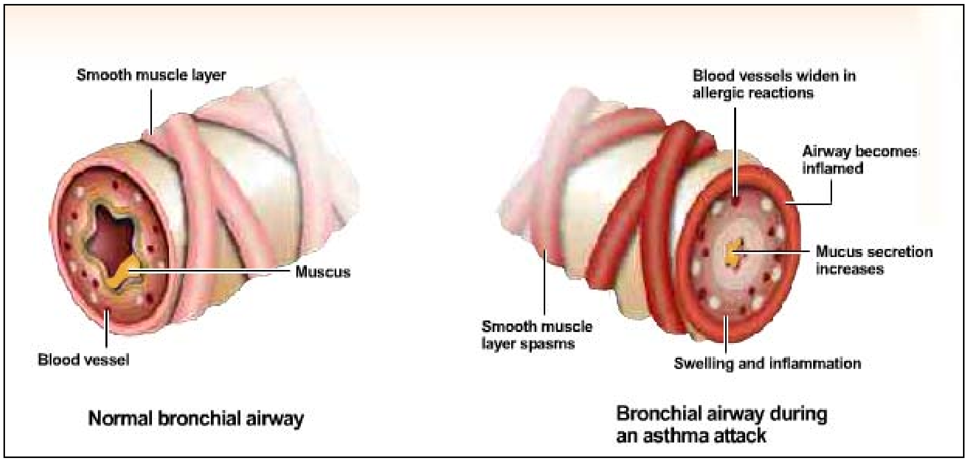
Asthma

Asthma is a disorder of the airways characterised by paroxysmal or persistent symptoms such as wheeze and cough, dyspnea and chest tightness, with variable airflow limitation and hyperresponsiveness of the airways brought about by a variety of stimuli.[24]

It is a type of allergic lung disease which involves an accumulation in the airways of mucus and inflammatory cells, which results in bronchoconstriction and airflow limitation. A complex cascade of mediators occurs causing airway narrowing and inflammation as a result of subsequent exposure to allergens.[3]

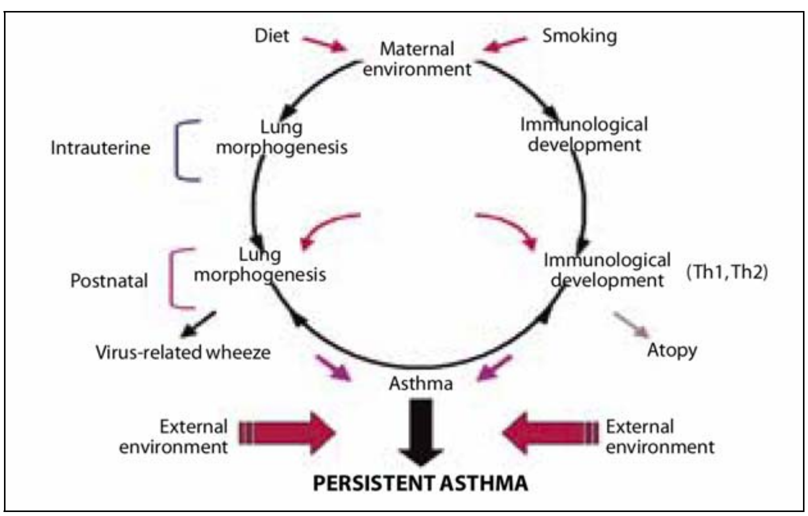
A strong argument exists for the recommendation that the management of asthma focuses on the reduction of this inflammatory state through environmental control measures. This might be achieved by considering the importance of the pathogenesis and persistence of asthma with regard to airway inflammation including mast cells and eosinophils, or its consequences.[25]

Figure 6: Bronchial airway before and during an asthma attack [25]



The exact cause of asthma is unknown but it appears to be the consequence of a complex interaction of predisposing allergy factors to foreign substances, causal sensitising factors (*e.g.* pets and dust mites), and other factors including poor air quality (Figure 7).[26]

Figure 7: Early life interactions in the development of asthma [26]



The management of asthma may consist of education about asthma and in particular its management. This includes the control of and/or avoidance of stressors or triggers such as poor air quality, individualised use of medication, monitoring and follow-up, and regular physical activity but not in areas of poor air quality.[19]

Primary prevention strategies may include encouraging breastfeeding, reducing exposure to passive smoke, reducing exposure to airborne contaminants such as air pollution, decreasing exposure to house dust mites and household moulds, and decreasing exposure to known individual specific sensitisers.[19]

Overall, the following four main concepts define asthma:[24]

1. It is a chronic inflammatory disorder.
2. There are typical identifiable symptoms.
3. There is airflow limitation that is reversible.
4. A variety of stimuli can trigger the airways' response.

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is a condition where breathing passages are obstructed and the tissue inside the lungs is damaged. It is sometimes called CORD (Chronic Obstructive Respiratory Disease) or COAD (Chronic Obstructive Airways Disease). Cases may be mild, moderate or severe, and are often slowly progressive.[27]

Chronic bronchitis and emphysema are both COPD conditions. In the case of chronic bronchitis, the airways may also become narrower and have increased mucus production with inflammation.

In the case of emphysema, the air sacs in the lungs are gradually destroyed so sufferers have difficulty absorbing enough oxygen.

Symptoms of COPD include breathlessness, cough, wheeze, and increased phlegm. These symptoms are similar to asthma, and some people may suffer both conditions. However, where asthma is reversible in so far as the airways of a person with asthma can revert back to normal, those with COPD cannot be 'cured' since it is mostly non-reversible. The symptoms of COPD can however be controlled and further subsequent damage prevented.[27]

While cigarette smoking is the most common cause of COPD, with other types of tobacco smoking also being strong risk factors, other causes include exposure to indoor and outdoor air pollution, dusts and other chemicals (vapours, irritants and fumes).[28]

COPD is rarely seen in children but it is important to consider in the context of respiratory disease and environmental stressors, since air pollution and childhood respiratory infections can result in COPD in later life.[29]

It is also important to note that the increased survival of children with significant lung disease and associated respiratory impairment is producing a growing number of young adults with increased susceptibilities to environmental hazards.[30]

Bronchitis

It is important to consider the definitions of childhood respiratory disease, since they can misrepresent what appear to be important regional differences in disease manifestation and childhood asthma and bronchitis are typical examples.[30]

While asthma has been defined as intermittent episodes of airway obstruction that either reverses spontaneously or responds to treatment, this definition separates it from COPD which is less responsive to therapy and seen typically in middle to late adult life. However, in Central and Eastern Europe, the term ‘bronchitis’ is more widely used than in Northern and Western European countries.[30]

The description ‘bronchitis’ relates to a population of children with chronic cough and sputum production that can also be features of asthma. It remains unclear whether these differences are entirely explained by differences in diagnostic fashion or to real differences in host susceptibility and environmental exposures. However, differences in the prevalence of these two conditions in East and West Germany and associated differences in the expression of atopy before unification suggest that these differences are real and that they have an underlying environmental explanation.[31]

THE HEALTH EFFECTS OF PM_{10}

The 3 main clusters of causal factors usually involved in ill health and disease may be described as:[30]

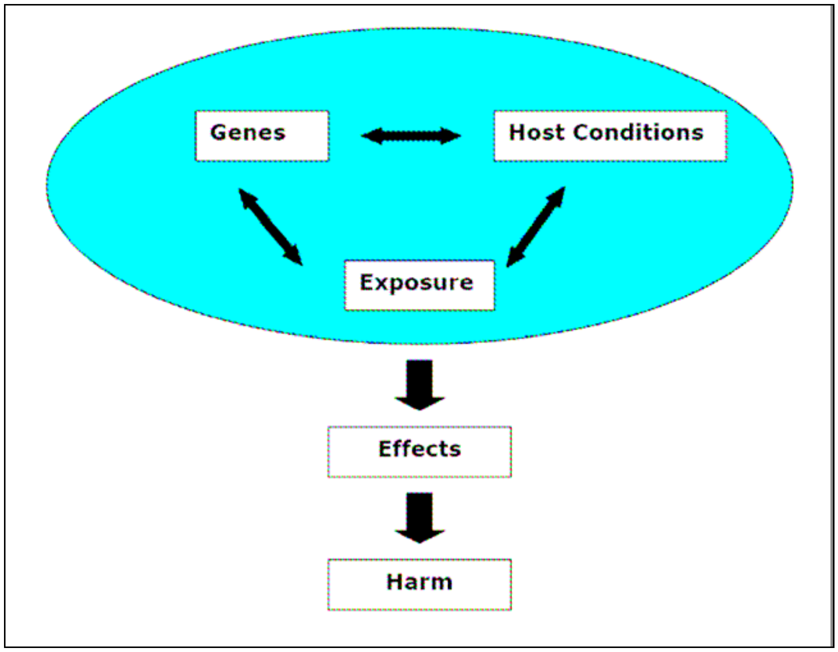
1. The *genetics* of the individual
2. The *host condition* of the individual
3. *Environmental stressors* or triggers.

The host condition of the individual includes most of the factors more often expressed as 'lifestyle factors' that can affect immune, nutritional and health status. Many of these factors are to a degree determined by the wider issues that are generally outside the control of the individual, such as societal choices over the built environment, transport, energy, and the food manufacturing and distribution systems. Such factors also include employment, income and housing, as well as the age of the individual.[30]

Environmental stressors or triggers include environmental exposures from polluted air, land, water, and food, as well as exposure to extreme climate conditions, noise, radiation, and poor housing, etc. that arise from some of the host conditions; factors such as transport, food and planning policies.[30]

Asthma along with most diseases, including cancers and the neurological or endocrine mediated diseases is the result of different combinations of causal factors arising from all three clusters *i.e.* genes, the host condition and environmental stressors, and involve an environment/genetic interaction which is mediated by the host body condition (*e.g.* adult, child, or foetus) before it receives the environmental stressors (Figure 8).[21]

Figure 8: Multi-causality framework for environment and health [21]



General Health Effects

Both long-term and short-term exposure to ambient levels of PM_{10} are consistently associated with cardiovascular and respiratory illness and mortality, and other ill-health effects. These associations are believed to be causal. In particular, their effects are considered to be dominated by long-term exposure to particles.[32]

It is not currently possible to distinguish whether there is a threshold particle concentration level below which there are no adverse health effects for the population as a whole or the individual.[11]

Most evidence of the health effects of PM_{10} has been derived from epidemiological studies of human populations in a variety of locations, most of which have been urban. In the last 20 years, epidemiological studies carried out in five different countries have shown that there are associations between a range of adverse health effects and increased levels of all common air pollutants including PM_{10}.[32]

Adverse health effects associated with PM_{10} include; total mortality, hospital admissions for cardiovascular and respiratory disease, emergency hospital and GP visits, asthma attacks, acute bronchitis, respiratory symptoms, loss of schooling and employment, and restrictions in activity.[33]

When considering the health effects of particulates, it is the size of the particle which is of most importance since this affects how far or deep into the lungs it may penetrate, which is the deciding factor for its causal adverse health effect. The larger particles, *e.g.* those greater than 10 microns deposit in the nose and mouth and are unlikely to pose a health risk. However, finer particles, *i.e.* PM_{10}, can penetrate further into the lungs and alveoli and are therefore associated with more severe health effects (Figure 9).[34]

Figure 9: The penetration of different sized particles (nm) [35]

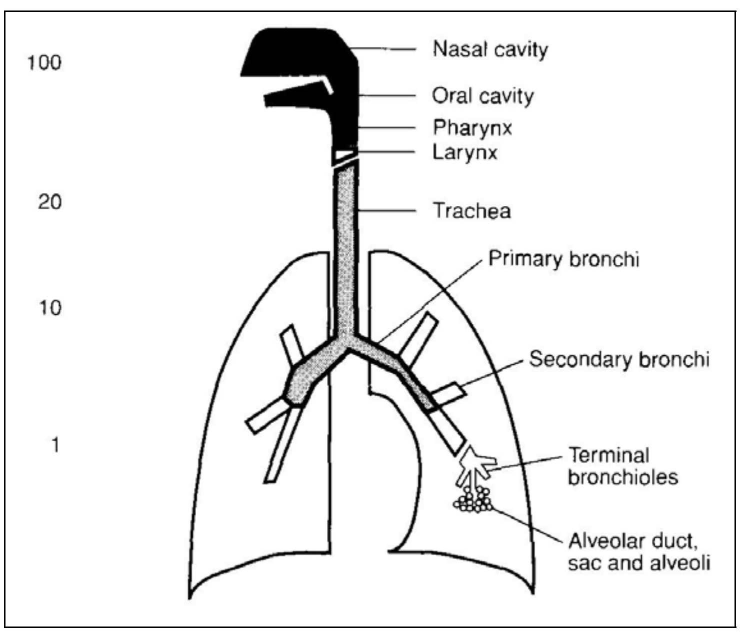


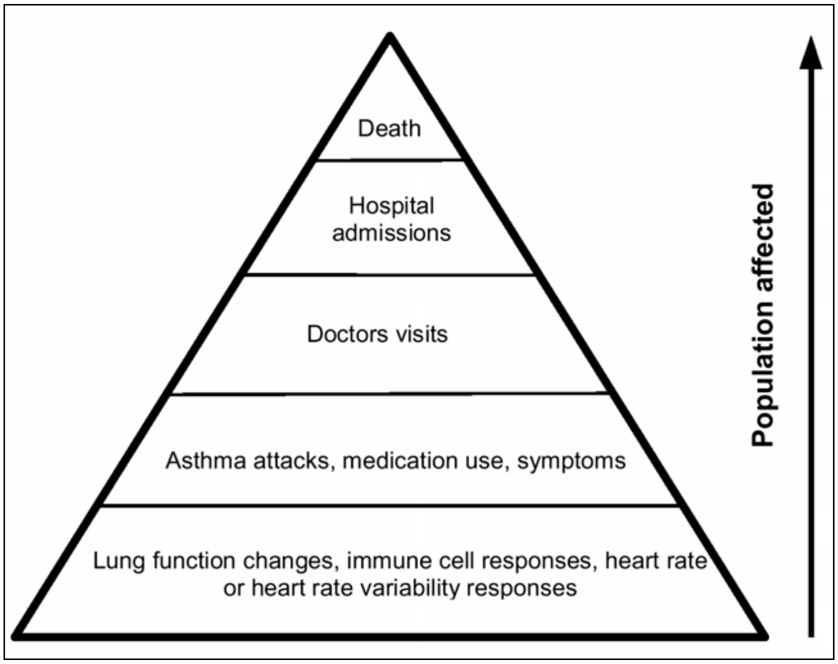
Figure 10 provides an indication of the amount of PM_{10} which could be inhaled in one day at two different air quality monitoring sites in Auckland.[36]

The left filter was collected on a day when PM_{10} levels were acceptable while the filter on the right was collected on a day when PM_{10} levels breached the air quality standard for PM_{10}.

Figure 10: PM_{10} monitored at two different sites in Auckland [36]

In general, the impact and health effects caused by PM_{10} vary from minor throat and nose irritations to more severe effects such as hospitalisations and premature mortality. An affected population vulnerable to the different impacts varies by effect (Figure 11).[34]

Figure 11: Pyramid of the impacts of particle pollution [34]



Health effects caused by exposure to particles are likely to be borne predominantly by susceptible population sub groups. Of greatest significance are those suffering pre-existing lung and heart disease and/or the elderly and children.[14]

The World Health Organization's environmental burden of disease (EBD) estimates for outdoor air pollution are based upon three main health outcomes in specific populations:[16]

1. Adult mortality (cardiopulmonary and lung cancer) related to long-term exposure,
2. Child mortality (respiratory) related to short-term exposure,
3. Full population all-cause mortality related to short-term exposure.

Evidence currently available suggests that it is the combustion-derived, *i.e.* motor vehicle-derived compounds of PM_{10}, which are significantly the most harmful to human health since they comprise the finer particles and may be enriched with trace metals and other organic compounds.[16]

Diesel exhaust particulate (DEP) presents a large number of particles, with approximately 100 times more particles per mile than petrol engines of equivalent power. Although diesel engines emit far less carbon monoxide than petrol engines, they emit over 10 times more PM_{10} than petrol engines and over 100 times more than engines fitted with catalytic converters.[37]

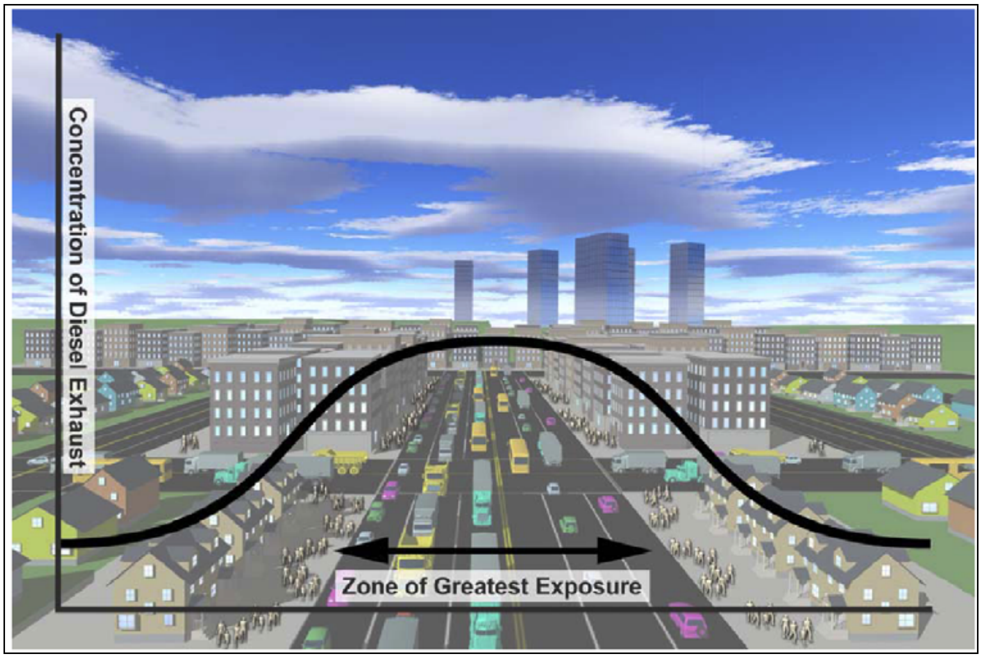
DEPs bring about their effects by the activities of specific chemical agents, *e.g.* polynuclear aromatic hydrocarbons. The DEPs are deposited on the airway's mucosa and due to their hydrophobic disposition the PAHs allow them to easily diffuse through cell membranes where they bind to a cytosolic receptor complex. PAHs can modify the growth and the differentiation programmes of cells through their subsequent nuclear action.[38]

Acute exposure to DEPs causes irritation of the nose and eyes, respiratory and lung function changes, fatigue, headache, and nausea, while chronic exposure is associated more with sputum production and cough, as well as reductions in lung function.[39]

DEPs are present in fresh diesel exhaust and linger nearby and generally within 150 metres of a diesel source such as a busy road.[40]

Their effects are said to be most marked within individuals who spend a large part of their time or live within 150 metres of a busy road, since this is the distance within which the main pollutants from vehicle traffic, particularly PM_{10}, are raised above ambient background levels (Figure 12).[15]

Figure 12: Zone of greatest exposure to diesel exhaust [15]



Experimental studies have shown that particles from diesel exhaust cause respiratory symptoms and that these particles have the ability to modify the immune response in predisposed humans and animals.[41, 42]

It is important to note that there is little evidence which links secondary particulate matter and larger coarse particles with harmful health effects.[15]

Target Tissues

Airways

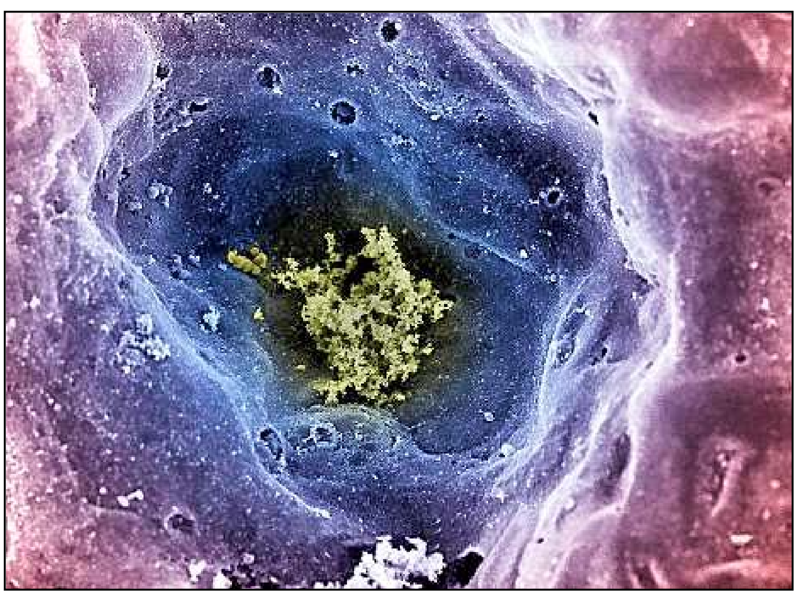
Both asthma and chronic obstructive pulmonary disease are inflammatory diseases of the airways. The defences of the pulmonary airways comprise the mucociliary escalator, where mucus-secreting cells release mucus which traps deposited particles. Ciliated cells then propel the mucus with its trapped particles upwards, which is then either swallowed or spat out. In addition, the epithelial cells themselves are capable of responding with the release of inflammatory mediators to particle stimulation.[43]

Macrophages are also present in the walls of the airways as well as on their surfaces and these can phagocytose particles and release mediators. Within the airway walls are smooth muscle cells and mesenchymal cells which could also be targets for particles.[44]

Terminal Airways and Proximal Alveoli

Beyond the ciliated airways, particles deposit in large numbers in both the terminal airways and proximal alveoli (Figure 13). Here, the net air flow is zero and deposition efficiency is increased for very small particles, due to the high efficiency of deposition by diffusion.[45]

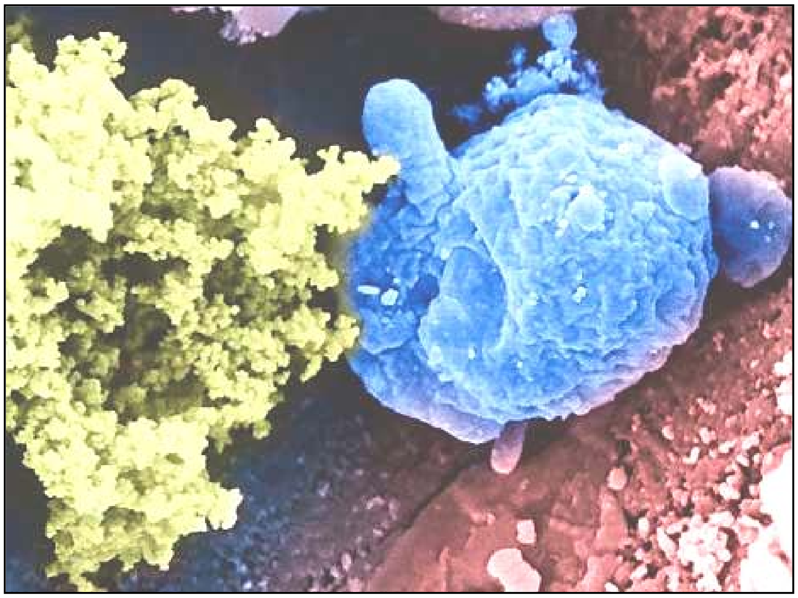
Figure 13: A particle deposited in the alveoli



Photographer: Lennart Nilsson

In this region it is the macrophages that play the most important role in removing particles. Macrophages phagocytose (engulf) particles (Figure 14) and eventually they migrate to the start of the mucociliary escalator and leave the lung with their cargo of particles, bound for the gut.[45]

Figure 14: Macrophage phagocytosing a particle



Photographer: Lennart Nilsson

The Pulmonary Interstitium

If particles cross the epithelium and go through into the lung interstitium they are no longer cleared by natural processes and may either be taken to the draining lymph nodes or remain in the subepithelial regions. These regions are close to key responsive cell populations, such as endothelial cells, fibroblasts and interstitial macrophages. Here, interstitial inflammation is likely to be more harmful than alveolar inflammation.[3]

The deposition fraction is high for PM_{10}, and the deposition efficiency is greater in a susceptible population (COPDs) than in normals. This could be explained by the slower breaths of COPD patients that allow a longer residence time for these small particles and favours deposition that depends largely on Brownian motion.[46]

Overload

The phenomenon of overload is associated with slowed clearance from the deep lung (macrophage-mediated clearance) and subsequent rapid accumulation of dose with ongoing exposure, culminating in the effects described above.

As the particle diameter reduces for a constant mass of monodispersed (single diameter) particles, then the surface area increases dramatically.[47] It would appear, for this reason, that the surface area is the aspect of the particles that the body is reacting to and that PM_{10} may be more likely to cause overload at any given mass burden in the lungs because of their large surface area per unit mass.

Macrophages attempting to phagocytose a large number of particles could be stimulated by the high particle load to release inflammatory mediators. In addition, the large numbers of particles may exceed the ability of the macrophages to phagocytose them, resulting in sustained stimulation of epithelial cells. This could cause the release of chemokines such as IL-8/MIP-1α that would contribute to inflammation.[48]

Anything that interferes with the natural process of phagocytosis and macrophage migration to the mucociliary escalator can cause the adverse outcome of interstitialisation.[49]

Interstitialisation is an adverse outcome because interstitial particles cannot now be cleared via the normal pathways and must either transfer to the lymph nodes, or remain in the interstitium, where they can chronically stimulate interstitial cells.[49]

Interstitialisation is likely to occur when there is failed clearance, which could result from (a) overload, or (b) particle-mediated macrophage toxicity, *i.e.* impairment of macrophage motility.[50]

The deposition of particles on the epithelium prior to phagocytosis suggests that the epithelium is the target for PM_{10} in leading to increased asthma and COPD attacks. Antigens for asthma are present in most atmospheres and to trigger an asthma attack the antigen need only gain access to the subepithelial lymphoid tissue.

There is evidence that injury or oxidative stress caused by various kinds of environmental particles, such as PM_{10}, can compromise the epithelium.[50]

This presents the possibility that increased production of inflammatory mediators and increased permeability to antigens may be a mechanism for the induction of asthma attacks, additional to the fact that the underlying inflammation in the airways of asthmatics means that they are in a primed state for the further oxidative stress caused by depositing PM_{10}.

It should be noted that the main pulmonary effects of PM_{10} are seen in those susceptible populations with pre-existing airways disease. If the effects of PM_{10} are caused mainly by the mechanism of oxidative stress, then these susceptible populations might be susceptible because of pre-existing oxidative stress.

The levels of PM_{10} associated with adverse effects are extremely low and indeed some studies have suggested that there is no safe level of PM_{10} below which there are no adverse health effects, *i.e.* no threshold level.[51]

Since PM_{10} appears to have adverse health effects without a threshold in some studies even at very low levels as measured by mass, this suggests that PM_{10} is a highly toxic material.

CHILDREN AS A SUSCEPTIBLE GROUP

The state of children's respiratory health is determined by the interaction of many factors including potential stressors from their environment, patterns of exposure, individual vulnerability and genetics. Identifiable risk factors include infection, air pollution (indoors and outdoors), diet, lifestyle, social condition, occupation, and provision of medical care.[30]

Susceptibility

In ecology, susceptible communities are defined as 'those that inhabit areas of environmental disturbance and are unlikely to adapt to change'[52]. In contrast, in public health, most of our efforts are concerned with preventing individuals from falling ill.[53]

Many factors alter an individual's risk for an environmentally related disease such as genetic makeup, lifestyle, age, and nutrition, all of which are influenced by each other. However, the major determinant is most often the age of the individual.[54]

The genome controls prenatal and postnatal growth and function, but genes and the countless molecular processes they control can be disrupted by many environmental hazards. Inherited mutations and a wide range of social, behavioural, or other factors that increase exposure to environmental hazards can all increase a child's susceptibility.[55]

Children may be exposed to environmental pollutants in air, water, soil, dust and food by ingestion, inhalation or dermal contact. This exposure may result from a variety of environmental pollutants, many of which are anthropogenic sources including air pollution.

Child Susceptibility

Children may be classed as a susceptible group specifically when considering the health effects caused by air pollution since:[56]

- they often spend more time outdoors
- they exercise more than adults
- their growing lungs may be more sensitive to air pollution.

In comparison to adults, children also have:[57]

- a higher metabolic rate and oxygen consumption and consequently greater intake of air per unit body weight
- a larger body surface area in relation to weight
- different body composition, and
- greater energy and fluid requirements per unit body weight.

As much as two-thirds of all preventable world-wide disease caused by environmental factors occurs in children.[58] Furthermore, children as a subpopulation make up the largest group of those susceptible to the adverse effects of poor air quality.[59]

The toxicodynamic processes that determine exposure, metabolism, excretion, absorption, and tissue vulnerability are all affected by the age of an individual. In the case of a child, their exposure, pathways of absorption, tissue distribution, ability to biotransform and eliminate chemicals are all different, and their bodies respond differently to environmental pollutants. Each of these differences is dependent on the developmental stage of the child.[54]

Why Children?

Exposure

The first step in the sequence of environmentally related health effects is exposure to an environmental hazard. Exposure differs within each developmental stage of a child because numerous environments of a child different greatly from those of an adult.[54]

Physical Location

As a child develops, so the physical location of that child changes. For example, a school-aged child will spend a significant period of his or her time based at school, which is an extremely different physical location compared to a home. Schools are frequently close to busy roads or industries, located under power lines, or built upon comparatively undesirable land, very often for economic reasons.[54]

At school a child explores new environments and starts to self-determine each different physical environment, often ignoring or misjudging the risks involved.[54]

Of most importance is the fact that children spend much more of their time outdoors, in comparison to adults, who spend most of their time at work or in the home.[57]

Breathing Zones

Typically, an adult's breathing zone is 1.5 to 2 metres above ground level. However, for a child this is much closer to the ground, and depends upon the height and mobility of the child. This is particularly important since it is at these lower breathing zones that the large respirable particulates and heavier chemicals descend, including PM_{10} from motor vehicles (Figure 15).[59]

Figure 15: An example of height in relation to pollutants [60]

Metabolism

The metabolic rate of a child is higher than that of an adult's due to a child's larger surface-to-volume ratio. Consequently a child's oxygen consumption is also greater than that of an adult's, which results in a greater exposure to any air pollutant. The metabolic rate per kilogram weight of children is much higher than that of an adult, in part because children are still developing and they are smaller. This means that their respiratory rate is proportionately greater and they breathe in much more pollution in relation to their body weight compared to an adult in similar circumstances.[35]

In asthmatic children, this higher respiratory rate and tidal volume which gives children a special susceptibility to pollutants is significantly increased.[61]

Children also spend more time engaged in play and sports activities requiring a higher rate of ventilation, which enhances air pollutant penetration.[62]

Absorption

Absorption generally occurs by four major pathways:[54]

- transplacental,
- percutaneous,
- gastrointestinal, and
- respiratory.

Each of these pathways or modes of entry is dependent on the developmental stage of the child.[54] In the case of the respiratory tract, while the surface absorptive properties of the lung do not essentially alter during a child's development, from birth to late childhood the lungs continue to develop alveoli.[63] This development results in an increasing surface absorptive area in the lung.

Because of their physiologically higher ventilation rates and their pulmonary anatomy, children inhale and retain larger volumes of air pollutants per unit of body weight compared to adults, resulting in a higher rate of absorption of air pollutants and particle deposition. Consequently, the narrow bronchioles of young children are more likely to be constricted in response to environmental pollutants than those of adults.[64]

Distribution

The distribution of pollutants and chemicals across the various target tissues varies with the developmental stage of a child. For example, many drugs in a newborn child demonstrate higher apparent volumes of distribution.[65]

One important factor affecting distribution is that most of the cells of the tissues and organs of a child are smaller than those of adults. Smaller cells, similar to smaller bodies, have a bigger surface area in relation to mass than larger cells and larger bodies. In itself, this most probably has important implications for pollutants that may enter the cells.[66]

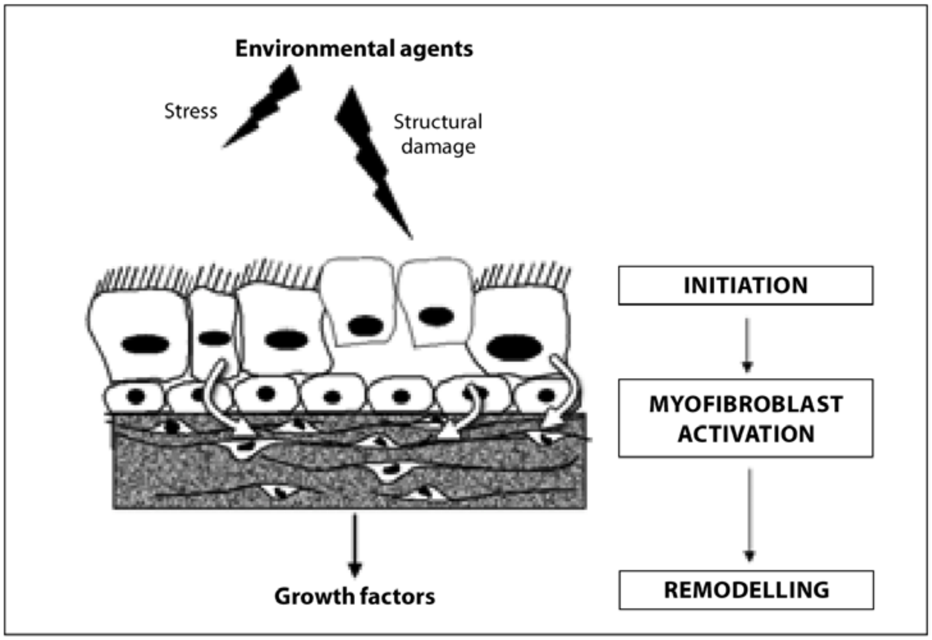
Target Organ Susceptibility

Because their organs are constantly undergoing growth and differentiation, children are also different from adults with regard to susceptibility of their organs. The result may be seen both in the nature of the effect and in the degree of severity of effect. As a child's body grows and develops, these processes may be disrupted as a result of exposure to environmental pollutants leading to different outcomes, *e.g.* diminished lung volume.[54]

The lungs and the brain are the main organs that have a prolonged period of development in early childhood. Alveolarisation is not complete until late childhood and this extended period of growth and development increases the susceptibility of these two main organs in a child.[63]

Furthermore, the exposure of a child to environmental pollution can give rise to both immediate and late manifestations as a result of the disturbed development and maturation of organ systems and their altered response to environmental stressors (Figure 16).[59]

Figure 16: Effects of environmental agents on airway epithelium [26]



Children are potentially more susceptible than adults to the adverse effects of air pollution due to a variety of factors related to age, physiological maturity, and exposure patterns. It is important to note that as well as acute manifestations, exposure during childhood may have longer lasting effects and require special follow-up treatment and support.

EARLY CHILDHOOD CENTRES

What is an Early Childhood Centre?

Section 308 of the Education Act 1989 defines an early childhood centre as:

> *'premises used for the education or care of three or more children (not being children of the persons providing the education or care) under 6 years, by the day or part of a day but not for any continuous period of more than 7 days.'*

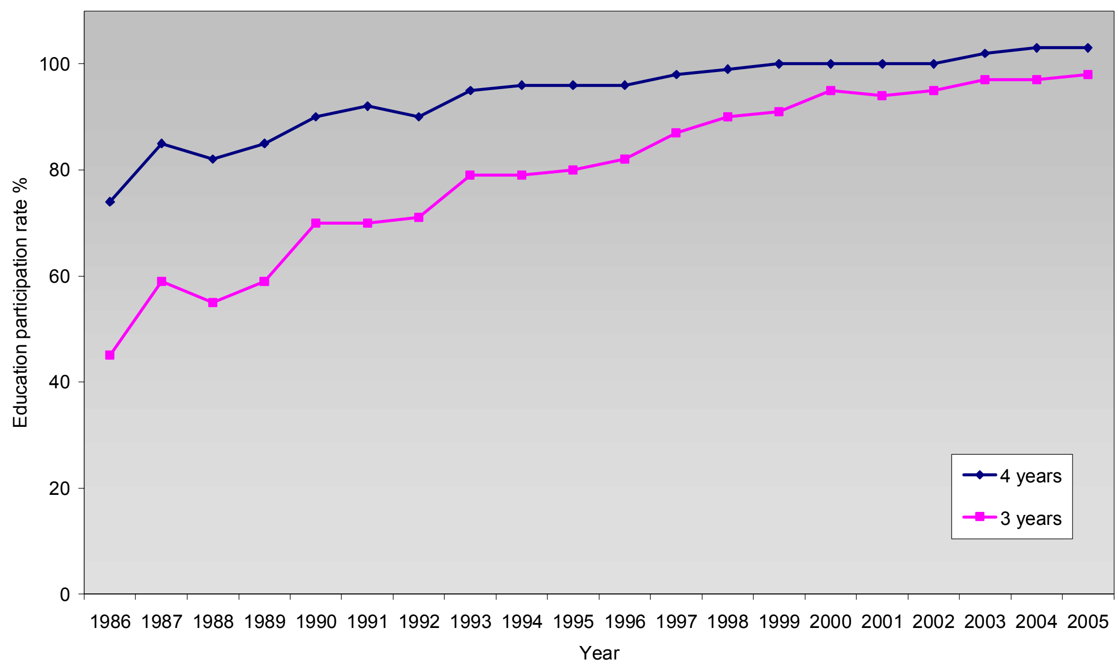
New Zealand enjoys a diverse range of education and care providers for young children. There are many types of early childhood services to choose from. Each type has its own way of working with children and their parents. Some offer full day education and care, some only part day. Some are led by trained teachers; in others, parents, whānau or caregivers provide the education.[67]

The main providers are education and care centres which provide sessional, all day, or flexible hours programmes for children from birth to school age. They may be privately owned, non-profit making, community-based services, or operated as an adjunct to the main purpose of a business or organisation (*e.g.* a crèche at a university or hospital).

There are currently approximately 230 early childhood centres in Auckland City providing early childhood education for up to 10,000 children aged between 0 and 5 years.[68]

In 2005 the 'evident' participation rate for early childhood education was 98% for children aged 3 years and 103% for children aged 4 years. A rate of more than 100% suggests that some children attended more than one early childhood provider (Figure 17). Furthermore, these rates signify a considerable increase from 43% and 73%, respectively, in 1986. The majority of these increases in attendance at early childhood centres occurred from 1986 until 1991, and slowed thereafter.[69]

Figure 17: Early childhood education participation rate [69]



Ninety four percent of all 5-6 year old school children (year one students) in 2005 had participated in some type of early childhood education prior to starting school. This was the same rate for 2003 and 2004, in comparison to 91% in 2000.[69]

Children's growth and development are most rapid during their early years and young children learn in a range of settings. Parents are key to their children's development and most children experience much of their early learning within the home. However, while New Zealand children are not required to attend any formal early childhood education service, the majority do so at some stage before they begin school.[70]

Early childhood education is a vital first stage in building the foundation for a child's ongoing learning and development, since it is the early years of a child's learning that play a vital role in their childhood development, as well as their later learning in adulthood.[69]

Licensing of Early Childhood Centres

The Ministry of Education licenses early childhood centres under the provisions of the Education (Early Childhood Centres) Regulations 1998, and the premises must comply with the requirements of the regulations.

Outdoor Play

One of the requirements of the regulations is the provision of outdoor play areas for outdoor activities to enhance the learning and development of children attending early childhood centres.

In early childhood education, it is an agreed reality that children learn most through their own free play and discovery and by experiencing the natural outdoors environment including plants, animals, insects, water and sand, and movement; and not simply being outdoors in the sun and air.[71, 72]

Children's free play is a complex concept that typically is pleasurable, self-motivated, imaginative, non-goal directed, spontaneous, active, and free of adult-imposed rules.[73]

Such free play involves the 'whole child approach' which includes gross and fine motor senses, emotion, intellect, individual growth and social interaction.[74]

By experiencing and learning from their interactions with the outdoors environment, children experience age-appropriate obstacles, frustrations, and risks enabling them to develop skills to manage their inner feelings and resources, as well as the occurrences and demands of the outer world.[75]

Outdoor play further provides opportunities that reduce a child's anxiety and build conflict resolution skills so as to assist the child in their adaptation to reality. It also provides opportunities that facilitate a child to explore their natural environment, including their manipulation of objects, development of physical skills, and fostering of their own self-expression (Figure 18).[74]

Figure 18: An example of an outdoor environment of an early childhood centre [76]

Requirements for Outdoor Play Areas

The US National Resource Centre for Health and Safety in Child Care provides performance standards for early childhood centres.[75]

Standard 2.009 of the performance standards – Playing Outdoors, states that:

- Children shall play outdoors daily when the weather and air quality conditions do not pose a significant health risk.
- Weather that poses a significant health risk shall include wind chill at or below minus 9 degrees Celsius and heat index at or above 32 degrees Celsius.
- Air quality conditions that pose a significant health risk shall be identified by announcements from local health authorities or through smog alerts.

The standard goes on to require that when episodes of poor air quality are predicted, the children should not use the outdoor play areas but remain indoors and that air conditioning units should ventilate indoor air to the outdoors. It further advises that children with existing respiratory problems including asthma should not play outdoors when air quality is close to but within standard and guideline values.

In New Zealand, it is the safety of children while playing outdoors that appears to take priority over protection of their health, and although provision of shade is considered (Figure 19), air quality is not.

Figure 19: An example of shading of an outdoor play area [77]

Part 3 – Health and Safety Standards – Section 17 of the New Zealand Education (Early Childhood Centres) Regulations 1998 refers to the premises in general and requires that:

- The outdoor space must be close enough to the indoor space as to allow for quick, easy, and safe access by children.
- The outdoor space must comprise a safe space, suitably surfaced and drained for a variety of activities, and closed in by secure fences and gates.
- The licensee of a licensed centre must ensure that where children under the age of 2 years attend the centre, safe spaces for crawling, walking, and floor play are provided to the satisfaction of the Secretary.

Section 24 of the same Part 3 of the regulations refers to safety and hygiene and requires that:

- The centre has at least 2 separate outside doors that allow people to get out easily.
- Outside doors, fences, and gates are secure and safe enough to ensure that children are not able to leave the centre without the knowledge of a staff member.
- Every person responsible for the control of a centre, every staff member of a centre, and the licensee of a licensed centre must ensure that, so far as is reasonably practicable, hazards to the safety of the children are corrected, repaired, removed, or made inaccessible to the children.

Section 28 of the regulations refers specifically to child health and deals mainly with infectious disease and illness.

Part 4 – Curriculum, Management and Staffing Standards – Section 32 of the Education (Early Childhood Centres) Regulations 1998 refers to the programme of activities and requires a licensee of a licensed centre to:

- Enhance children's learning and development through planning, providing and evaluating a range of appropriate activities that cater for the learning and developmental needs of the children (including children with special needs) fostering their cognitive, creative, cultural, emotional, physical, and social development, including both individual and group experiences, indoors and outdoors.

Within these regulations, therefore, there is no consideration or reference made to the air quality of the outdoor play area of an early childhood centre.

Further to the Education (Early Childhood Centres) Regulations 1998, Early Childhood Development New Zealand provides guidance on establishing an early childhood centre.[78]

Step 8 of this guidance refers to the outdoor play area and requires that:

- The outdoor play area is carefully planned with safe play spaces which comply with the New Zealand safety standards.
- Non-poisonous trees and shrubs should be a feature.
- Shade should be provided.
- Safety surfacing is provided.

Step 10 of the guidance refers to health, fire and civil defence and states only that a health report is required by the Ministry of Education prior to licensing. Public Health Units usually based within District Health Boards carry out these inspections, and provide information on children's health, and centre hygiene and safety to the Ministry of Education.

The Ministry of Education also provides advice on establishing an early childhood centre.[79] With regards to choosing a site, it refers to:

- Climate (wind, sun and shade protection).
- Health issues (lead-based paint, asbestos, and chemicals).
- Outdoors (drainage, surface safety, visibility, and activity space per child).

Within both these guiding documents, there is once again no consideration or reference made to the air quality of the outdoor play area of an early childhood centre.

The University of Sydney, Australia has developed an Early Childhood Physical Environment Rating Scale (ECPERS) to reliably and viably assess the quality of the designed environment of early childhood centres.[80]

ECPERS is based upon an interactional-constructivist theory of child development and the environment which considers the built environment and cognitive development in childcare.[81]

ECPERS identifies the outdoors play area as being one of several items of major importance. However, this is with regard to its presence and size and air quality is not taken into consideration.

The Auckland Regional Public Health Service of the Auckland District Health Board is one of the few organisations within New Zealand to consider air quality and the location of the early childhood centre in relation to sources of air pollution.[82] It considers children under the age of 5 years to be significantly at risk from environmental hazards including air pollution.

Furthermore, it believes that early childhood centres are being located in inappropriate locations and therefore states that it *prefers* centres are not located:

- adjacent to motorways, major roads, railways and industrial areas, and
- in locations where air quality fails to meet ambient air quality guidelines.

However, since it states that it only *prefers* centres are not located in these environments, and it is not a licensing requirement but only a preference, it is not enforceable.

There would therefore appear to be a major oversight in considering air quality in the outdoor play areas of those policies and standards influencing the development, location, administration and management of early childhood centres.

3: LITERATURE REVIEW (ASSOCIATIONS BETWEEN PM_{10} AND HEALTH)

INTRODUCTION

A review was undertaken of relevant published literature. The following databases were searched:

- Medline
- EMBASE
- ENVIROnetBASE
- PubMed
- ERIC
- Scirus
- EVA
- Google Scholar

The following terms were used in various combinations:

- Particulates
- Particulate matter
- PM_{10}
- Air pollution
- Traffic
- Vehicles
- Emissions
- Health effects
- Respiratory disease
- Respiratory disorders
- Asthma
- Children
- Child
- Early childhood centres
- Day care centres

Reference lists from key articles were used to source other relevant publications. Relevant government documents were also reviewed.

LITERATURE REVIEW

Asthma is one of several allergic respiratory diseases, the prevalence of which appears to have increased significantly over time, particularly in industrialised countries.[14]

It is unlikely that changes in genetic predisposition are to blame since such genetic changes within a population require thousands of years to take effect. Therefore, this increase is more likely to be associated with changes in environmental factors, *e.g.* drugs, nutrition and food, infectious diseases, emotional mechanisms, housing and working conditions, and indoor and outdoor air pollution.[14]

This well documented rise in the prevalence of asthma in industrialised countries has coincided with a general increase in the density of road traffic in the majority of these countries. Therefore, a number of studies have investigated the possibility that traffic pollution is an exposure that is associated with respiratory health in children. Clear evidence exists, which demonstrates that air pollution is associated with troublesome respiratory symptoms, particularly in children.[30]

The last 25 years have seen an increasing interest in studies of air pollution and its effects on the health of populations. While the exact role played by atmospheric pollutants in allergic sensitisation of the airways has still yet to be confirmed, substantial evidence exists which suggests that urbanisation and the increased quantity of vehicle emissions associated with it, together with a Westernised lifestyle, are all linked to the increase in the prevalence of respiratory allergic diseases seen in most industrialised countries.[14] There is also considerable evidence that people already suffering from asthma have an increased risk of developing exacerbations with exposure to inhalable particulate pollution.[14]

Table 3: Summary of relevant papers from literature review

Country	Name	Year	Authors	Study type
UK	1. Quantification of the effects of air pollution on health in the United Kingdom	1998	COMEAP	Case-controlled
	2. Particulate matter and daily mortality and hospital admissions in the West Midlands conurbation of the United Kingdom	2001	Anderson et al.	Case-controlled
	3. Living near a main road and the risk of wheezing illness in children	2001	Venn et al.	Case-controlled
Europe	1. Exposure to PM_{10} in eight major Italian cities and quantification of the health effects	2000	WHO	Cross-sectional
	2. Meta-analysis of time-series studies and panel studies of particulate matter and ozone	2004	WHO	Quantitative meta-analysis
	3. Public health impact of outdoor and traffic-related air pollution: a European assessment	2000	Kunzli et al.	Case-controlled
	4. Association between mortality and indicators of traffic-related air pollution in The Netherlands	2002	Hoek et al.	Longitudinal
	5. Differences among black smoke, PM_{10} and $PM_{1.0}$ levels at urban measurement sites	2001	Roemer, W.H., van Wijnen, J.H.	Cohort
	6. Acute effects of urban air pollution on respiratory health of children with and without chronic respiratory symptoms	1999	van der Zee et al.	Case-controlled
	7. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways	1997	van Vliet et al.	Cross-sectional

Country		Name	Year	Authors	Study type
Canada	1.	Association between particulate air pollution and first hospital admission for childhood respiratory illness in Vancouver	2004	Yang et al.	Case-controlled
USA	1.	Effects of ambient air pollution on symptoms of asthma in Seattle-area children enrolled in the CAMP study	2000	Yu et al.	Cohort
	2.	Childhood asthma hospitalization and residential exposure to state route traffic	2002	Lin et al.	Case-controlled
	3.	Elementary school absences and PM_{10} pollution in Utah Valley	1992	Ransom, M.R., Pope, C.A.	Case-controlled
	4.	Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study	2007	Gauderman et al.	Longitudinal
Hong Kong	1.	Comparison between two districts of the effects of an air pollution intervention on bronchial responsiveness in primary school children in Hong Kong	1998	Wong et al.	Case-crossover
China	1.	Children's respiratory morbidity prevalence in relation to air pollution in four Chinese cities	2002	Zhang et al.	Cross-sectional
Australia	1.	Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children	2004	Jalaludin et al.	Cross-sectional
	2.	Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand	2005	Barnett et al.	Case-crossover

Country		Name	Year	Authors	Study type
New Zealand	1.	Health and air quality in New Zealand: Christchurch pilot study	2005	Fisher et al.	Cross-sectional
	2.	Daily mortality in relation to weather and air pollution in Christchurch, New Zealand	1999	Hales et al.	Case-controlled
	3.	Spatial patterns of mortality in relation to particulate air pollution in Christchurch, 1988-1997	2000	Hales et al.	Longitudinal
	4.	Particulate air pollution and hospital admissions in Christchurch	2002	McGowan et al.	Longitudinal
	5.	Health effects due to motor vehicle air pollution in New Zealand	2002	Fisher et al.	Cross-sectional

The majority of previous studies have relied upon ambient (background) air quality results measured across the wider region and exposure assessments have not been based upon air quality monitoring of the specific target study areas, *e.g.* alongside a busy road, in a school playground, etc. Consequently, assessment of personal exposure to air pollutants in these studies will not be as accurate when compared to monitoring of the specific target study site.

The same may be said of studies that have only relied upon the distance of the residential or school address to major roads as a measure of exposure to air pollution, while others have merely used traffic density data.

The United Kingdom

In the UK, there have been three major studies of relevance. The first was conducted by the UK Committee on the Medical Aspects of Air Pollutants (COMEAP) who estimate that exposure to PM_{10} in urban areas in the UK in 1998 caused 8,100 deaths to be brought forward and 10,500 hospital admissions due to respiratory disorders to be either brought forward or additionally caused.[83]

For their study, the country was divided into 1 kilometre square grids, within each of which the annual average concentration of PM_{10} and resident population was recorded. A baseline level of accepted health-related and pollution affected events *e.g.* hospital admissions for the treatment of respiratory diseases, daily deaths, etc. was assigned to each square grid. The data from both were combined and a coefficient linking pollutant concentrations with the relevant effects applied, so as to calculate the estimated health impact of PM_{10} for each square grid. Summing the results obtained gave the relevant totals for the UK.

The second study in the UK was carried out in the West Midlands from 1994 to 1996, and Anderson et al. 2001 showed evidence of associations between PM_{10} and respiratory admissions in the 0-14 year age group.[84]

In that study, counts of daily death rates and emergency hospital admissions for those people resident in and dying, or admitted to hospital in the study area were constructed for respiratory and cardiovascular diagnoses by age group (0-14, 15-64, >65). Air quality data were also obtained for background monitoring from sites within the study area.

Analysis of admissions by age group found that while there were no significant associations in the 15-64 year age group, significant associations between PM_{10} and respiratory admissions were found in the 0-14 year age group (8.3%, 95% CI 1.7-15.3). When respiratory admissions were broken down for the 0-14 age group, the strongest associations with PM_{10} were found to be asthma and COPD.

The third study was carried out in 1995 in Nottingham, UK, and investigated the relationship between proximity of the family home to the nearest main road (estimated objectively using geographical information system software) and the risk of wheeze in the past year in a case-controlled sample of 6,147 primary school-children (aged 4-11 years) and a random cross-sectional sample of 3,709 secondary schoolchildren (aged 11-16 years).[6]

Using parental questionnaires for primary schoolchildren and self-completion questionnaires for secondary schoolchildren, respiratory symptoms were surveyed to study the effects of local school traffic density on asthma. Detailed data were collected on residential location, respiratory symptoms, and lifestyle factors. Distance from the child's home to the nearest main road (motorway, A or B class road) was computed using GIS software.

The study concluded that the risk of wheeze in children is increased in relation to proximity to main roads, as might be expected from the profile of traffic pollutant levels close to the road and that this increase in risk applies primarily to those living less than approximately 90 metres from the roadside.

It found that among children living within 150 metres of a main road, the risk of wheeze increased with increasing proximity by an odds ratio (OR) of 1.08 (95% CI 1.00-1.16) per 30 metres increment in primary schoolchildren, and 1.16 (1.02-1.32) in secondary schoolchildren.

Europe

Across Europe there have been seven studies of relevance within several major cities. A World Health Organization study in 2000 estimated the overall health burden due to exposure to urban PM_{10} pollution in eight major Italian cities.[85]

Risk assessment for PM_{10} exposure in the eight largest Italian cities (with population more than 400,000 at 1991 census): Turin, Genoa, Milan, Bologna, Florence, Rome, Naples and Palermo (total population is around 15% of Italian population) was assessed using PM_{10} levels from the period of 1994-99. PM_{10} concentrations for risk assessment were estimated as an average for the biennium 1998-99.

The number of cases which could be attributed to air pollution was estimated, based upon observed occurrence of selected health outcomes, PM_{10} data, and dose-response functions obtained by a meta-analysis of the literature.

It was concluded that a sizable proportion of morbidity, mortality and hospital admissions are attributable to PM_{10} air pollution (Table 4).

Table 4: Health outcomes attributable to $PM_{10} > 30 \mu g/m^3$ [85]

Health outcome	Estimated attributed proportion (%)	95% Confidence limits		Estimated number of attributable cases
Mortality (excluding accidental causes)	4.7	1.7	7.5	3,472
Hospital admissions for respiratory disease	3.0	2.5	3.7	1,887
Chronic bronchitis (age >25)	14.1	1.7	22.1	606
Acute bronchitis (age <15)	28.6	18.4	32.9	31,524
Asthma exacerbation (age <15)	8.7	8.1	9.2	29,730
Occurrence of respiratory symptoms	11.3	3.7	16.0	10,409,836

While uncertainties were found with regards to exposure assessment, extrapolation of dose-response functions from other populations and analytical outcomes indicated that the results are likely to underestimate the true health burden.

The main source of PM_{10} in Italian cities is stated to be motor vehicle traffic, including diesel and two-stroke motorcycles and therefore the health burden due to PM_{10} is considered to be caused by such traffic.

The second study, also conducted by the WHO, examined the short-term effects of PM_{10} in several cities in Europe in 2004.[86]

A quantitative meta-analysis of peer reviewed studies was conducted to obtain summary estimates for certain health effects linked to the exposure to PM_{10} (and ozone) as part of the WHO project 'Systematic review of health aspects of air pollution in Europe', which was funded by the European Commission and intended to provide input into the Clean Air For Europe (CAFE) programme.

The data for the analyses came from a database of ecological and individual time-series studies developed prior to the study. Estimated percentage increase in risk per 10µg/m^3 PM_{10} data were available for between 8 and 34 major European cities.

The study indicated that short-term changes in PM_{10} at all levels lead to short-term changes in acute health effects such as respiratory symptoms, inflammatory lung reactions, and increases in hospital admissions and mortality (Table 5).

Table 5: Short-term effects on health from 10µg/m^3 increases in PM_{10} [86]

Health outcome	Estimated percentage increase in risk per 10µg/m^3 PM_{10} (95% confidence interval)	Estimates available for meta-analysis (cities)
All-cause mortality	0.6 (0.4-0.8)	33
Mortality from respiratory diseases	1.3 (0.5-2.0)	18
Mortality from cardiovascular diseases	0.9 (0.5-1.3)	17
Hospital admissions for respiratory disease, people aged 65 years and over	0.7 (0.2-1.3)	8
Cough, children aged 5–15 years with chronic symptoms	0.0 (–1.3-1.1)	34
Medication use, children aged 5–15 years with chronic symptoms	0.5 (–1.9-2.9)	31

Other studies included one carried out in Austria, France, and Switzerland, which estimated the impact of outdoor (total) and traffic-related air pollution on public health using attributable cases of morbidity and mortality.[87]

The effects of air pollution were quantified using epidemiology-based exposure-response events for a $10\mu g/m^3$ increase in PM_{10}. Cases attributable to air pollution were estimated for mortality (adults > 30 years), cardiovascular and respiratory hospital admissions (all ages), bronchitis episodes in children (< 15 years), incidence of chronic bronchitis (adults > 25 years), restricted activity days (adults > 20 years), and asthma attacks in adults and children.

It was concluded that air pollution caused more than 40,000 attributable cases per year (6% of total mortality); motorised traffic accounted for more than 25,000 new cases of chronic bronchitis in adults (approximately 50% all mortality caused by air pollution), more than 0.5 million asthma attacks, more than 290,000 episodes of bronchitis (children), and more than 16 million person-days of restricted activities.

Several studies of significance have been carried out in The Netherlands. The first, a cohort study from 1986 to 1994, indicated that traffic-related particulate matter was significantly associated with increased mortality and that the relative risk for living near a major road was 1.95 (95% CI 1.09-3.52).[7]

That study estimated the effects of long-term exposure to particulates for residential addresses situated near major roads. Exposure was characterised using background monitoring results. Mortality records were collected during the study timeframe.

A consistent association between cardiopulmonary mortality and living near a major road was identified and it was concluded that long-term exposure to traffic-related air pollution may shorten life expectancy.

Another study in The Netherlands measured airborne particulate matter at an urban background site, a busy street and alongside a motorway.[88]

Median daily concentrations were found to be elevated at sites experiencing more traffic. The study showed PM_{10} levels were lowest for the urban background site, higher at the street site and highest alongside the motorway, and that the relationship of mortality with PM_{10} was twice as steep for subjects living on busy roads in urban areas than those living elsewhere.

Other research also carried out in The Netherlands investigated to what extent different components of air pollution are associated with acute respiratory health effects in children with and without chronic respiratory symptoms.[89]

During three consecutive winters starting in 1992 to 1993, peak expiratory flow (PEF) and respiratory symptoms were registered daily in panels of children aged 7-11 years with and without symptoms, living in urban areas with high traffic intensity. Simultaneously, panels of children living in non-urban areas were studied. Daily measurements of PM_{10} were assessed in both areas.

The contrast in PM_{10} concentrations between urban and non-urban areas was small, but in children with symptoms from both areas, significant associations were found between PM_{10}

concentrations and the prevalence of symptoms of the lower respiratory tract (LRS) and decrements in PEF. Use of bronchodilators in urban areas, but not in non-urban areas, was also associated with particle concentrations.

Stronger associations following stratification by use of medication were found in children who used medication than in those who did not. The magnitude of the estimated effects was in the order of a twofold increase in the use of bronchodilators, a 50% increase in LRS, and an 80% increase in decrements in PEF for a 100 $\mu g/m^3$ increase in the 5-day mean PM_{10} concentration.

In children without symptoms, significant associations were found between concentrations of PM_{10} and decrements in PEF in both areas, but these associations were smaller than those for children with symptoms.

The study concluded that children with symptoms are more vulnerable to the effects of particulate air pollution than those without symptoms, and that the adverse effects of particulate air pollution in children with symptoms is not prevented by the use of medication for their asthma.

A further study carried out in The Netherlands examined whether emissions from motor vehicles had an effect on the respiratory health of children living near motorways.[8]

Lung function and chronic respiratory symptoms were measured in children from 13 schools that were situated less than 1000 metres from a major motorway. Distances from the motorway and traffic intensity were used as exposure variables, and air pollution levels were measured at each of the schools.

Cough, wheeze, runny nose, and other respiratory problems were significantly more often reported by children living within 100 metres from a motorway. Traffic intensity and particulates levels measured in the schools were found to be significantly associated with chronic respiratory symptoms.

Canada

One relevant study was carried out in Vancouver, Canada, which involved an assessment of the impact of PM_{10} on respiratory hospitalisation and suggested harmful effects from PM_{10} on first hospitalisation for respiratory disease in early childhood.[90]

In that study, associations between children under the age of 3 years who had their first hospitalisation due to a respiratory disease and concentrations of PM_{10} were estimated using logistic regression.

There was a total of 1,610 cases indicating emergent or urgent care for children less than 3 years old who had their first hospital admission for respiratory disease (excluding birth-related) during the study period.

Ambient PM_{10} levels from continuous monitoring were obtained at several sites across the study region. Results indicated that PM_{10} levels, with a lag of three days, were significantly associated with respiratory hospital admissions and that PM_{10} had an adverse effect in early childhood.

The United States

There have been four studies of relevance carried out in the US. A similar study to that conducted in Vancouver was carried out in Seattle, which looked at the effects of air pollution on symptoms of asthma in children enrolled in the CAMP (Childhood Asthma Management Programme) study.[91]

A panel of children aged 5-13 years with asthma living in Seattle was observed during screening for enrolment in the CAMP study. Ambient air pollution levels were compared to daily self-reports of asthma symptoms.

Population estimates indicated an 11% (95% CI 3-20%) increase for a 10µg/m^3 increase in PM_{10} lagged by one day. Conditional on the previous day's asthma symptoms a 10% (95% CI 3-16%) increase in the odds of asthma symptoms was estimated to be associated with an increase in PM_{10} levels. It concluded that there is an association between changes in short-term PM_{10} levels and the occurrence of asthma symptoms among children.

Another study conducted in New York looked at childhood asthma hospitalisation and residential exposure to state route traffic.[5]

This case-controlled study investigated whether paediatric hospitalisation for asthma was related to living near a heavily trafficked road and involved children aged 0-14 years who were admitted for asthma. Controls were children in the same age group, admitted during the same time period but for non-respiratory diseases. Subjects' residential addresses were linked to traffic data.

It was found that children hospitalised for asthma were more likely to live in neighbourhoods with heavy traffic density or within 200 metres of major busy roads. It concluded that such children had increased risks of asthma hospitalisations.

The third study carried out in Utah Valley looked at elementary school absences and PM_{10} pollution and assessed the association between school absenteeism and respirable particulate pollution for the six school years of 1985 to 1990.[4]

School absenteeism data were analysed for kindergarten through sixth grade and compared to PM_{10} levels during the study period. Estimated associations between absenteeism and PM_{10} pollution were positive and statistically significant ($P<0.01$).

PM_{10} effects persisted for up to 3 or 4 weeks. Regression results indicated that an increase in 28-day moving average PM_{10} equal to 100 $\mu g/m^3$ was associated with an increase in the absence rate equal to approximately two percentage points or an increase in overall absences equal to approximately 40%.

The most recent and significant study (published January 2007) was also conducted in the US which investigated the association between residential exposure to traffic and 8-year lung-function in 3677 children (mean age 10 years) in 12 California communities.[9]

That study examined whether local exposure to major roadways can adversely affect lung-function growth during the period of rapid lung development that takes place in young children.

Children were followed up for 8 years with yearly lung-function measurements recorded. Pulmonary-function data were obtained yearly via maximum effort spirometry. For each child, several indicators of residential exposure to traffic from large roads were identified.

Regional air pollution was continuously monitored at one central site location within each study community over the course of the investigation, which included PM_{10}.

Regression analysis was used to establish whether 8-year growth in lung function was associated with local traffic exposure, and whether local traffic effects were independent of regional air quality.

The study found that children who lived within 500 metres of a motorway had substantial deficits in 8-year growth of forced expiratory volume (FEV = –81ml, P=0·01 [95% CI –143 to –18]) and maximum mid-expiratory flow rate (MMEF = –127 ml/s, P=0·03 [–243 to –11]), compared with children who lived at least 1500 metres from a motorway (Table 6).

Joint models showed that both local exposure to motorways and regional air pollution had detrimental, and independent, effects on lung-function growth. Pronounced deficits in attained lung function at age 18 years were recorded for those living within 500 metres of a motorway, with mean percent-predicted 97·0% for FEV (P=0·013, relative to >1500 m [95% CI 94·6-99 ·4]) and 93 ·4% for MMEF (P=0·006 [95% CI 89·1-97 ·7]).

The study concluded that local exposure to traffic on a motorway has adverse effects on children's lung development, which are independent of regional air quality, and which could result in important deficits in attained lung function in later life.

Table 6: Cumulative effect of motorway distance with full 8-year follow-up [9]

		Lung function		8–year growth
		Age 10 years Difference* (95% CI)	Age 18 years Difference* (95% CI)	Difference* (95% CI)
FEV	Motorway distance			
	<500 m	–23 (–73 to 28)	–121 (–219 to –23)	–98 (–182 to –15)
	500 –1000 m	–32 (–78 to 14)	–93 (–183 to –4)	–61 (–137 to 15)
	1000 –1500 m	–34 (–81 to 14)	–78 (–170 to 14)	–44 (–122 to 34)
MMEF	Motorway distance			
	<500 m	–57 (–169 to 56)	–230 (–432 to –28)	–173 (–327 to –19)
	500 –1000 m	–92 (–195 to 10)	–105 (–289 to 79)	–12 (–152 to 128)
	1000 –1500 m	–45 (–150 to 60)	–151 (–340 to 38)	–106 (–250 to 38)

*Difference in 8–year lung function or growth relative to children living >1500 m from a motorway.

Hong Kong

A study carried out in Hong Kong examined the impact of a government air quality intervention on the respiratory health of children.[92]

The study examined the changes after the introduction of the intervention, in airway hyperactivity in school children living in polluted and non-polluted districts. Using a histamine challenge test, the between-district differences for changes in bronchial responsiveness in school children were examined before and after the implementation of the intervention. An improvement in air quality was seen in both districts after the introduction of the intervention.

The findings suggested that bronchial hyper-responsiveness associated with PM_{10} in well populations of children is reversible after a reduction in PM_{10} levels.

China

In China, a study examined the respiratory health effects of long-term exposure to air pollution in schoolchildren within four very different cities, each of which showed wide variations in PM_{10} levels.[93]

City specific prevalence of various respiratory problems within schoolchildren were obtained including asthma, wheeze, bronchitis, persistent cough and hospitalisation for respiratory disease. Associations between these city specific prevalence rates and city specific PM_{10} levels were examined.

Positive associations between morbidity prevalence and levels of PM of all sizes were found but the strongest association appeared to be for coarse particulates of PM_{10} to $PM_{2.5}$. The study concluded that ambient particulates concentrations can be an effective index of air pollution in relation to children's respiratory symptoms.

Australia

In Australia, two significant studies have been conducted, one of which involved a joint study in five Australian cities and two New Zealand cities (Christchurch and Auckland) estimating the impact of outdoor air pollution on respiratory morbidity in children.[94]

That study used data on respiratory hospital admissions in children aged 1, 1-4, and 5-14 years. Daily hospital and ambient background pollution data, including PM_{10}, were collected for the period 1998 to 2001 for the seven cities.

The study showed strong and consistent associations between children's hospital admissions and outdoor air pollutants, including PM_{10}, in the urban centres of all seven cities. Significant increases across the cities were observed for hospital admissions in children for pneumonia and acute bronchitis (0, 1-4 years), respiratory disease (0, 1-4, 5-14 years), and asthma (5-14 years).

The other study involved an enrolled cohort of primary school children with a history of wheeze (n=148) in an 11-month longitudinal study to examine the relationship between ambient air pollution and respiratory morbidity.[95]

Associations were explored between air pollution and respiratory symptoms, asthma medication use, and doctor visits for asthma in three groups of children in western Sydney where higher levels of air pollution than in other regions of Sydney are found. The three groups of children were those with recent wheeze, positive histamine challenge (airway hyper-responsiveness), and a doctor diagnosis of asthma; another group with recent wheeze and doctor diagnosis of asthma; and a third group with recent wheeze only.

The cross-sectional study included a parent-completed asthma questionnaire, measurement of children's airway responsiveness by histamine challenge and skin prick testing to nine common allergens. Daily air pollution and meteorological data were obtained from six ambient air quality monitoring stations in western and south western Sydney.

While there were no associations between ambient ozone concentrations and respiratory symptoms, there was an association between PM_{10} concentrations and doctor visits for asthma (RR=1.11, 95% CI 1.04-1.19).

New Zealand

Very little research has been carried out in New Zealand with regard to the health effects of PM_{10}, particularly in children and as a result of motor vehicle traffic. Early studies that have been conducted in New Zealand have had significant methodological weaknesses, such as a reliance on extrapolated data from overseas work or low power resulting from a small sample size. [96, 97]

Most work has been carried out in Christchurch for two main reasons; (a) it has been identified as the New Zealand city with, at certain times of the year, the most significant air quality problem – due mainly to winter-time home heating using wood and coal burning, and (b) reasonable amounts of data are available from the regional air quality monitoring programme.[98]

There are five studies of some significance which have been carried out in New Zealand. One, carried out in 1999, looked at daily mortality in relation to weather and air pollution in Christchurch and found a positive association between PM_{10} on the day prior to death.[99]

Respiratory and cardiovascular mortality data were extracted and analysed with hourly PM_{10} measurements. Statistically significant associations were found, which although reported as weak, were considered to be of public health significance if causal.

Another study also carried out in Christchurch involved an analysis of mortality among census areas in Christchurch from 1988 to 1997, and compared the number of deaths following days with high particulate air pollution with deaths on matched unpolluted days.[100]

The daily numbers of deaths by census area unit (n=104, average population 3000, range 300-6000) were obtained for the years 1988 to 1997 for the Christchurch Territorial Local Authority area (population approximately 300,000).

Hourly measurements of airborne PM_{10} were available from a single, centrally located city site maintained by the Canterbury Regional Council. Daily average particulate estimates were calculated from the hourly data.

Mortality within each census area unit was summed over all 'exposed' days with high air pollution (24-hour average PM_{10} level greater than $50\mu g/m^3$) and matched 'unexposed' days with low pollution (24-hour average PM_{10} less than $50\mu g/m^3$). Mortality rate ratios (MRR) and 95% CIs were calculated.

A statistically significant association between mortality and air pollution was found with substantial variation in pollution-related mortality among census area units. Mortality was significantly increased following polluted days with a combined MRR of 1.05 (95% CI 1.03-1.08).

A third study in Christchurch explored the relationship between PM_{10} pollution and admissions to hospital with cardio-respiratory illnesses.[101]

PM_{10} statistics were obtained together with data on hospital admissions (including pneumonia, acute respiratory infections, chronic lung disease and asthma) for the period June 1988 to December 1998 for both adults and children with cardiac and respiratory disorders.

The relationship between PM_{10} and admissions was explored and found to be a significant association. For all age groups combined there was a 3.37% increase in respiratory admissions for each interquartile rise in PM_{10} (interquartile value 14.8$\mu g/m^3$). There was no relationship between PM_{10} and the control group (admissions for appendicitis).

A current three-year long study in New Zealand involves identifying and quantifying the health risks due to peoples' exposure to air pollution. The first phase of the project is a pilot study on Christchurch.[98]

Before the study methodology is applied to the whole of New Zealand, the pilot study on Christchurch will be reviewed, evaluated and circulated for comment.

The results obtained from the study so far are wide-ranging and detailed, and include:

- The results of previous studies on the effects of air pollution in Christchurch are broadly confirmed, but with greater detail on the location and scale of these effects.
- There are defined health effects, in some portions of the population, down to relatively modest air pollution levels (Table 7).
- The findings are reasonably consistent with similar studies conducted overseas.
- The greatest effect and greatest cost occurs due to premature mortality caused by long-term exposure to particulates from combustion sources.

Table 7: Annual effect of PM_{10} pollution in Christchurch [98]

Health effect	Annual effect attributed to PM_{10} pollution
Chronic bronchitis (and related diseases)	52 cases
Acute cardiac admissions	53 cases
Acute respiratory admissions	194 cases
Doctors visits, medicine	Not assessed
Minor direct hospital costs	$200,000
Restricted activity days	285,000 days

The study comments that there are also adverse effects from air pollution that may not have direct and obvious public health implications, but nevertheless have costs to society. These include restricted activity days, which can affect large portions of the population on bad air pollution days, and extra medical costs associated with treating respiratory problems such as asthma.

Furthermore, it highlights that the most sensitive portions of the population are (a) older people, particularly over-65s, (b) infants, particularly under-1s, (c) asthmatics and people with bronchitis, (d) people with other respiratory problems, (e) people that are health compromised in other ways, such as those susceptible to heart disease.

Of most significance in New Zealand is the research commissioned by the Ministry of Transport of a study carried out in 2002 which assessed the health effects of air pollution emissions from vehicles on the population of New Zealand.[1]

This study involved an analysis of the relevance to New Zealand of overseas research with regard to the effects of air pollution from motor vehicles. It concluded that the outcomes of research from overseas were applicable to New Zealand and that the methodologies were also valid for making such an assessment in New Zealand.

It was a preliminary study considered as the first attempt in New Zealand to quantify health effects due to air pollution from motor vehicles. The input data utilised all available and appropriate particulate monitoring data from across New Zealand, and the study was based on average annual exposures in each city and town with a population of over 5,000 people.

Mortality effects were estimated using the methodology of Kunzli.[87] The most likely estimate of the number of people above 30 years of age who experience premature mortality in New Zealand due to exposure to emissions of PM_{10} particulates from motor vehicles was estimated to be 399 per year (with a 95% confidence range of 241-566 people). This compares with 502 people dying from road traffic crashes (all ages).

Analysed on a regional basis, it was estimated that most of the increased mortality due to vehicle emissions (253 people, or 64% of the total) occurs in the greater Auckland region.

For some purposes, such as a health cost analysis, or a comparison with the road traffic crash toll, the study comments that traffic-related air pollution mortality in terms of years of life lost is better to be assessed because of the fact that air pollution mortality generally affects older people, which results in fewer years of life lost than for other causes of death. This was achieved by an analysis of the causes of death, with an ‘adjusted’ mortality due to PM_{10} of 200 people per year (although there are still 399 premature deaths per year).

The results of the study were consistent with other studies across Europe, which show that mortality caused by air pollution from vehicle emissions is twice that of the road accident toll. New Zealand has a relatively higher road toll per capita, and a relatively better air quality than many European countries, but the results still show that the public health impacts in New Zealand from vehicle-related air pollution emissions are significant.

The study also concluded that while the report is concerned only with deaths in adults aged over 30 years, relatively little is known about susceptibility and that high-risk groups are likely to include children.

It goes on to identify epidemiological research priorities for New Zealand as:

- to analyse the different effects on different risk groups, and
- to further study the effects on infants and younger age groups.

Summary

These studies have demonstrated significant positive associations between traffic-related PM_{10} levels and adverse health effects, in particular with regard to children's health.

The findings of Anderson et al. 2001[84] and Venn et al. 2001[6] as discussed are the most significant of recent studies showing evidence of associations between PM_{10} and respiratory admissions in the 0-14 year age group, and increased risk of wheeze in children in relation to proximity to main roads, respectively. The findings of both these studies in particular are applicable to New Zealand.

4: AIR QUALITY

AIR QUALITY GUIDELINES AND STANDARDS

Guidelines and Standards

The majority of developed countries have in place ambient air quality standards for controlling the levels of air pollutants. These have traditionally been based on standards developed by the US Environmental Protection Agency (USEPA) and/or the World Health Organization guidelines, although the European Union (EU) is now also prominent in this area.

Guidelines are usually set as goals or targets as a foundation for the development of regulatory standards, which are enforceable as a legal mandate. These standards take into consideration toxicological and epidemiological studies of animals and humans before they are set and in some cases also consider the impact on plants and crop losses.

The World Health Organization Air Quality Guidelines

The WHO Air Quality Guidelines (AQGs)[102] are designed to offer guidance in reducing the health impacts of air pollution, based on expert evaluation of current scientific evidence. These evaluators include; experts in toxicology and epidemiology, air quality risk and exposure assessment, air quality management, and public policy.

A review of the WHO Air Quality Guidelines - Second Edition 2000,[12] found that for some key pollutants, such as PM_{10}, there was increasing evidence for adverse health effects caused at low levels of exposure, and that evaluators have been unable to identify an absolute threshold, or level below which there were no adverse health effects. This is viewed as problematic by the World Health Organization, given that the prevailing concept of an AQG value assumed a 'concentration(s) of chemical compounds in the air that would not pose adverse effects of health.'[12]

Furthermore, the WHO is concerned that this approach taken for PM_{10} has not been well accepted by those responsible for air quality management and therefore recommended that the updated guidelines describe concentrations for each relevant pollutant, which if complied with, would result in significantly reduced rates of adverse health effects.[12] Such concentration levels are based on the available scientific evidence and provide an explicit objective for air quality managers and policy makers to consider when setting their national air quality standards and air quality management strategies.

The WHO guidelines are written for worldwide use, and are intended to support and complement actions aimed at achieving an optimal level of public health protection in air quality within a range of varying contexts. Air quality standards play an important role in risk management and environmental policy development, and should be set by each individual country to protect the public health of their populations. The standards set in each country vary according to differing country-specific approaches, which balance the risks to human health, technology, the economy, and other social and political factors.

Although current scientific evidence suggests that guidelines cannot be defined for PM_{10} that will provide optimal protection against adverse health effects, the WHO AQGs for PM_{10} are currently set as:

- PM_{10} Annual mean $20\mu g/m^3$
- PM_{10} 24-hour mean $50\mu g/m^3$

Besides the guideline values, three interim targets (IT) are also defined, to assist in gauging progress over time in the difficult process of progressively reducing population exposures to PM_{10} (Tables 8 and 9).

Table 8: WHO air quality guideline and interim targets for PM_{10}: annual mean [102]

Annual mean level	PM_{10} ($\mu g/m^3$)	Basis for the selected level
WHO interim target-1 (IT-1)	70	These levels are estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% ([2-11%) compared to WHO IT-1
WHO interim target-3 (IT-3)	30	In addition to other health benefits, these levels reduce mortality risk by approximately another 6% ([2-11%) compared to WHO IT-2 levels.
WHO Air quality guideline (AQG)	20	These are the lowest levels at which total, cardiopulmonary mortality have been shown to increase with more than 95% confidence

Table 9: WHO air quality guideline and interim targets for PM_{10}: 24-hour mean [102]

24-hour mean level	PM_{10} ($\mu g/m^3$)	Basis for the selected level
WHO interim target-1 (IT-1)	150	Approximately 5% increase of short-term mortality over AQG
WHO interim target-2 (IT-2)	100	Approximately 2.5% increase of short-term mortality over AQG
WHO interim target-3 (IT-3)	75	Approximately 1.2% increase of short-term mortality over AQG
WHO Air quality guideline (AQG)	50	Based upon relationship between 24-hour and annual PM_{10} levels

In the evaluation of the WHO AQGs and their interim targets, it is recommended that the annual average guideline take precedence over the 24-hour mean guideline since, at low levels, there is less concern about remaining episodic deviations. Complying with the 24-hour mean guideline should protect against peaks of pollution that would lead to considerable excess mortality or morbidity.

The New Zealand National Environmental Standards for Air Quality

In October 2004, the New Zealand Government introduced the National Environmental Standards for Air Quality (NES).[103]

The primary purpose of the ambient standards is to provide a guaranteed level of protection for the health of all New Zealanders. They are the 'minimum requirements that outdoor air quality should meet in order to guarantee a set level of protection for human health and the environment'.

The ambient standards are based upon the existing Ambient Air Quality Guidelines.[104] These guidelines were developed following a comprehensive review of international and national research, and are widely accepted amongst New Zealand practitioners and replace any previous guideline levels for that particular pollutant and averaging period.

National environmental standards are mandatory technical environmental regulations. They have the force of regulation and are implemented by agencies and parties with responsibilities under the Resource Management Act 1991 (RMA).

Regulation 13 of the NES provides for ambient air quality concentration limits as follows:

(1) The ambient air quality standard for a contaminant listed in the first column of the table in Schedule 1 is that the concentration of the contaminant must not exceed its threshold concentration except to the extent and in the circumstances (if any) listed in the third column of that table.

(2) For the purposes of these regulations, an ambient air quality standard is breached if the concentration of the contaminant concerned exceeds its threshold concentration otherwise than to the extent and in the circumstances (if any) listed in the third column of the table in Schedule 1.

(3) For the purposes of this regulation and Schedule 1, threshold concentration means the concentration of the contaminant listed in the second column of the table in Schedule 1 calculated over the time interval specified in that column.

Schedule 1 of the regulation sets out ambient air quality concentration limits for five main pollutants, including PM_{10}, which are specified for a particular time average. Table 10 shows the ambient air quality standard for PM_{10}.

Table 10: New Zealand ambient air quality standards for PM_{10} [103]

Pollutant	Standard	Time average	Allowable exceedences per year
Particulates (PM_{10})	50µg/m³	24-hour mean	1

The regulations do not set an annual mean level for PM_{10} and therefore the level set by the WHO must be used when interpreting annual PM_{10} values.

Air Quality Category Classifications

In New Zealand, the Ministry for the Environment's Environmental Performance Indicators (EPIs)[105] classifies air quality into categories, each based upon a percentage of the overall guideline value (Table 11 and Figure 20).

Table 11: Air quality category classifications [105]

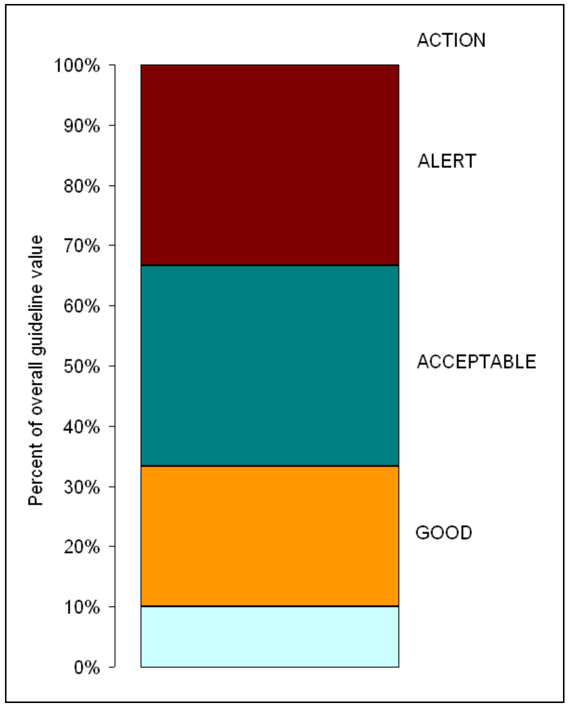
Category	Maximum measured value	Comment
Action	Exceeds the guideline	Completely unacceptable, by national and international standards.
Alert	66 - 100% of guideline	A warning level, which can lead to exceedences if trends are not curbed.
Acceptable	33 - 66% of guideline	A broad category, where maximum values might be of concern in some sensitive locations but generally at a level which does not warrant dramatic action.
Good	10 - 33% of guideline	Peak measurements in this range are unlikely to impact air quality.
Excellent	< 10% of guideline	Of little concern, if maximum values are less than a tenth of the guideline, average values are likely to be much less.

This process grades air quality in a qualitative manner and provides for an early warning device of possible air pollution problems.

Early warning is required because the management strategies required to bring about improvements in air quality may take some time to be investigated, agreed upon and then implemented.

Categories that describe air quality can be used to present information and assist in setting air quality management goals (Figure 20).

Figure 20: Diagram of air quality categories [105]



The Setting of Air Quality Standards

The setting of air quality standards cannot be absolutely precise since fundamentals of uncertainty and judgment are unavoidable. Nonetheless, a standard, in the sense of an agreeable set level which protects human health, remains essential, and a practical requirement for meeting statutory obligations in reducing air pollution to minimal levels that fully protect human health.

Clearly, standards must be based on the best available scientific and medical knowledge and experience. However, it is important to recognise that standards should not be regarded as precise dividing lines between levels of pollutants which pose no threat to health and those levels which do.[106]

Regardless of the setting of standards and guidelines for PM_{10}, evidence is steadily increasing which suggests that levels or concentrations below existing agreed standards and guidelines have the potential to cause or contribute to adverse human health effects and that present levels of protection most probably do not provide adequate public health protection.[107]

Consequently, the WHO emphasises the need to reduce exposure to air pollutants, particularly PM_{10}, even where current concentrations comply with the proposed guideline levels.

It must also be noted that there will always remain susceptible populations who are adversely affected when exposed to levels below the WHO air quality guidelines, *e.g.* children.

AMBIENT PM_{10} LEVELS IN AUCKLAND

Reasons for Monitoring

Ambient (background) air quality monitoring is one of the three main processes which are necessary to develop a comprehensive picture of the air quality within a given region. The quantification of emissions of pollutants into the air through source appropriation on a spatial distribution basis (*i.e.* emissions inventory) and the recording of meteorological conditions in a region are the other two main processes.[108]

The Auckland Regional Council is responsible for air quality management across the Auckland region. It monitors ambient air quality at several sites across the region as part of its air quality monitoring programme. These sites may be classified as residential, roadside or industrial sites (Table 12).

The purpose of the Auckland Regional Council's air quality monitoring programme is to ensure that there is a sufficient understanding of its air quality so as to reasonably manage the discharges of pollutants into the receiving environment, together with their direct, cumulative and synergistic potential for causing adverse health effects. This enables air quality to be maintained and, where possible, enhanced, so as to ensure the life supporting capacity of the air provides public health protection.

Furthermore, it is the early identification of adverse trends and associated future problems which provide an essential tool for air quality management and allows for the intelligent targeting of public policies and regulations so as to avoid, remedy and mitigate any adverse health effects.

Table 12: Ambient PM_{10} monitoring sites in Auckland [109]

Site name	Height (m)	Micro meteorological characteristics	Site classification
Henderson	<20	Surrounding area is flat.	Residential neighbourhood
Khyber Pass	80	Buildings on the southern side may shield the intakes from southern flow. Buildings upon the southern side and the valley nature of the road may result in some canyon effect.	Traffic peak
Queen Street	15	Pollutants may be entrained within the urban canyon formed by the tall buildings on either side during calm conditions. Wind flows are also likely to be channelled along this corridor.	Traffic dense
Takapuna	20	This site is relatively well exposed to winds from all directions. However, the hills to the south will influence flow condition from this direction and channel N and S wind flows.	Residential dense
Mt Eden	70	Hilly; Mt Eden (summit 198m) 2km to SSE. Surrounding buildings may cause localised turbulence.	Residential neighbourhood
Penrose	20	Surrounding buildings to the NE, E and SE will shield the monitor and introduce turbulence.	Industrial dense

The aim of the air quality monitoring programme is to:

- determine background and peak levels of air pollutants across the region
- determine those meteorological conditions which may effect the concentration and dispersion of air pollutants
- determine the relative contributions of each of the many sources of air pollutants by the development of emissions inventories
- identify the presence and direction of any trends in air quality by data analysis
- predict any future problems by the use of predictive models
- examine the formation of photochemical smog
- investigate the potential for the deterioration of visibility.

Figure 21: Air quality monitoring site Queen Street [110]

Figure 22: Air quality monitoring site Khyber Pass Road [110]

Meteorological Conditions

Auckland enjoys a subtropical climate which provides a comparatively high average wind speed of 15 knots (7-8 metres per second). While this results in good ventilation of air pollutants, stable atmospheric conditions especially experienced during still winter nights, cause the air pollutants to disperse more slowly, which results in higher pollutant concentrations.[109]

Auckland's sea breezes which blow onshore typically in the afternoons between late October and early March also have the potential to cause air pollution episodes. When solar radiation is highest during this period, the strong sea breezes opposing from the east and west coastlines predominate, and meet along a band known as the 'Sea Breeze Convergence Zone'. It is this convergence zone which can lead to stagnation or recirculation of the air mass over the isthmus area.

Such conditions often cause the daily discharges of pollutants to be added to discharges from previous days, thereby creating much greater levels of pollutants than normal. Together with lower wind speeds, hotter air temperatures, and higher solar radiation, conditions favourable for the formation of photochemical smog occur.

It should also be noted, however, that Auckland's weather is also strongly influenced by the El Nino cycle which results in fewer calm periods and therefore less potential for high air pollution levels.[110]

Ambient PM_{10} Results

In New Zealand, PM_{10} monitoring has not been carried out for a sufficient length of time to indicate any long term trends.

Monitoring sites across Auckland produce differing results dependent upon their classification, *i.e.* residential, roadside or industrial.

Roadside sites at Queen Street and Khyber Pass Road continually produce annual averages above the WHO Air Quality Guideline of 20µg/m³ (Figures 23 and 24). Since 2003, a residential site at Takapuna has also produced annual averages above the WHO Air Quality Guideline, also due to high volumes of traffic (Figure 25). Other sites in Auckland produce annual averages below the WHO Air Quality Guideline (Figures 26 and 27).[111]

Figure 23: PM_{10} annual averages at Queen Street [111]

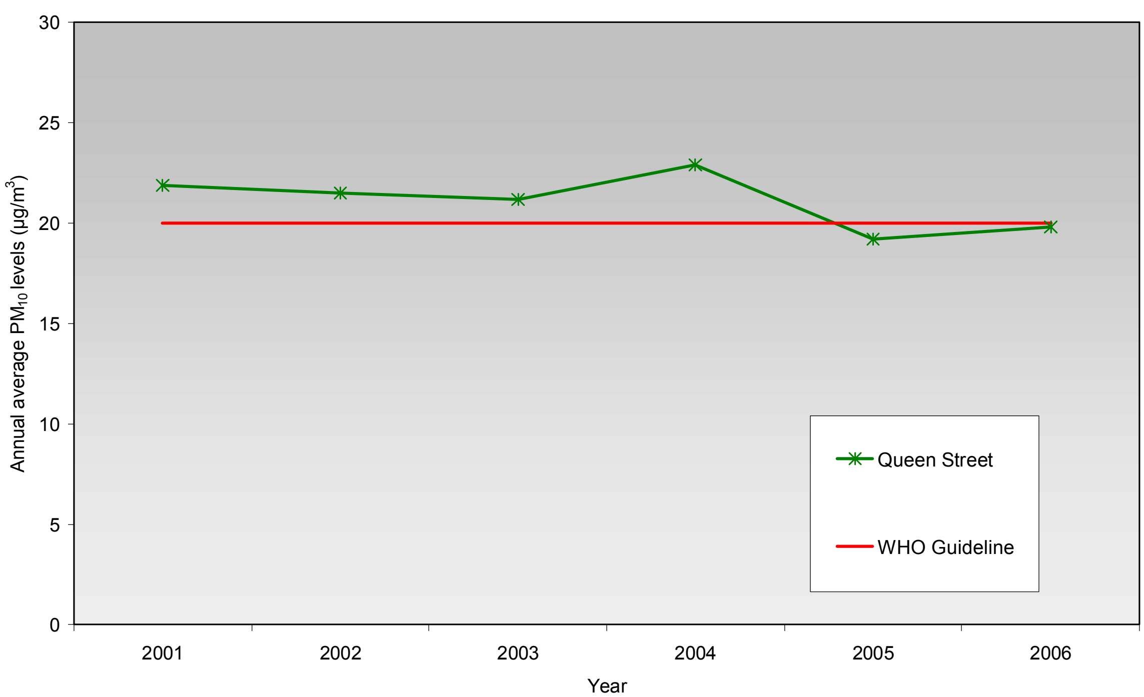


Figure 24: PM_{10} annual averages at Khyber Pass Road [111]

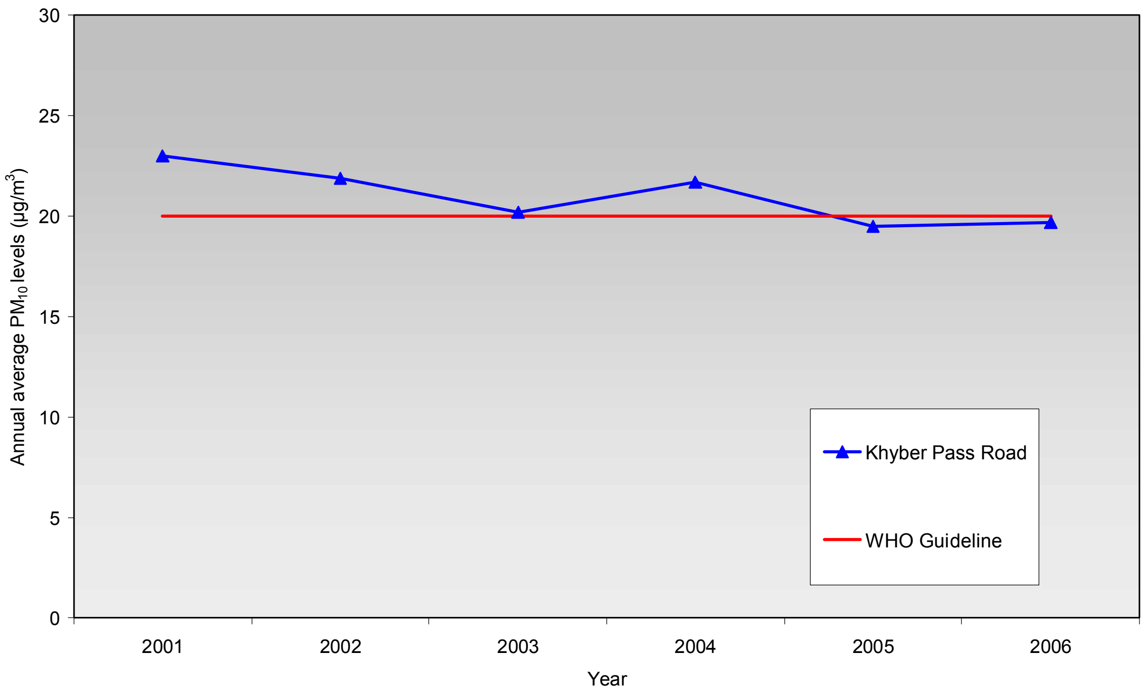


Figure 25: PM_{10} annual averages at Takapuna [111]

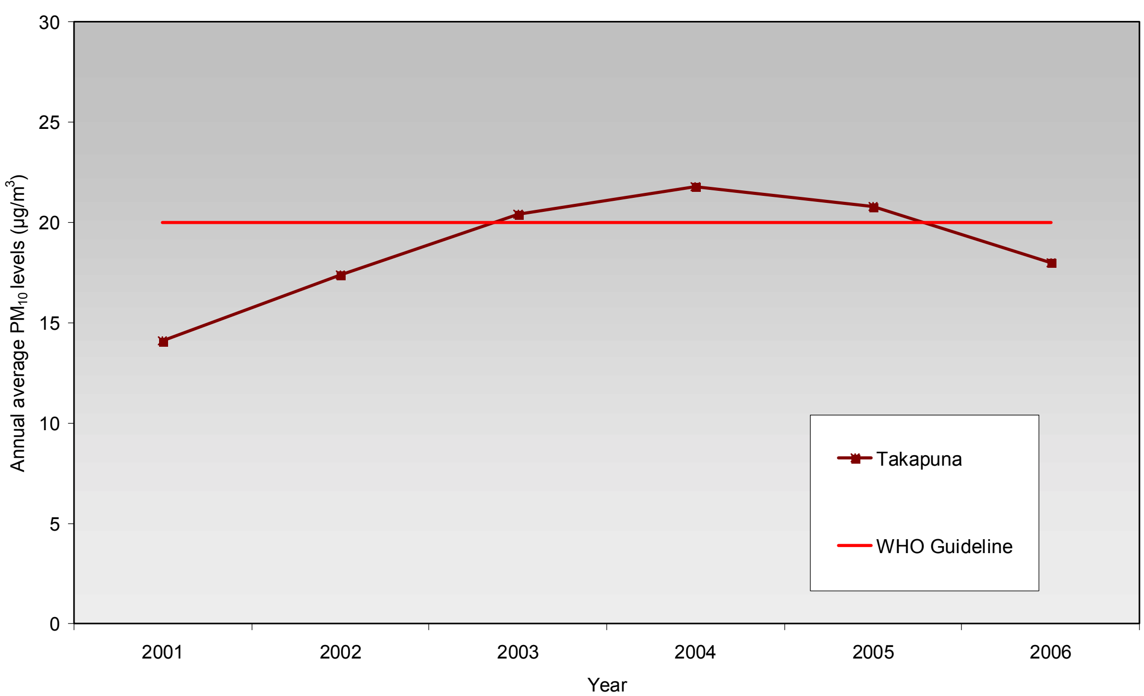


Figure 26: PM_{10} annual averages at Mt Eden [111]

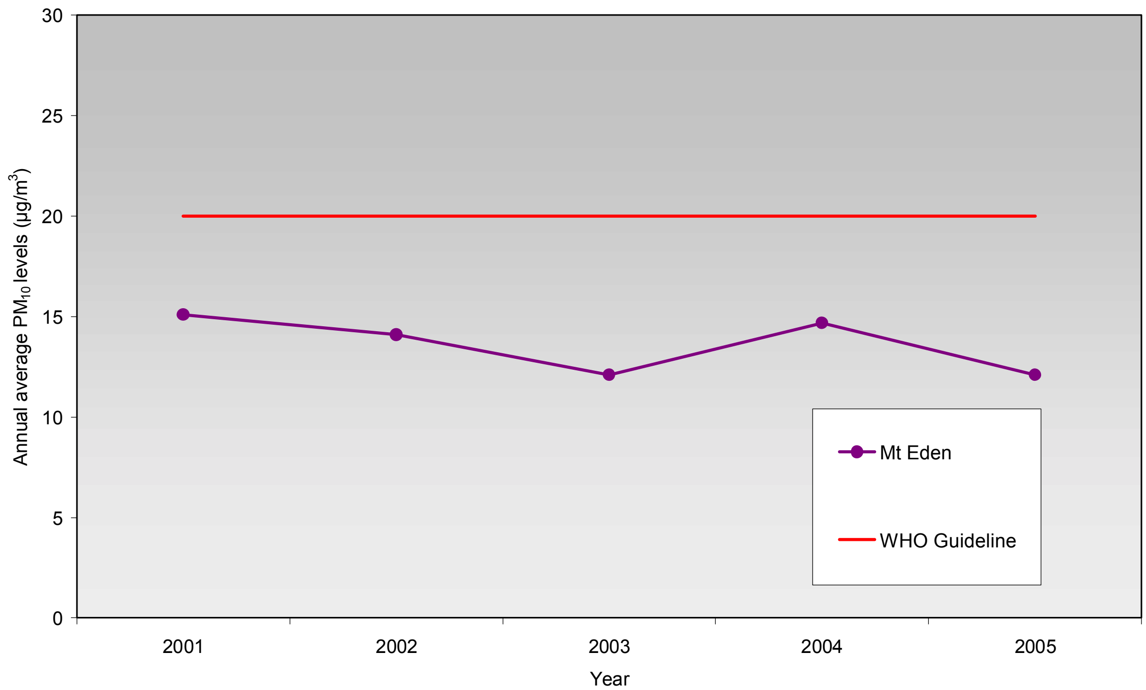


Figure 27: PM_{10} annual averages at Penrose [111]

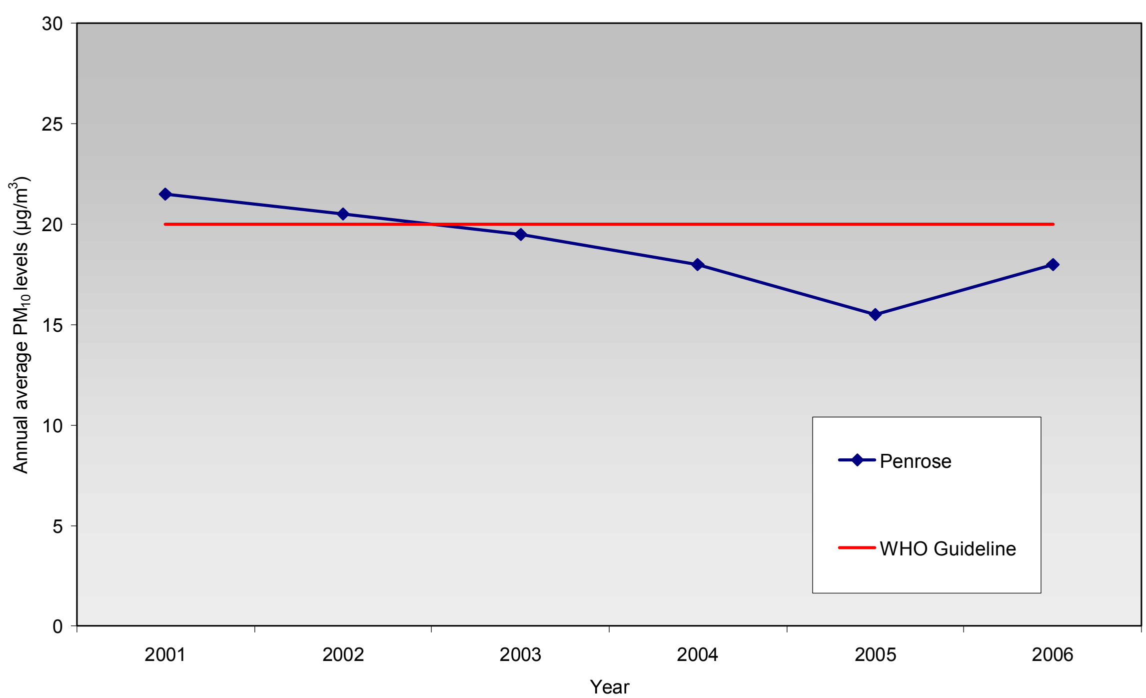


Table 13 shows that 24-hour maximum PM_{10} levels exceeded the 24-hour MfE National Air Quality Standard at several sites in Auckland.

Table 13: 24-hour maximum PM_{10} levels at selected Auckland sites [111]

Location	Year	24-hour maximum (μg/m³)	24-hour standard (μg/m³)	Standard exceeded
Henderson	2003	58	50	Y
	2004	52	50	Y
	2005	36	50	N
Khyber Pass Road	2003	43	50	N
	2004	47	50	N
	2005	84	50	Y
Queen Street	2003	46	50	N
	2004	53	50	Y
	2005	44	50	N
Takapuna	2003	50	50	N
	2004	56	50	Y
	2005	86	50	Y
Mt Eden	2003	46	50	N
	2004	50	50	N
	2005	33	50	N
Penrose	2003	62	50	Y
	2004	45	50	N
	2005	44	50	N

AIR QUALITY MONITORING

CONSIDERATIONS

A wide variety of methods are available for measuring air pollutants, which vary in cost and precision. The purpose and objectives of any air quality monitoring should be taken into consideration when choosing specific monitoring methods. This should also include consideration with regard to available resources, *i.e.* budget, as well as whether there is a requirement to comply with standard monitoring methods and/or national practice.[112]

Air monitoring methods are defined in several different categories:

High Precision Instrumental Methods

These provide continuous monitoring of air pollutant concentrations over long periods of time (weeks or months) and require minimal operator involvement. They provide high measurement precision and detection levels of these systems are more often one order of magnitude or more below typical background levels. However, detailed calibration and operating methods are needed to ensure high precision, and consequently these methods are the most expensive to deploy.[112]

Lower Level Instrumental Methods

These methods are often much cheaper than the high precision instrumental methods and their cost may be as little as one tenth of the corresponding high precision monitors, although some of this gain in savings will be offset by the increased maintenance and operational costs, since they often require more frequent operating checks and adjustments. Furthermore, their measurement precision is only marginally below typical background levels.[112]

Manual Particulate Methods

Manual methods form the basis of most of the particulate monitoring carried out in New Zealand. They provide time-averaged results, typically over a 24-hour or 7-day period. However, most of these instruments require significant operator intervention including manual changes of the sampling filters in between each collected sample, although a number of semi-automated systems are becoming more available. The precision of most manual particulate methods is about 10–20% of typical background levels. [112]

All of the above methods have significant but differing roles in air quality monitoring. Where the aim of the monitoring is to demonstrate compliance with the National Environmental Standards for Air Quality, the higher precision instrumental methods must be used. However, it is accepted that the manual methods are sufficient for monitoring particulates.[112]

The cheaper low level instrumental methods are generally used for preliminary surveys, where the aim is to determine a quick snap-shot of pollution levels in an area of interest. These same methods can then be used for further surveys over following measurement periods (months or years).

While the type of monitoring information required often dictates budget requirements, the duration of the monitoring (*i.e.* weeks, months or years) and the number of monitoring sites are also determining factors.

MONITORING METHODS

High-volume Gravimetric

In many parts of the world, the high volume air sampler forms the standard method for measuring total suspended particulate (TSP). It operates by drawing in air through a 25cm x 20cm glass-fibre filter at a rate of approximately 1.5m^3/min. The filter is weighed before and after sampling under constant humidity conditions. The filter is mounted horizontally on the top of the sampler and is protected from rain and other weather conditions by a small roofing structure.

Sampling normally occurs over 24-hour periods (midnight to midnight) using a 7-day sampling regime, although sampling may occur over 7-day periods (one individual weekly sample) as part of a longer sampling regime. Both are intended to give representative coverage of the expected variations in particulate levels throughout any year.

Medium-volume Gravimetric

A scaled-down version of the high volume sampler has been used in New Zealand for TSP monitoring for many years, and in some locations continues to be used.

This method is based on a 55mm glass fibre filter, held in a plastic holder and mounted under a small aluminium conical roofing. Samples are collected over periods of seven days with an air sampling rate of approximately 50-75 litres per minute.

The New Zealand system was developed for several reasons such as reliability, portability and cost. However, it has been demonstrated that over the last several years the system is not equivalent to the high-volume sampler and tends to give lower results. Consequently, it is now only used at sites with a significant history of results, in the interests of maintaining data continuity.

Several other medium-volume samplers are also available for monitoring particulates which are easier to position and use. Some of these systems are able to operate in a sequential mode and allow multiple samples to be collected with little operator involvement.

Low-volume Gravimetric

This is the cheapest option and more often utilises a portable, battery operated pump. These systems are well suited for short-term one-off survey work, since they avoid most of the difficulties involved in setting up the permanent monitoring stations that are usually required for high- and medium volume systems. However, none of the available low-volume systems are classed as 'equivalent' methods, in accordance with USEPA requirements, since measurement precision is less than that obtained with the high and medium volume systems.[113]

Standard Methods

Several standard air monitoring methods are recommended within the National Environmental Standards for Air Quality by the Ministry for the Environment. [103]

Monitoring for PM_{10}, for the purposes of the regulations, requires continuous monitoring in order to calculate a daily 24-hour mean. This is necessary to properly assess compliance with the PM_{10} standard (50µg/m³ not to be exceeded more than one 24-hour period in a 12-month period). Consequently, 'one day in three' or 'one day in two' monitoring is not sufficient for measuring ambient fine particles for the purposes of the standard.

Schedule 2 of the regulations provides standard methods for ambient air quality monitoring, which must be used for determining compliance with the standards. This schedule provides for two methods for monitoring fine particles – both of them gravimetric. Included in the US gravimetric method, however, are equivalent methods such as beta attenuation monitors (BAMs), tapered element oscillating microbalance monitors (TEOMs) and low volume samplers (which must be capable of providing continuous monitoring).

SITE SELECTION

It is important to acknowledge that where an air quality monitor is positioned has a significant effect on what it measures and the source of the pollutants. Consequently, the objectives of any air quality monitoring programme will significantly affect where the monitors are located.[112]

While there may be a perfectly good reason for monitoring at a particular (*e.g.* specific monitoring of an affected location of for compliance monitoring), this must be clearly identified. It may be misleading to analyse data intended for one purpose *(e.g.* effects at a busy road intersection) to interpret another problem (*e.g.* background air quality across a region).

For monitoring air quality within an urban area, high pollutant concentration levels can be recorded that are not indicative of the overall air quality in that area; if for example a monitor is positioned too close to a point source, such as an extract vent or chimney from an industry.

In contrast, for specific air quality issues such as monitoring pollution from road traffic vehicles, or monitoring specific industrial discharges, then it is appropriate to site the monitoring equipment close to the source (particularly when ensuring that the influences of other sources are eliminated or reduced). Local airflows, shielding and funnelling should also all be taken into account.

It is important that the monitoring location reflects the affected environment, *i.e.* where adverse human health effects are of concern, monitoring equipment should be located where humans have the potential to be affected, both at that time as well as in the future. Similarly, if ecological impacts are of concern, monitoring equipment should be located close to any affected sensitive ecosystems.

METEOROLOGICAL MONITORING

It is highly recommended that air quality monitoring be accompanied by appropriate meteorological monitoring, since the weather has a very strong influence on contaminant dispersion and concentrations. In some cases, data from a nearby meteorological monitoring station may be suitable, but in many cases measurements are required at the air quality monitoring site itself.[113]

AIR QUALITY MODELLING

Air quality modelling (or atmospheric dispersion modelling) is an essential tool in air quality management, providing the link between environmental effects and discharges to air. Its use has grown rapidly in New Zealand over the past 10 years.[114]

It is used for determining and visualising the significance and impact of emissions to the atmosphere and is particularly of benefit to policy-makers, whose decisions are often based on emission measurements.[115]

A model is a simplified picture of reality. It must be noted that it does not contain all the features of the real system but contains the features of interest for the management issue or scientific problem to be solved by its use. Models are widely used in science to make predictions and are often used to identify the best solutions for the management of specific environmental problems.[114]

Atmospheric models may be described as 'any mathematical procedure, which results in an estimation of ambient air quality entities (*i.e.* concentrations, deposition, exceedences)'.[115]

An atmospheric dispersion model is:

- a mathematical simulation of the chemistry and physics which govern the transportation, dispersion and transformation of pollutants in the atmosphere, and
- a means of estimating downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere.

Contaminants discharged into the air may be dispersed by small-scale air-flows or turbulence, which mix contaminants with clean air, or transported over long distances by large-scale air-flows.

This dispersion by the wind is a very complex process due to the presence of different-sized eddies in atmospheric flow. Even under ideal conditions in a laboratory the dynamics of turbulence and turbulent diffusion are some of the most difficult in fluid mechanics to model. There is no complete theory that describes the relationship between concentrations of ambient air pollutants and the causative meteorological factors and processes.

Dispersion models can take many forms. The simplest are provided in the form of graphs, tables or formulae on paper. Today, dispersion models more commonly take the form of computer programmes, with user-friendly interfaces and online help facilities.

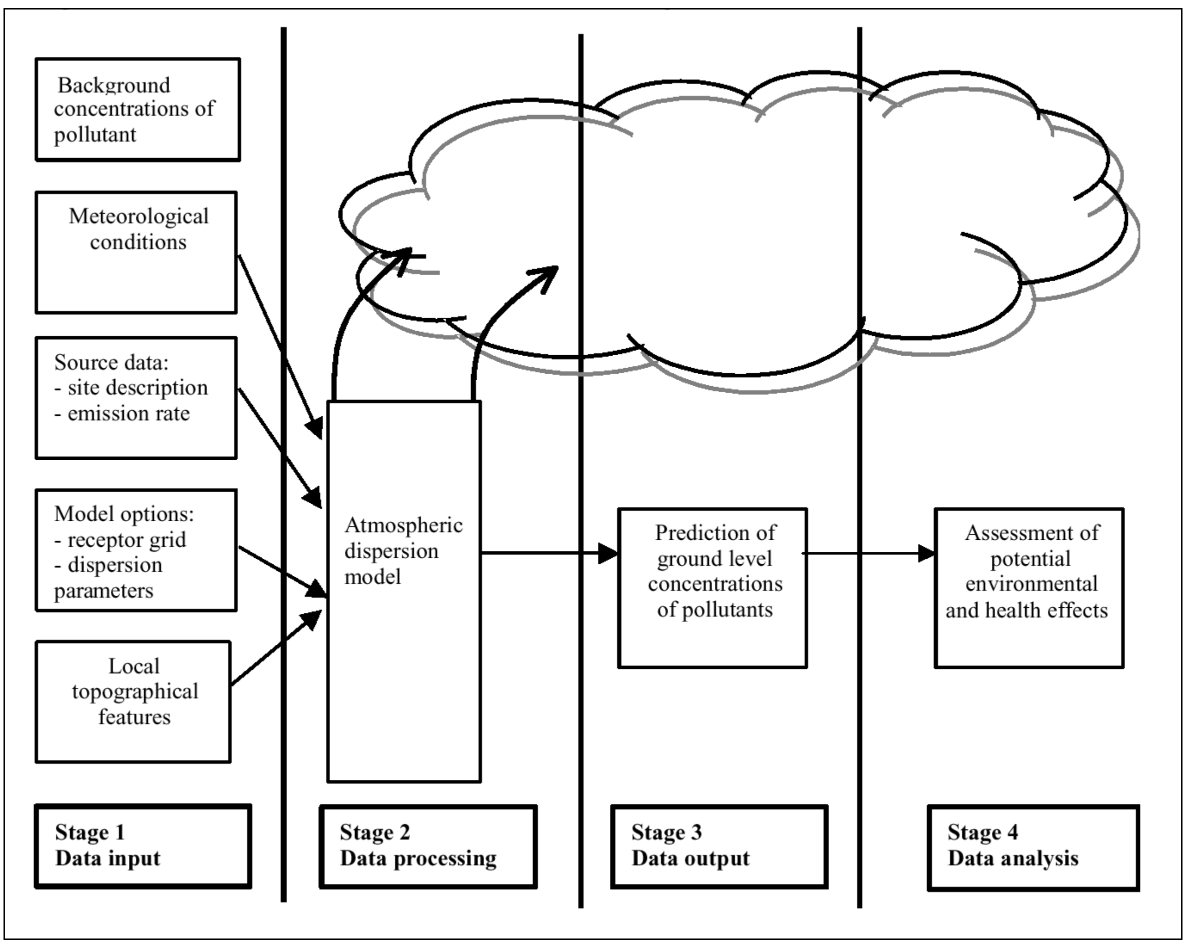
Most modern air pollution models are computer programmes that calculate the pollutant concentration downwind of a source using the following information:

- ambient concentrations of pollutant,
- characteristics of the emission source,
- contaminant emission rate,
- meteorology of the area, and
- local topography.

The process of air pollution modelling contains four stages (data input, dispersion calculations, deriving concentrations, and analysis). The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects.

A generic overview of how this information is used in a computer-based air pollution model is shown in Figure 28.

Figure 28: Overview of the air pollution modelling procedure [114]



Models can be used for estimating past, present and future air quality as long as the necessary emissions data are available. However, limitations in the use of atmospheric modelling should always be taken into account, even though these models play a role in air quality assessment studies. Once a model has been developed, further application of the model is relatively inexpensive, but collecting the necessary input data may be cumbersome.[115]

The ground-level concentrations which result from a constant discharge of contaminants change according to the weather (particularly the wind) conditions at the time. Meteorology is fundamental for the dispersion of pollutants because it is the primary factor determining the diluting effect of the atmosphere. Therefore, it is important that meteorology is carefully considered when modelling.

Modelling makes a number of assumptions which may limit their use since they use very simple meteorology to transport and diffuse the pollutant.[116]

The winds are applied as being the same at every point for a particular hour with the pollutant transported in straight lines from the source to the receptor. The winds and diffusion tend to be independent from one hour to the next and input meteorology requires hourly records of surface winds and temperatures as well as mixing heights and atmospheric stability. This is commonly based upon basic surface radiation, cloud and wind data.

The four main applications of modelling are for:

1. Regulatory purposes where results are used in issuing air discharge consents
2. Policy support where the effects of abatement are forecast
3. Public information particularly for the forecasting of the occurrence of smog episodes
4. Scientific research, although with limitations.

It is generally agreed that there is often a need for both monitoring and modelling and in some cases, modelling may be better than monitoring. Monitoring is usually not representative for an area of good air quality, and its quality is sometimes questionable. A model can provide an estimate of concentrations in an area where no monitoring has been carried out, allowing for certain refinements.

However, models are mostly used for forecasting and planning purposes. While models link emissions to air pollution concentrations and exposure via meteorological data, the models can normally only be as reliable as the emission inventories they use.[115]

5: METHODS

In this section, the regime for centre site selection is discussed, followed by the sampling methodology employed. Each early childhood centre is then described in detail with regard to its location to surrounding roads and volume of traffic. Aerial photographs and photographs of the outdoor play areas in relation to the nearest road(s) are also presented. This is followed by a description of the chosen monitoring method and calculation of PM_{10} levels.

SITE SELECTION

There are 230 early childhood centres in Auckland City. Approximately 35% of these are situated in background locations away from busy roads. Up to 50% of the centres are situated in roadside sites, with the remainder (approximately 15%) situated somewhere in between. In other words, approximately 65% are located adjacent to a busy or standard road, and 35% are located either adjacent to a quiet road or away from a road.

Of the eight centres identified for monitoring, 5 centres (62.5%) are located adjacent to very busy roads and 3 centres (37.5%) are located either away from a quiet road (2 centres) or adjacent to a very quiet road (1 centre). Therefore, since the ratio of these centres located on busy roads to those located on quiet roads is similar to that for the total number of centres in Auckland City, these eight centres may be said to be generally representative of the location of all early childhood centres in Auckland City.

A convenience sample was selected based upon the average traffic flow (number of vehicles averaged over the working week, Monday to Friday) for the road nearest to each centre.

Roads with more than 17,000 vehicles per day (traffic volume averaged over the working week, Monday to Friday) were considered to be busy roads. Those with less than 3,000 vehicles per day (traffic volume averaged over the working week, Monday to Friday) were considered to be quiet roads. The distance of the outdoor play area of the centres was also taken into consideration.

SAMPLING METHODOLOGY

For this study, air quality monitoring was chosen in preference to air quality modelling for several reasons:

- The majority of previous studies have relied upon ambient (background) air quality results measured across the wider region and exposure assessments have not been based upon specific air quality monitoring of the specific target study areas, *e.g.* alongside a busy road, in a school playground, etc.
- Budgetary constraint was a deciding factor and in this case air quality monitoring using MiniVol portable air samplers was substantially cheaper than air quality modelling,
- Air quality modelling makes a number of assumptions which may limit its use since it uses very simple meteorology to transport and diffuse the pollutant,
- Models are mostly used for forecasting and planning purposes.

MiniVol portable air samplers were installed at four of the eight early childhood centres for the first time series of 4 weeks. Weekly samples were collected over this period of time. The MiniVols were then installed at the other four early childhood centres for the second time series of 4 weeks also and weekly samples collected once again.

For the first time series, 2 centres located alongside busy roads, one centre located some distance from a reasonably quiet road, and one centre located alongside a very quiet road were monitored simultaneously.

For the second time series, 3 centres located alongside busy roads and one centre located some distance from a reasonably quiet road were monitored simultaneously.

The sampling method was carried out as described further in this section (page 121).

EARLY CHILDHOOD CENTRE DESCRIPTIONS

CENTRE A

This centre is located on a busy main road. The road is made up of two lanes of traffic, the nearest lane of which is approximately 8 metres from the outdoor play area of the centre. The average traffic flow for the road is 17,765 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117] This road is prone to congestion caused by morning and afternoon rush-hour traffic.

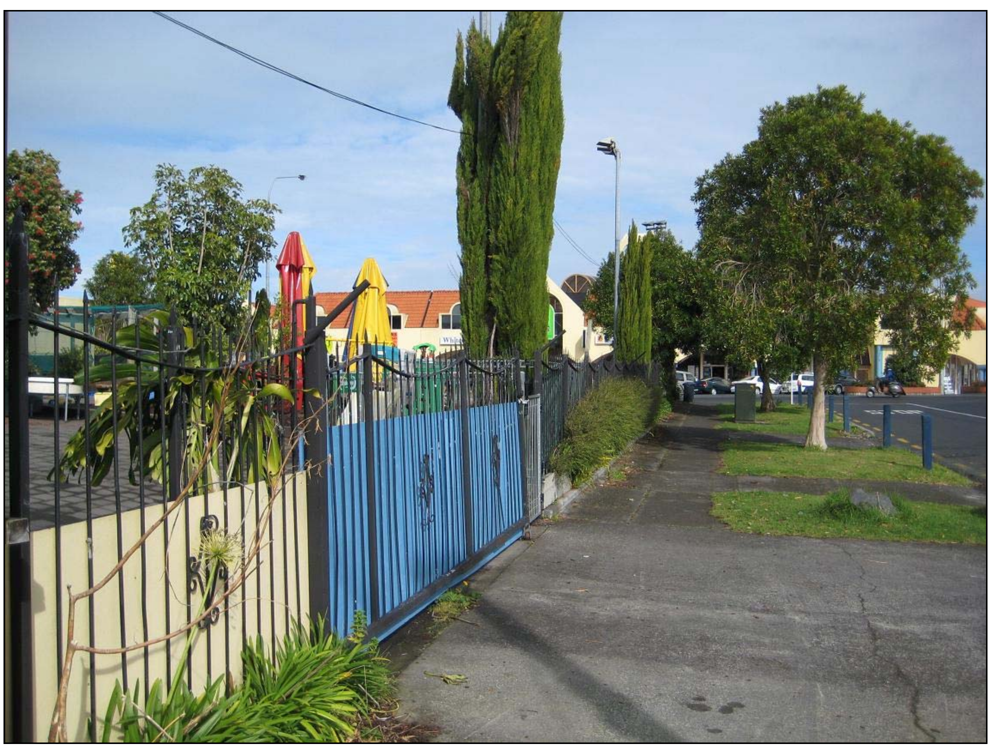
There is an additional residential road alongside the centre which feeds residential traffic and is also used as a bypass by some of the main traffic. The nearest lane of this road is approximately 5 metres from the outdoor play area of the centre. The average traffic flow for this road is 2,000 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117] The centre provides early education for 40 children, aged between 2 and 5 years.

Figure 29: Aerial photograph of Centre A [118]

Figure 30: Outdoor play area of Centre A in relation to both adjacent roads

Photographer: author

Figure 31: Outdoor play area of Centre A in relation to the adjacent residential road



Photographer: author

CENTRE B

This centre is located on a busy urban route road. The road is made up of four lanes of traffic, the nearest lane of which is 12 metres from the outdoor play area of the centre. The average traffic flow for the road is 27,782 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117]

This road is prone to congestion caused by morning and afternoon rush-hour traffic. To both sides of the centre are located rows of residential housing. The centre provides early education for 36 children, aged between 2 and 5 years.

Figure 32: Aerial photograph of Centre B [119]

Figure 33: Outdoor play area of Centre B in relation to the adjacent road

Photographer: author

Figure 34: The urban route road adjacent to Centre B

Photographer: author

CENTRE C

This centre is located on a busy inner city main road. The road is made up of three lanes of traffic, the nearest lane of which is approximately 10 meters from the outdoor play area of the centre. The average traffic flow for the road is 18,031 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117]

The centre is approximately 3 metres below the level of the road and two sides of the centre are bounded by adjacent tall buildings (Figure 37). The centre provides early education for 40 children, aged between 0 and 5 years.

Figure 35: Aerial photograph of Centre C [120]

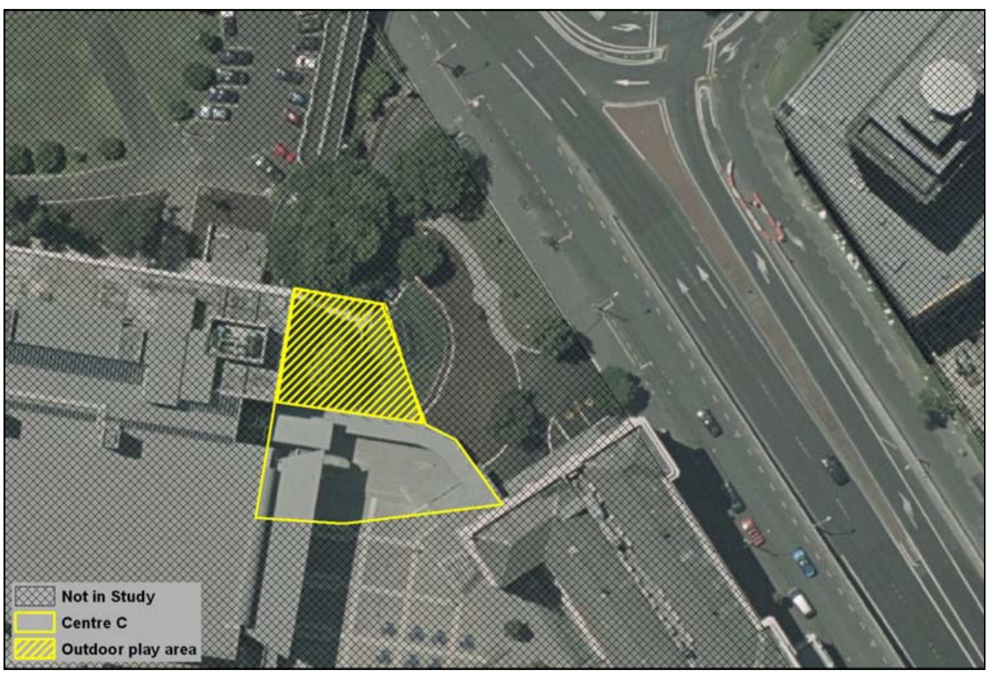


Figure 36: Outdoor play area of Centre C in relation to the adjacent road

Photographer: author

Figure 37: Outdoor play area of Centre C in relation to adjacent buildings

Photographer: author

CENTRE D

This centre is located on a busy urban route road. The road is made up of four lanes of traffic, the nearest lane of which is approximately 15 metres from the outdoor play area of the centre. The average traffic flow for the road is 20,754 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117] This road is prone to congestion caused by morning and afternoon rush-hour traffic.

The centre is also within approximately 200 metres of State Highway 1 motorway, which is also prone to congestion caused by morning and afternoon rush-hour traffic. The centre provides early education for 34 children, aged between 0 and 5 years.

Figure 38: Aerial photograph of Centre D [121]

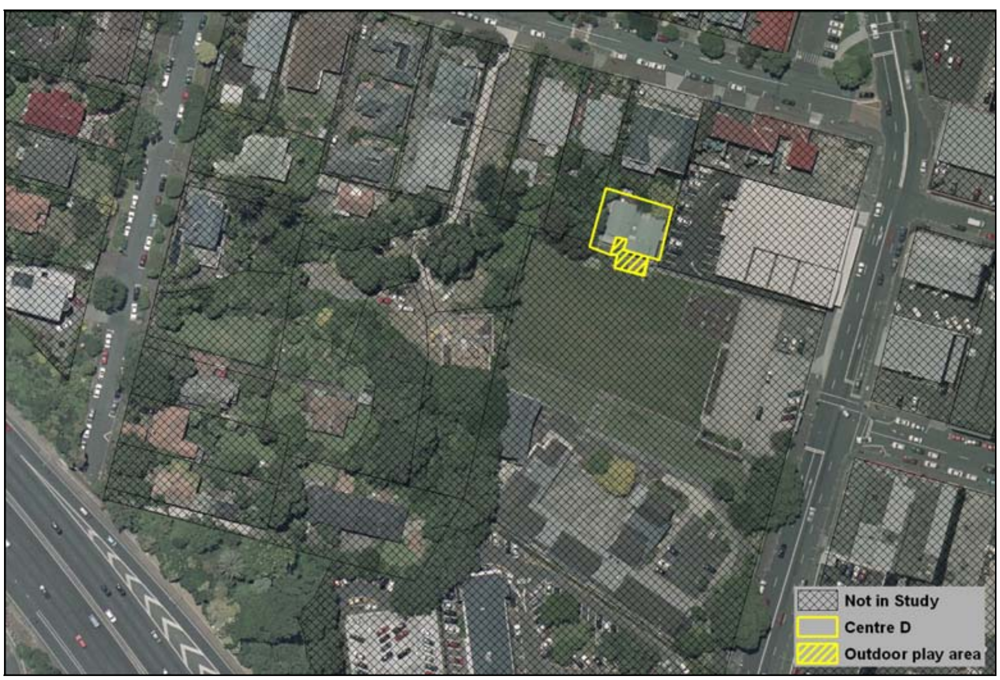
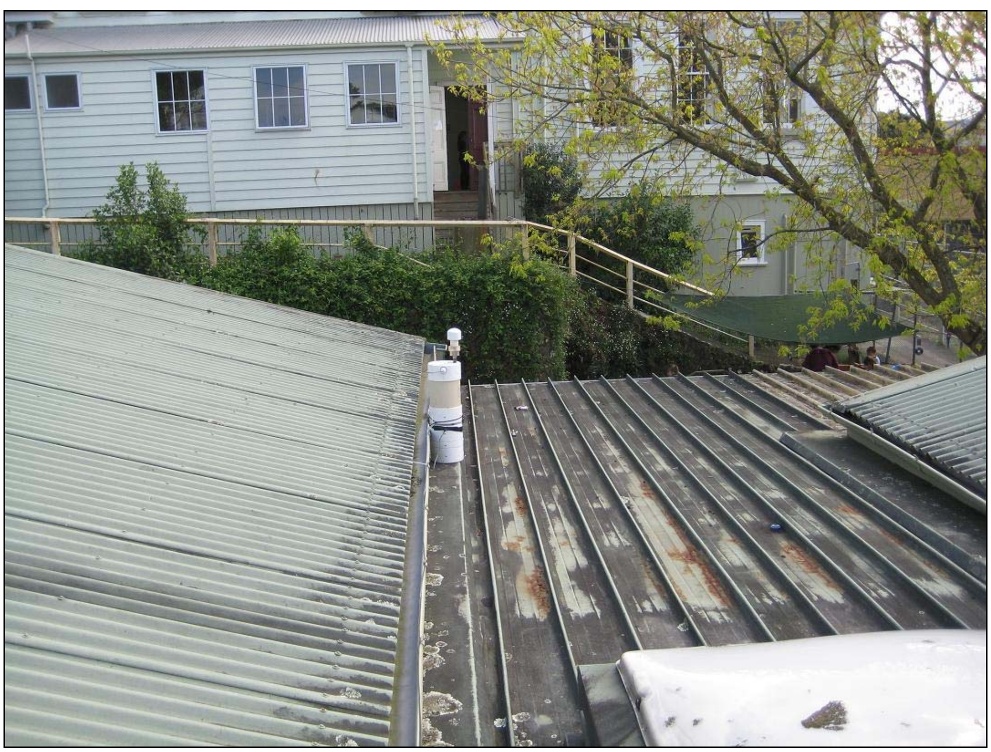


Figure 39: Outdoor play area of Centre D in relation to the adjacent road

Photographer: author

Figure 40: MiniVol sampler sited at Centre D



Photographer: author

CENTRE E

This centre is located on a busy inner city main road. The road is made up of four lanes of traffic, the nearest lane of which is approximately 4 metres from the outdoor play area of the centre. The average traffic flow for the road is 22,678 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117]

There is a similarly busy main road to one side of the centre, the nearest lane of which is approximately 20 metres from the outdoor play area. The average traffic flow for this road is 18,031 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117] The centre is also within approximately 150 metres of State Highway 16 motorway. The centre provides early education for 36 children, aged between 2 and 5 years.

Figure 41: Aerial photograph of Centre E [122]

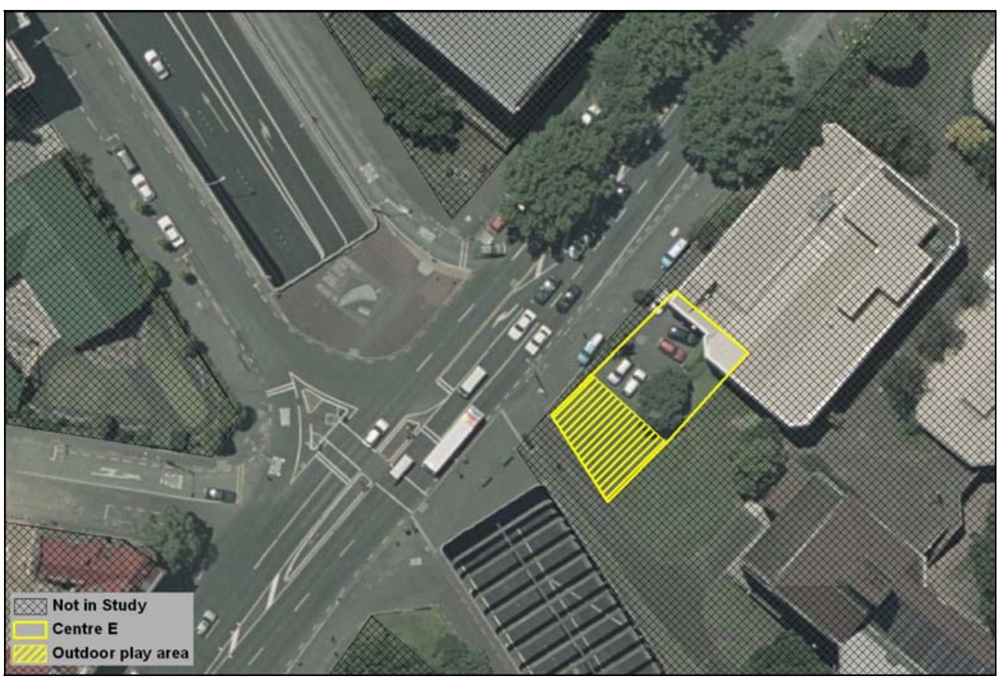


Figure 42: Outdoor play area of Centre E in relation to the adjacent road

Photographer: author

Figure 43: Centre E in relation to the motorway (lower right)

Photographer: author

CENTRE F

This centre is located adjacent to a reserve, accessed by a driveway on a quiet residential road. The nearest lane of the residential road is 60 metres from the outdoor play area of the centre. The average traffic flow for the road is 2,269 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117]

The centre provides early education for 22 children, aged between 0 and 5 years.

Figure 44: Aerial photograph of Centre F[123]

Figure 45: Outdoor play area of Centre F in relation to the reserve

Photographer: author

Figure 46: The immediate area adjacent to Centre F

Photographer: author

CENTRE G

This centre is located within a residential area and close to a reserve, accessed by a driveway on a quiet residential road. The nearest lane of the residential road is 50 metres from the outdoor play area of the centre. The average traffic flow for the road is 2,018 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117]

The centre provides early education for 45 children, aged between 2 and 5 years.

Figure 47: Aerial photograph of Centre G [124]

Figure 48: Outdoor play area of Centre G in relation to the adjacent reserve

Photographer: author

Figure 49: Access driveway of Centre G and adjacent residential road

Photographer: author

CENTRE H

This centre is located on an extremely quiet residential road. The nearest lane of the residential road is 3 metres from the outdoor play area of the centre. The average traffic flow for the road is 559 vehicles per day (traffic volume averaged over the working week, Monday to Friday).[117] The centre is surrounded by residential housing.

The centre provides early education for 30 children, aged between 0 and 5 years.

Figure 50: Aerial photograph of Centre H [125]

Figure 51: Outdoor play area of Centre H in relation to the adjacent road

Photographer: author

Figure 52: The residential road adjacent to Centre H

Photographer: author

Table 14: Summary of centre descriptions

Centre	Site Description	5-day average traffic flow (vehicles/day)	Distance of outdoor play area from road	Number of children
A	Busy main road	17,765	8m	40
B	Busy urban route road	27,782	12m	36
C	Busy inner city main road	18,031	10m	40
D	Busy urban route road	20,754	15m	34
E	Busy inner city main road	22,678	4m	36
F	Adjacent to a reserve, accessed by a driveway on a quiet residential road	2,269	60m	22
G	Close to a reserve, accessed by a driveway on a quiet residential road	2,018	50m	45
H	Quiet residential road	559	3m	30

MONITORING METHOD

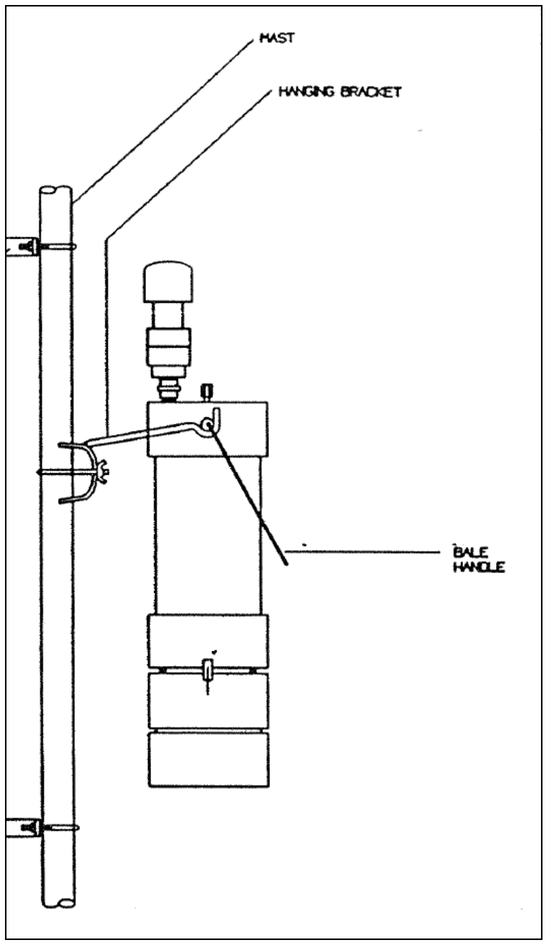
The MiniVol portable air sampler (Figure 53) is an ambient air sampler for particulate matter and other gaseous pollutants. It was developed jointly by the U.S. Environmental Protection Agency (USEPA) and the Lane Regional Air Protection Agency in an effort to address the need for portable air pollution sampling technology.

Figure 53: Airmetrics MiniVol sampler [126]

While not a reference method sampler, the MiniVol gives results that closely approximate reference method air quality data.[127] With its accuracy and precision, as well as being battery or mains operated, the lightweight MiniVol is ideal for sampling at remote sites or areas where no permanent site has been established. In addition, the low cost of the sampler allows a network of MiniVols to be deployed at a fraction of the cost for a similar reference station network.

The MiniVol is basically a pump controlled by a programmable timer which can be set to monitor over either a 24-hour period or throughout a week. When used outdoors it is hung from a bracket mounted on a variety of structures such as power or telephone poles, trees, fence posts, etc. (Figure 54).

Figure 54: Mounted sampler [127]



The sampler is equipped to operate from either AC or DC power sources. An elapsed time accumulator linked in parallel with the pump records the total time in hours of pump operation.

In the PM_{10} sampling mode, air is drawn through a particle size separator and then through a filter medium. Particle size separation is achieved by impaction. Critical to the collection of the correct particle size is the correct flow rate through the inlet. For the MiniVol, the actual volumetric flow rate must be 5 litres per minute at ambient conditions.

The inlet tube downstream from the filter takes the air to the twin cylinder diaphragm pump. From the pump, air is forced through a standard flowmeter where it is exhausted to the atmosphere inside the sampler body.

The programmable timer will automatically turn the pump off at the end of a sampling period. The sampler is then serviced and set up for the next sampling period. Servicing includes removing the sampler from its hanging bracket, removing the filter holder with the exposed filter inside from the sampler, and attaching a new filter holder with a fresh filter.

The sampling technique employed by the MiniVol is a modification of the PM_{10} reference method described in USEPA's Code of Federal Regulations (40 CFR 50, Appendix J).[127]

Under these criteria, a PM_{10} sampler must have:

1. a sample air inlet system to provide particle size discrimination
2. a flow control device capable of maintaining a flow rate within specified limits
3. a means to measure the flow rate during the sampling period, and
4. a timing control device capable of starting and stopping the sampler.

In New Zealand, this method has also been designated by the Ministry for the Environment as a reference or equivalent method under the provisions of Schedule 2 of the Resource Management (National environmental standards relating to certain air pollutants, dioxins and other toxics) Regulations 2004.

The Airmetrics MiniVol Portable Air Sampler meets all of these specifications. It is equipped with:

1. an inlet impactor capable of separating particulate matter to <10 μm,
2. a flow control device which will maintain a specified flow rate,
3. a flowmeter to measure the flow rate during the sampling period,
4. an elapsed time meter, and
5. a programmable timer that starts and stops the sampler unattended.

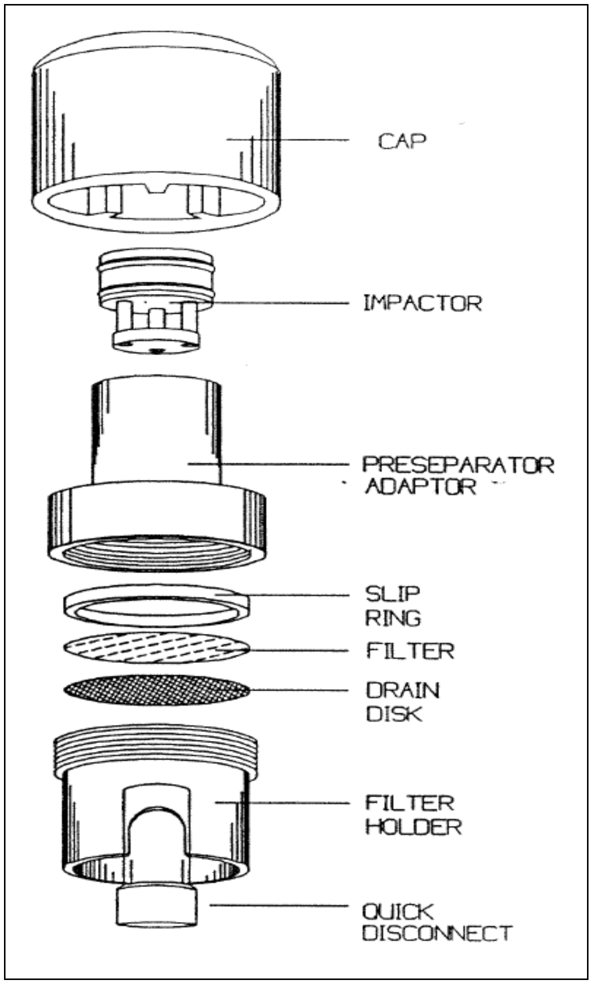
The MiniVol's flow rate is generally less than the flow rates used by reference method devices. At low concentrations of particulate matter, this reduced flow rate results in a greater deviation in accuracy where precision can be lost through the handling and weighing of the sample. However, at high particulate concentrations the sampler produces results that are precise and comparable to reference method samplers.

While the MiniVol's sampling method is not a reference or equivalent method, it has proven to be an excellent indicator of absolute ambient PM_{10} concentrations.[127]

Although the data generated do not wholly conform or comply with USEPA's National Ambient Air Quality Standards protocols or the New Zealand National Environmental

Standards for Air Quality, they still serve as a useful supplement to data generated by PM_{10} reference methods.

Figure 55: Preseparator and filter holder assembly [127]



The total mass of PM_{10} on the sample filter (W_g) is calculated by subtracting the clean filter mass (F_c) from the exposed filter mass (F_e):

$$W_g = F_e - F_c$$

Filters were weighed by a qualified and experienced environmental technician from the National Institute of Water and Atmospheric Research Ltd (NIWA), in laboratories that have obtained ISO 9001 certification for all air quality operations.

Control filters which have not been exposed are used and the change in weight of these between the clean and exposed filters (ΔC) is calculated:

$$\Delta C = \frac{\sum_{i=1}^{n} [(C_{ica} + C_{icb}) - (C_{iea} + C_{ieb})]}{2 \times n}$$

where n is the number of control filters used and $C_{1ea,2ea,3ea}$ are the control filter masses before weighing exposed sample filters and $C_{1eb,2eb,3eb}$ are the control filter masses after sampler filter weighing.

The total mass of PM_{10} on the sample filter (W_n) is obtained by correcting the total mass for the mass change of the control filters:

$$W_n = W_g + \Delta C$$

The sample air volume (V) in cubic metres is calculated by taking the average air flow (Q) over the sampling period in litres per minute, multiplied by the sample time (t) in minutes. This is further multiplied by 0.001 to convert litres into cubic metres:

$$V_{m^3} = 0.001_{m^3/l} \times Q_{l/\min} \times t_{\min}$$

Finally, the total measured mass of PM_{10} in micrograms per cubic metre for each sample is calculated by the formula:

$$PM_{\mu g/m^3} = 1000_{\mu g/mg} \times \frac{W_{n(mg)}}{V_{m^3}}$$

where 1000 is the conversion factor from milligrams to micrograms.

6: RESULTS

In this section the results of PM_{10} monitoring are presented for each centre in comparison to the WHO annual guideline value. Two separate groups, comprising four centres each, are then compared as separate time series of monitoring.

The following table (Table 15) shows all results of the monitoring carried out at the eight early childhood centres. Weekly concentrations of PM_{10} and their ranges over the 4-week period are given.

Table 15: Weekly measured PM_{10} levels ($\mu g/m^3$)

Centre	Site Type	Week								Range ($\mu g/m^3$)
		1	2	3	4	5	6	7	8	
A	Busy main road	13	26	12	12					12-26
B	Busy urban route road					11	15	19	17	11-19
C	Busy inner city main road					19	16	19	19	16-19
D	Busy urban route road					19	18	19	19	18-19
E	Busy inner city main road	22	25	14	17					14-25
F	Quiet residential road	14	15	8	10					8-15
G	Quiet residential road					9	14	10	10	9-14
H	Quiet residential road	13	15	10	11					10-15

Measurement error +/- 10% [128]

Table 16 shows meteorological conditions during the monitoring periods. For each sampling week, the most frequent wind direction (degrees and cardinal direction) is given as well as the mean wind speed during each period.

Table 16: Meteorological readings during sampling

Sampling week	Most frequent wind direction		Mean wind speed (m/s)
	Degrees direction	Cardinal direction*	
1	226	SW	2.0
2	234	SW	4.3
3	179	S	2.5
4	224	SW	2.6
5	55	NE	2.5
6	359	N	3.3
7	308	NW	3.0
8	306	NW	5.2

*Cardinal wind directions calculated from degrees directions using the wind calculator in Appendix 2

Figure 56 shows that the WHO guideline for PM_{10} was exceeded once during the four weeks of monitoring carried out at Centre A (busy main road).

Figure 57 shows that although all results for Centre B (busy urban route road) were within the WHO guideline, PM_{10} levels during two of the four weeks monitored were only marginally within the guideline value.

Figure 56: Weekly measured PM_{10} levels at Centre A

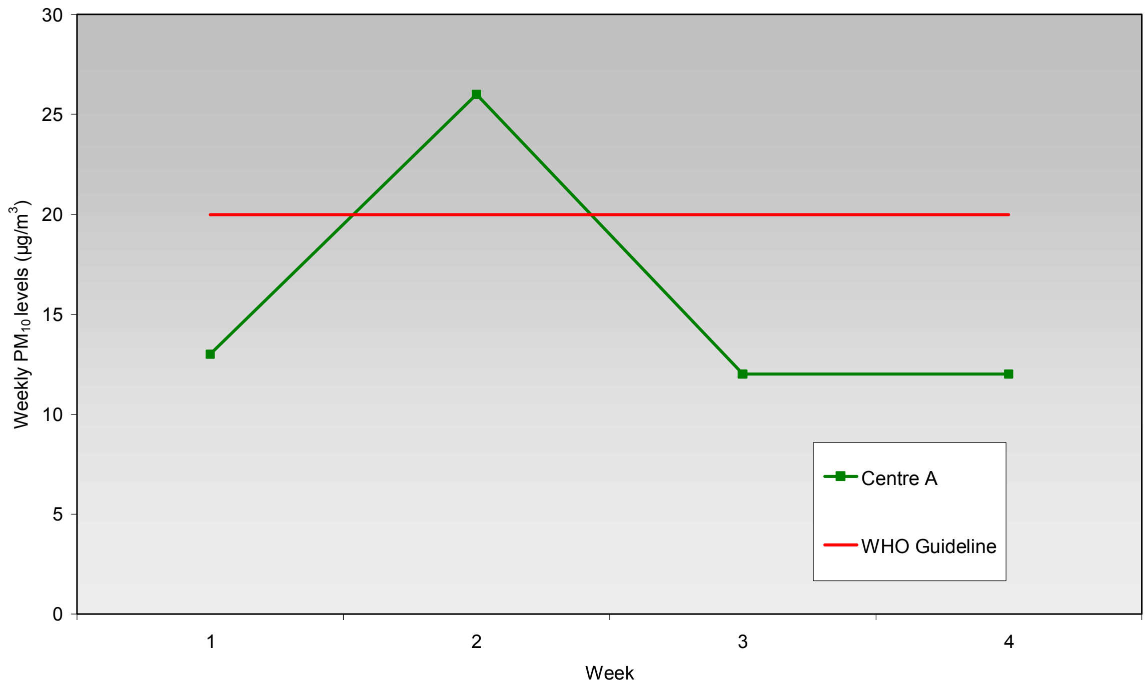
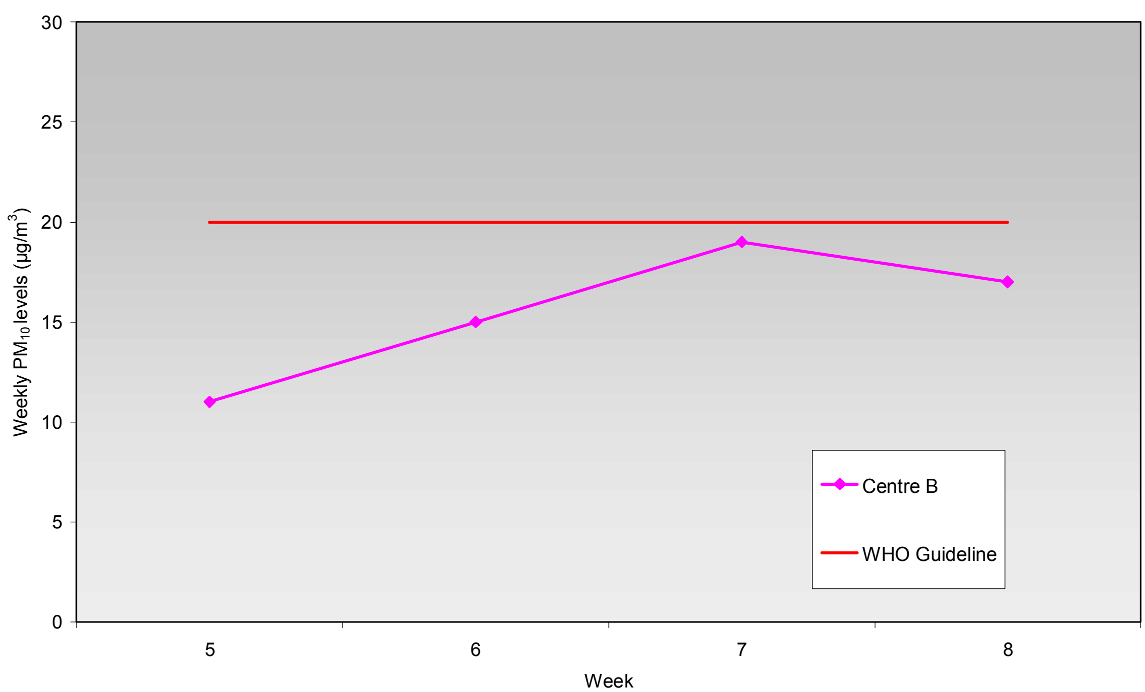


Figure 57: Weekly measured PM_{10} levels at Centre B



Figures 58 and 59 show that for each of these two Centres, C (busy inner city main road) and D (busy urban route road), results were only marginally within the WHO guideline.

Figure 58: Weekly measured PM_{10} levels at Centre C

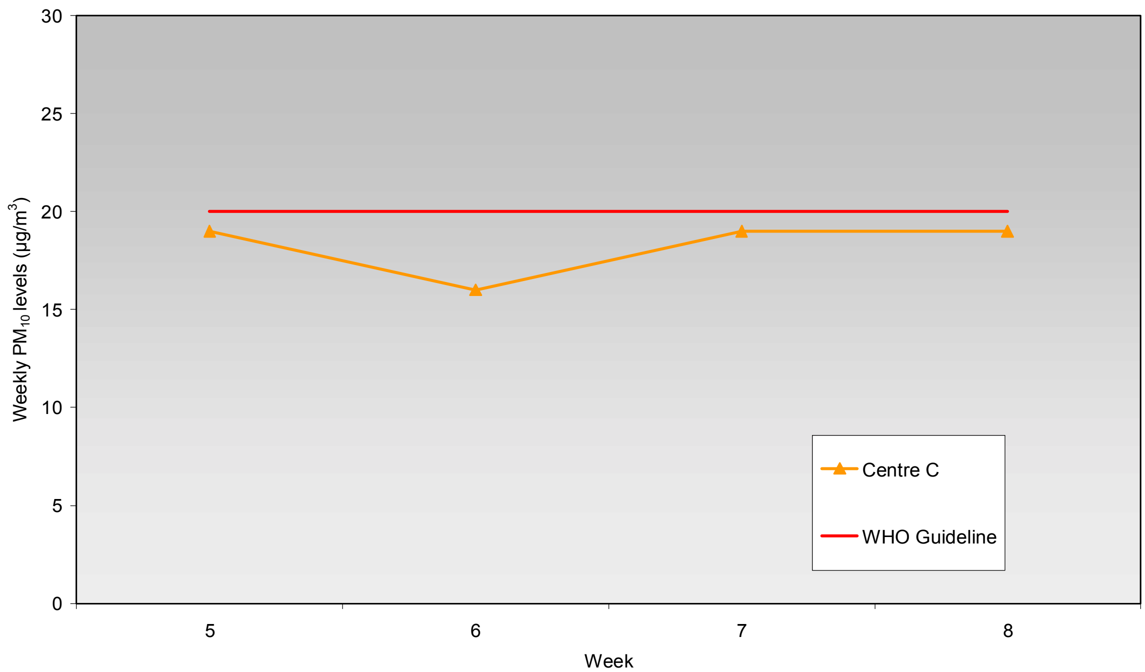


Figure 59: Weekly measured PM_{10} levels at Centre D

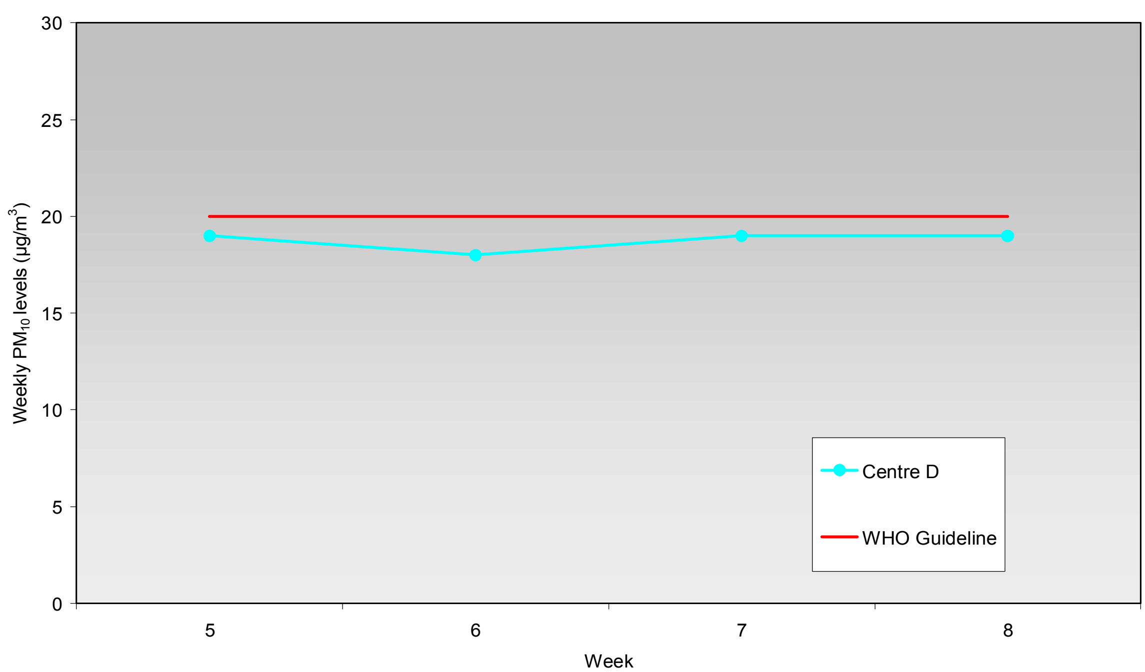


Figure 60 shows that the WHO guideline for PM_{10} was exceeded twice during the four weeks of monitoring carried out at Centre E (busy inner city main road).

Figure 60: Weekly measured PM_{10} levels at Centre E

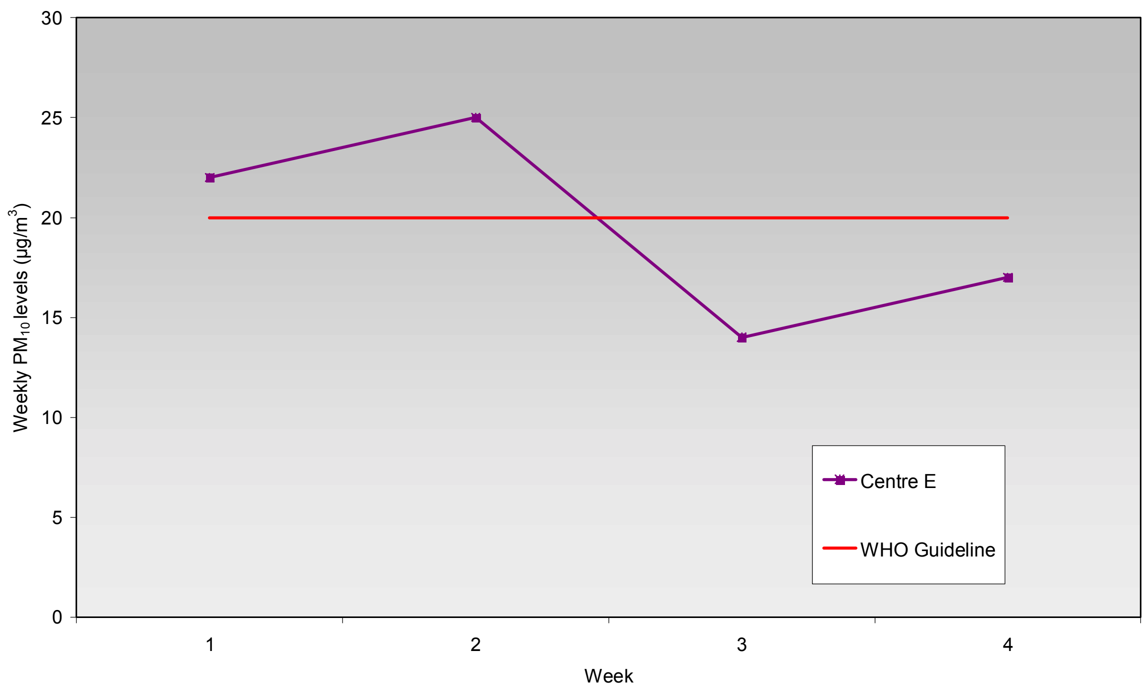
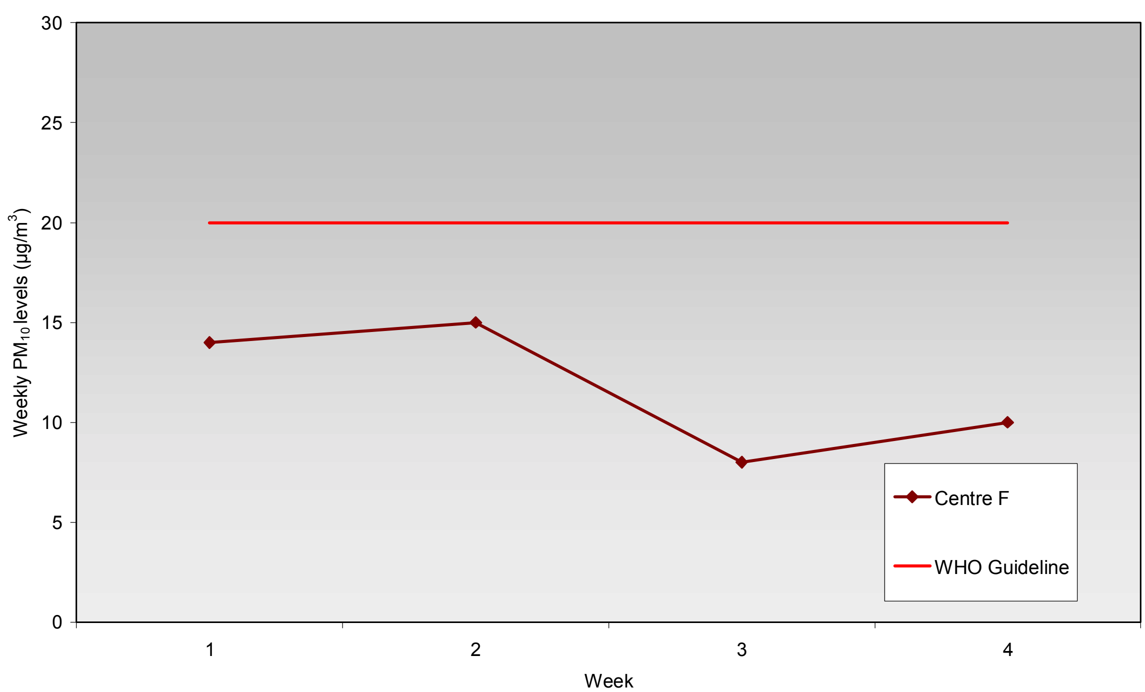


Figure 61: Weekly measured PM_{10} levels at Centre F



Figures 61, 62 and 63 show that for all these three Centres; F, G and H (all quiet residential roads), results were well below the WHO guideline for PM_{10}.

Figure 62: Weekly measured PM_{10} levels at Centre G

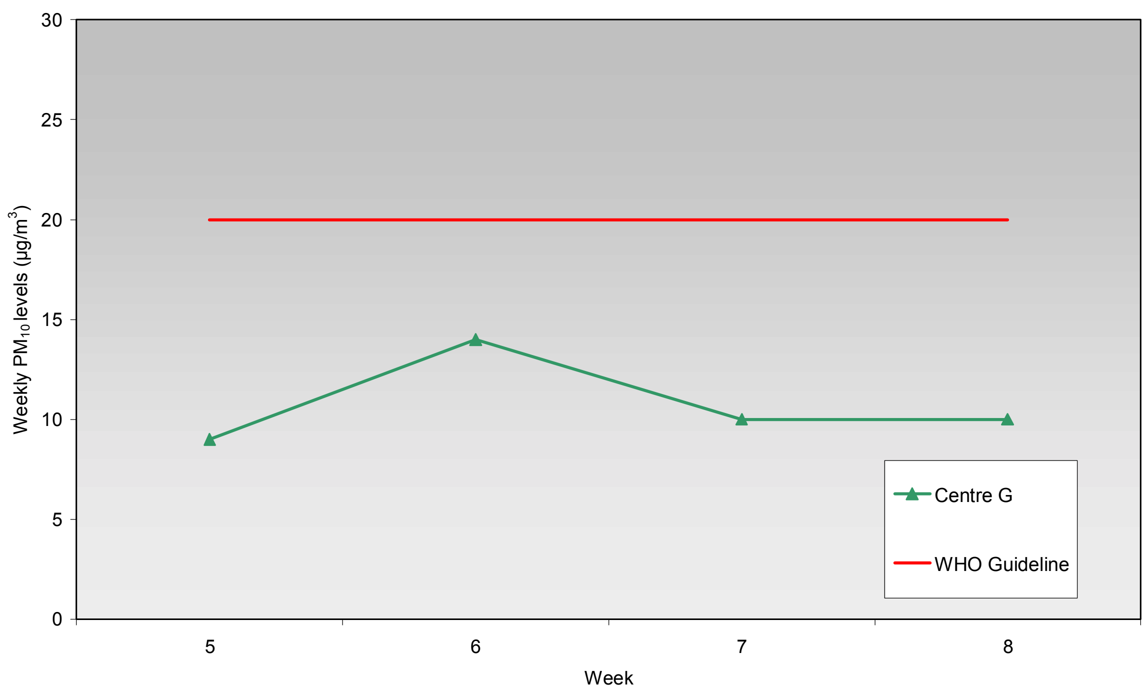
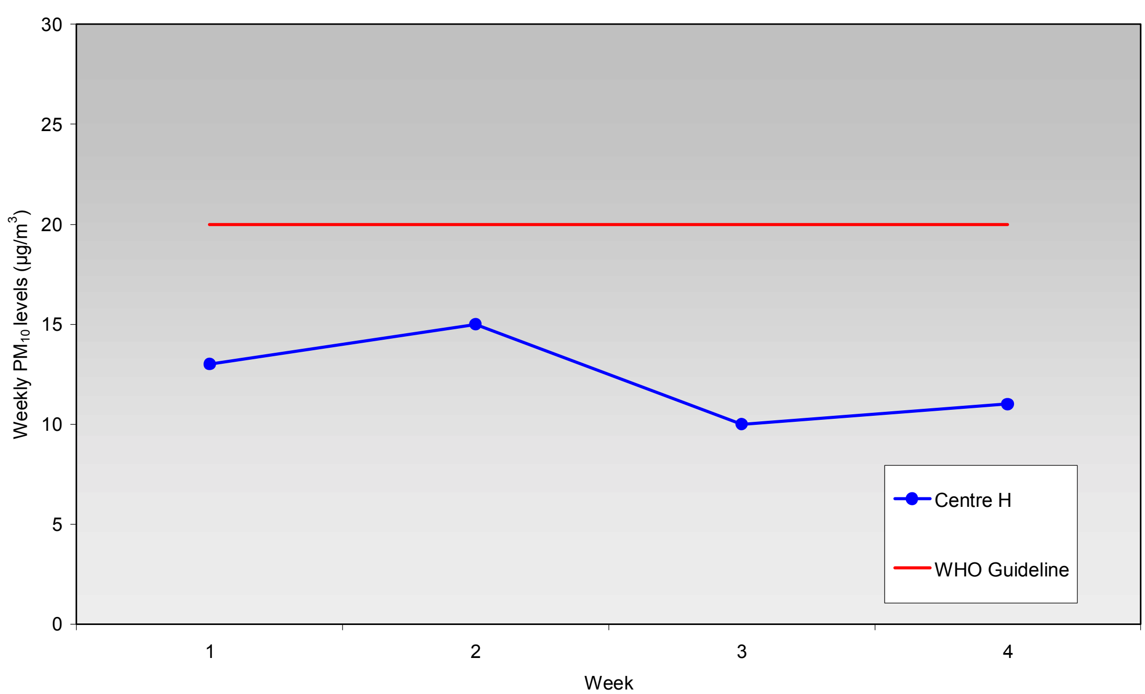
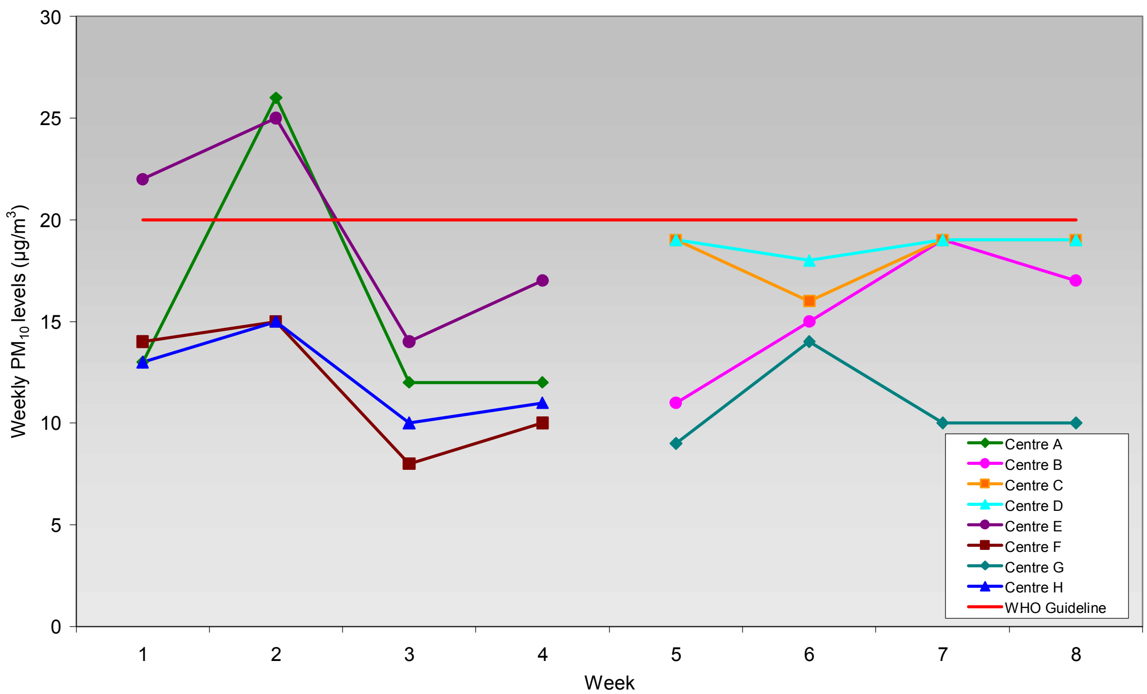


Figure 63: Weekly measured PM_{10} levels at Centre H



The following figure (Figure 64) shows the results of all eight centres for the two separate time series monitoring periods.

Figure 64: Weekly measured PM_{10} levels at all centres



Figures 65 and 66 show the results of monitoring for each of the centres as two separate time series for comparison (weeks 1-4 and 5-8). They identify those centres which are adjacent to busy roads for comparison to those centres which are adjacent to quiet roads. They clearly show that PM_{10} levels at those centres adjacent to busy roads (A, B, C, D and E) are higher than those centres adjacent to quiet roads (F, H and G).

Figure 65: Weekly measured PM_{10} levels at centres - first time series

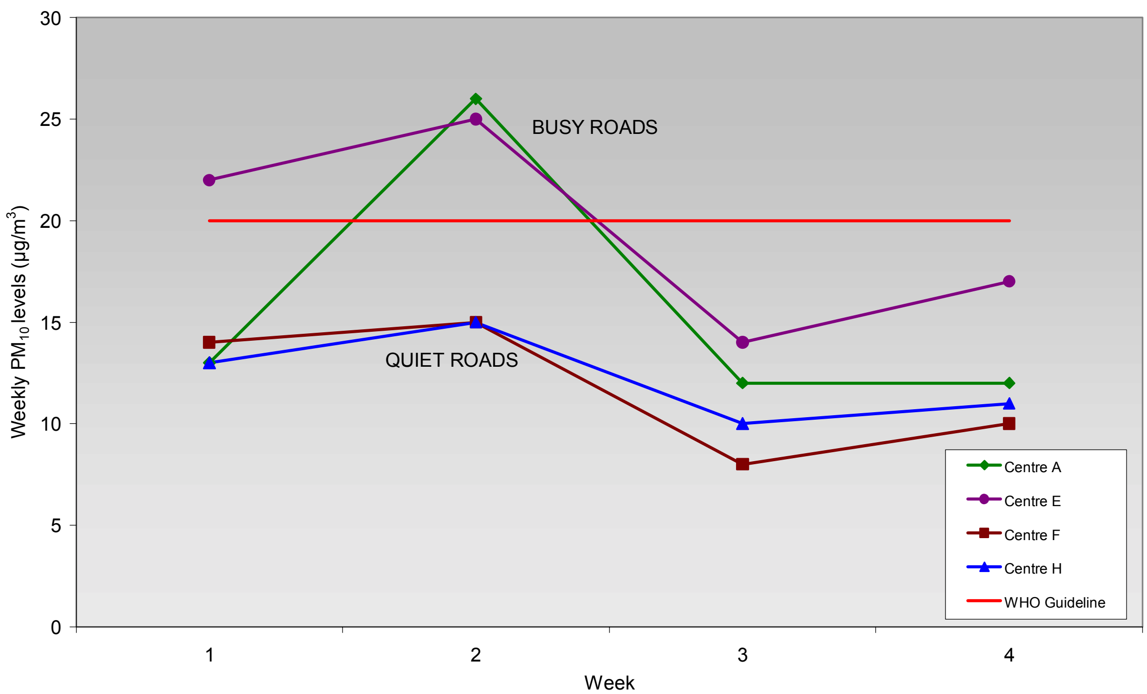
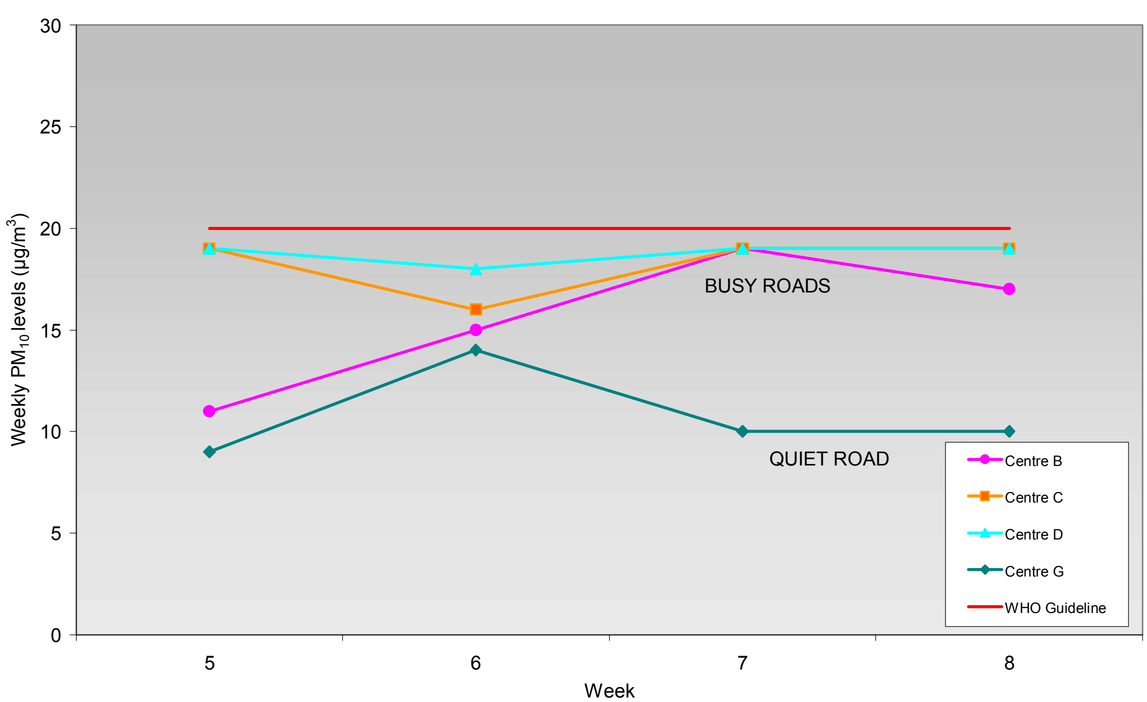


Figure 66: Weekly measured PM_{10} levels at centres - second time series



Figures 67 and 68 show the ranges and mean values of PM_{10} levels for each of the two separate time series. These too show that PM_{10} levels at those centres adjacent to busy roads (A, B, C, D & E) are higher than those centres adjacent to quiet roads (F, H & G).

Figure 67: Range of measured PM_{10} levels at centres - first time series

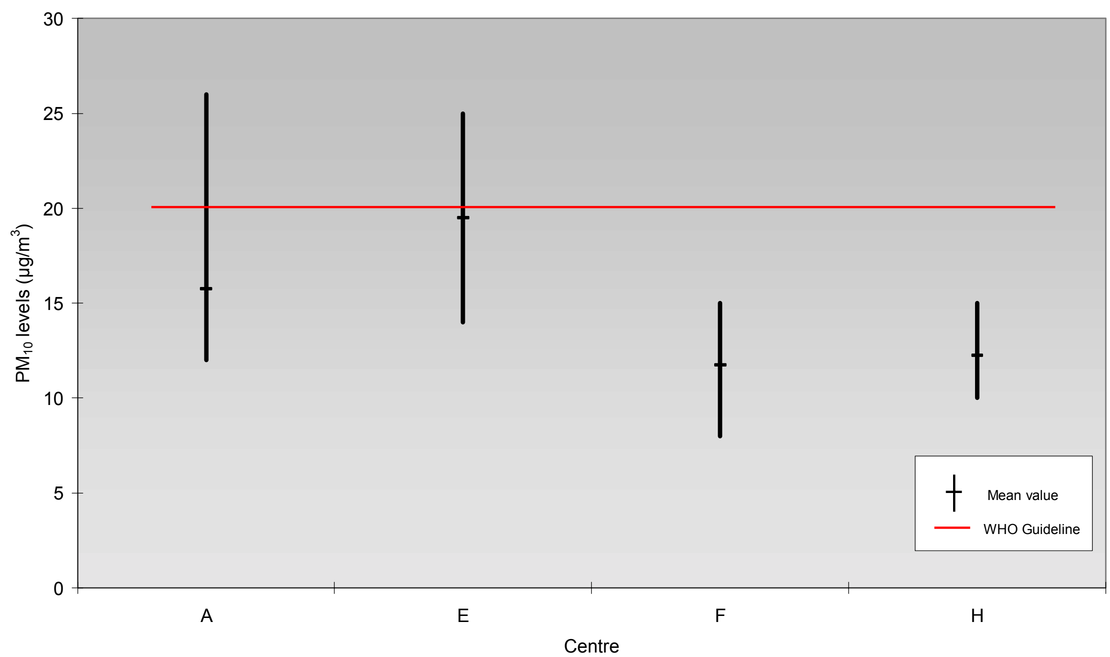
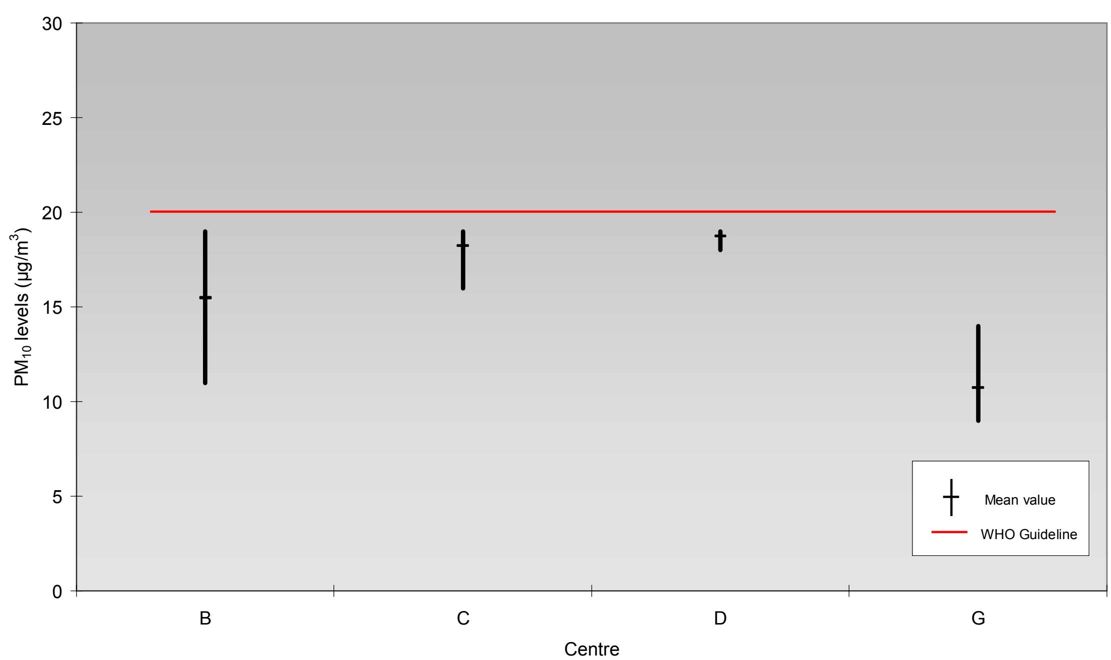


Figure 68: Range of measured PM_{10} levels at centres - second time series



Figures 69 and 70 present the results expressed as MfE air quality categories. These show that PM_{10} levels at those centres adjacent to busy roads fall into the *Action* and/or *Alert* categories while those centres adjacent to quiet roads fall into the *Acceptable* category.

Figure 69: PM_{10} levels - first time series compared to MfE air quality categories

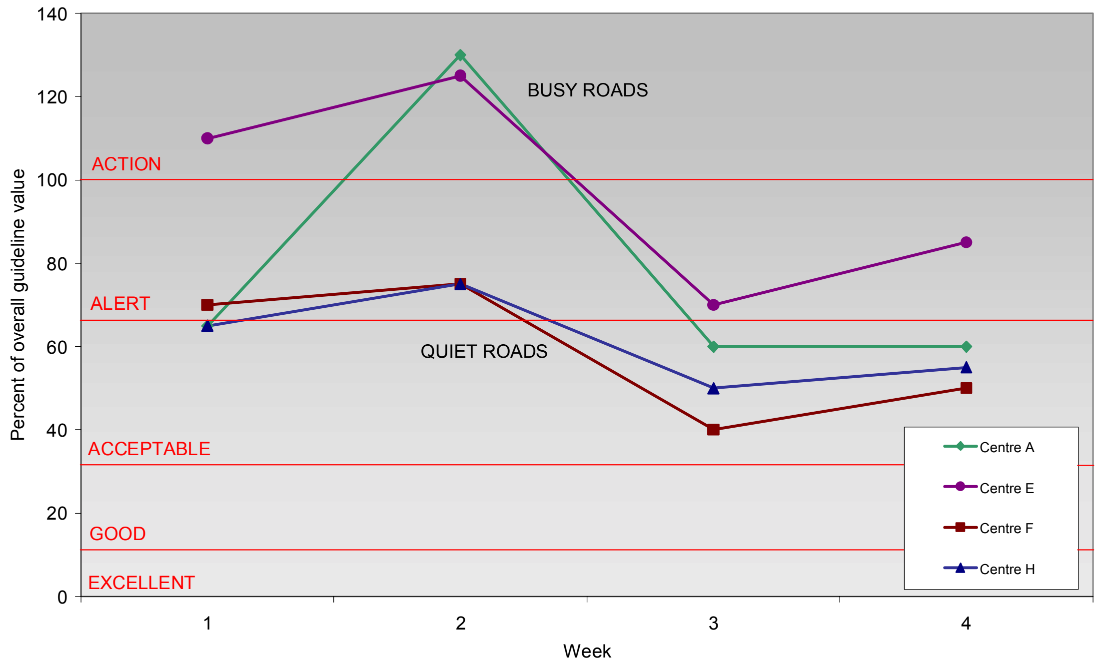
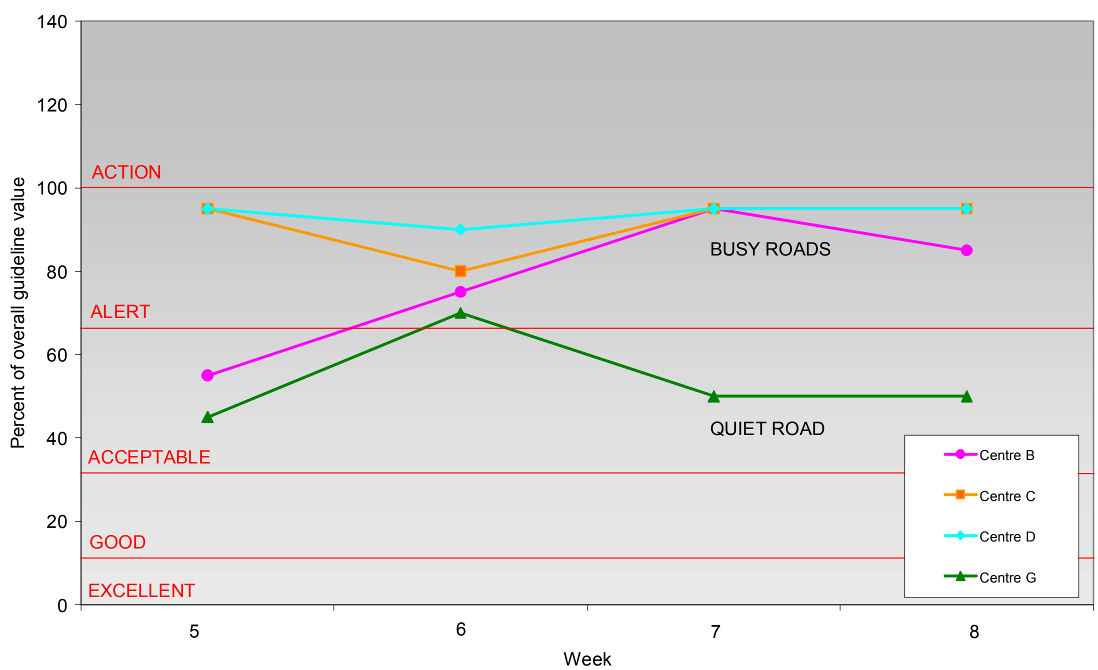


Figure 70: PM_{10} levels - second time series compared to MfE air quality categories



7: DISCUSSION

Key Findings

This pilot study provides evidence that children attending these particular early childhood centres that are located alongside busy roads are more exposed to traffic-related PM_{10} pollution than those attending early childhood centres that are either located away from a quiet road or adjacent to a very quiet road (Figures 65 and 66).

In the case of two of the five early childhood centres monitored that are adjacent to busy roads, PM_{10} levels exceeded the WHO guideline value for PM_{10}.

While PM_{10} levels at the other three centres also adjacent to busy roads did not exceed the WHO guideline value, results were often only marginally within this guideline value.

In comparison, PM_{10} levels monitored at the two centres that are located away from a quiet road and the centre that is adjacent to a very quiet road were all well within the WHO guideline value.

Using the Ministry for the Environment's Air Quality Classification system (page 79), air quality monitored at the two centres where PM_{10} levels exceeded the WHO guideline value (adjacent to busy roads) fall into the *Action* category, which states that levels are 'completely unacceptable by national and international standards'. Air quality monitored at the three centres where PM_{10} levels were marginally within the guideline value (also adjacent to busy roads) fall into the *Alert* category, which states that this is 'a warning level which can lead to exceedences if trends are not curbed'. Air quality monitored at the remaining three centres where PM_{10} levels were well within the guideline value (two located away from a quiet road and one adjacent to a very quiet road) fall into the *Acceptable* category, which states that this is 'a broad category where maximum levels might be of concern in some sensitive locations but generally at a level which does not warrant dramatic action' (Table 17 and Figures 69 and 70).

Table 17: PM_{10} levels at all centres expressed as MfE air quality categories

Centre	Site Type	Air quality category
A	Busy main road	ACTION
B	Busy urban route road	ALERT
C	Busy inner city main road	ALERT
D	Busy urban route road	ALERT
E	Busy inner city main road	ACTION
F	Quiet residential road	ACCEPTABLE
G	Quiet residential road	ACCEPTABLE
H	Quiet residential road	ACCEPTABLE

Measurements may be affected by wind direction and speed and the location of the centre in relation to the road. For instance, of those centres particularly affected by wind during the monitoring periods, PM_{10} levels monitored at Centre E (busy inner city main road), which produced two results above the WHO guideline value, are likely to be greater than those recorded (range = 14-25µg/m^3) when wind is only of mild strength or in a northerly direction, since during the first measurement period, the prevailing southerly winds are likely to have provided the centre with some degree of protection from the immediate roadside traffic-related pollution.

This may also be the case at Centre B (busy urban route road, range = 11-19μg/m^3) where during the second measurement period, the prevailing winds (northerlies) almost certainly provided the centre protection from the immediate roadside traffic-related pollution.

When we compare PM_{10} levels in New Zealand and Auckland to those in other countries and cities across the rest of the world it appears that New Zealand has little to be concerned about (Figures 71 and 72).

Figure 71: Annual average PM_{10} levels in major countries [129]

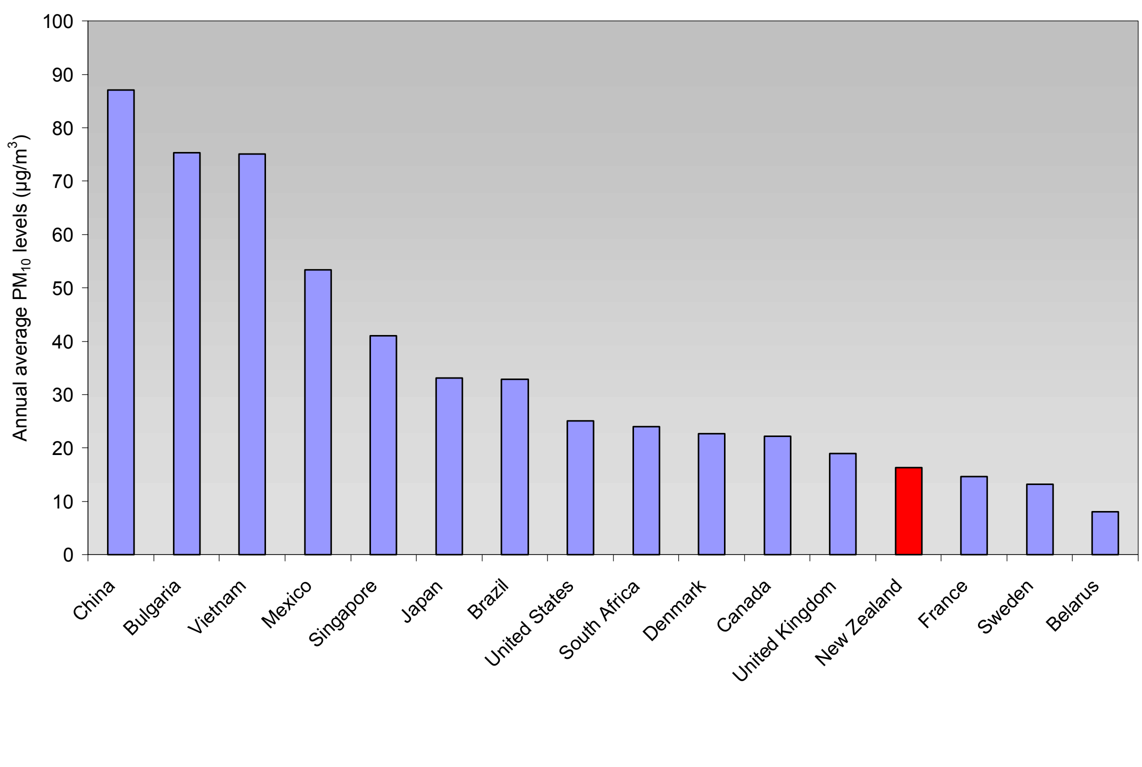
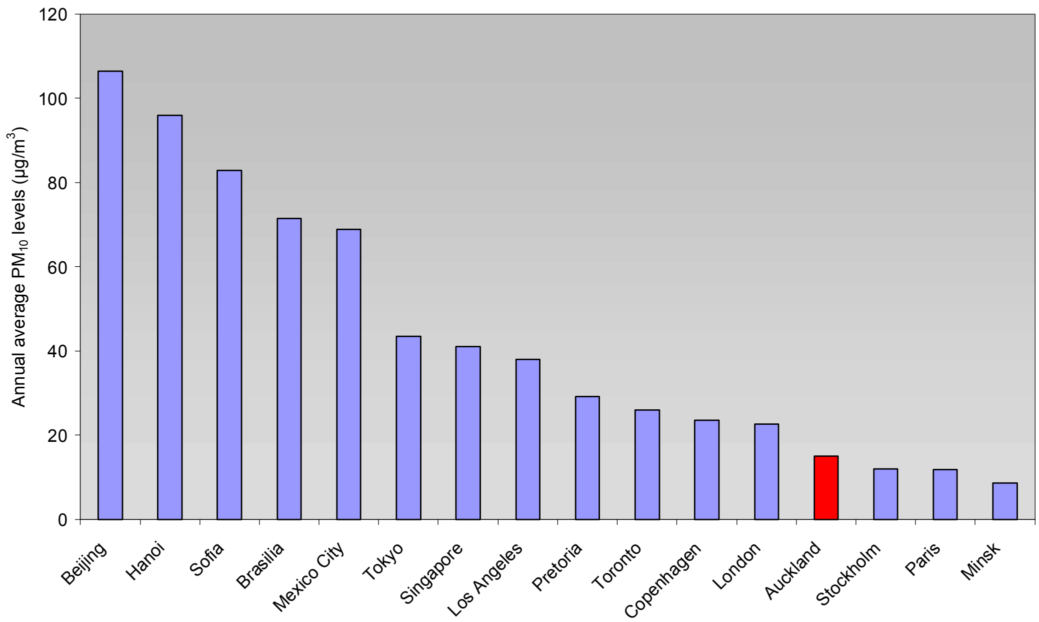
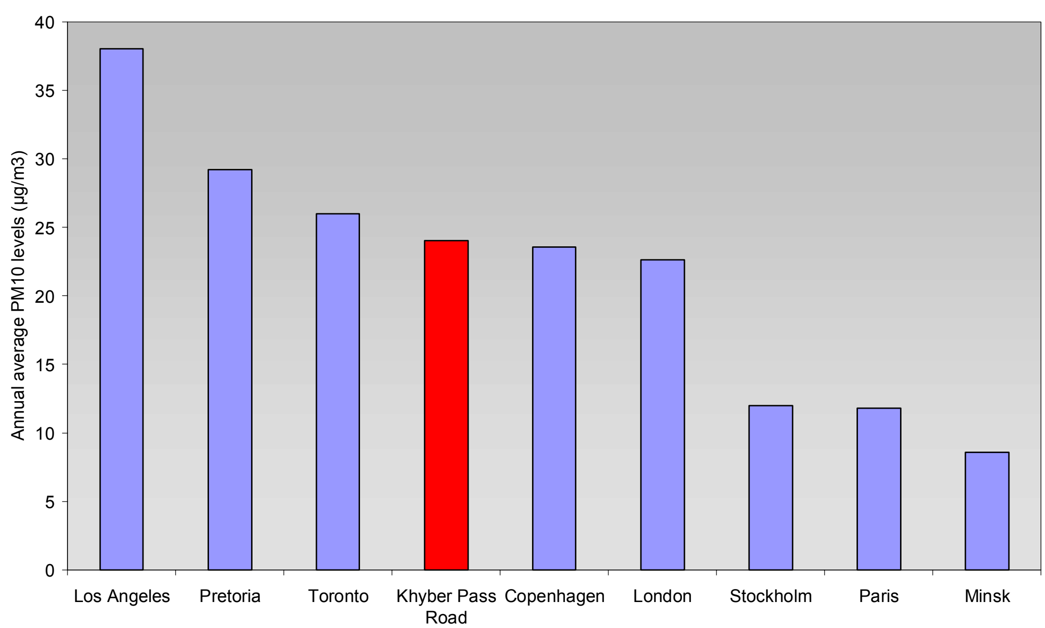


Figure 72: Annual average PM_{10} levels in major cities [129]



However, these results are averages for the country or city as a whole. If we compare one specific site, *e.g*. Khyber Pass Road (a major road) to other major cities such as London and Paris, PM_{10} levels may be the same or greater than in these and other major cities (Figure 73). The same applies to several of the early childhood centres monitored as part of this study.

Figure 73: Khyber Pass Road, Auckland in comparison to other cities [129]



Health Implications

Air pollution exposure is unequivocally associated with an increased risk of respiratory symptoms, particularly in children. Respiratory diseases such as asthma may be exacerbated by increases in PM_{10} emitted from motor vehicles and children are a significant vulnerable population group in this regard: proximity to busy roads is linked epidemiologically to increased childhood respiratory disease symptoms including hospitalisations for childhood asthma, as well as an increase in respiratory illnesses and in illness-related school absenteeism in school children due to increases in PM_{10} pollution.

Relating this evidence and that presented in the literature review to the results of the PM_{10} monitoring in this study suggests that children attending these early childhood centres that are located alongside busy roads may be at greater risk of respiratory illness due to traffic-related pollution than children attending early childhood centres which are located alongside quiet roads.

Furthermore, the WHO has emphasised the need to reduce exposure to pollutants even where current concentrations are close to or below the proposed guidelines. The WHO has also stated that it is not currently possible to distinguish whether there is a threshold concentration level for PM_{10} below which there are no adverse health effects for the population as a whole or the individual. Indeed, several studies suggest that there is no safe level of PM_{10} below which there are no adverse health effects, *i.e.* no threshold level. It is also important to note that there will always be susceptible populations, *e.g.* children who are even adversely affected when exposed to levels below the WHO air quality guidelines.

Policy Implications

The main policy implication from the results of this study is the consideration for air quality to be a licensing condition within the provisions of the Education (Early Childhood Centres) Regulations 1998. This may be imposed in a similar way in which the Auckland Regional Public Health Service states that it *prefers* centres are not located:

- adjacent to motorways, major roads, railways and industrial areas, and
- in locations where air quality fails to meet ambient air quality guidelines.

However, in the case of these being licensing conditions, they would become requirements and not preferences, and would subsequently be enforceable.

The problem with taking this approach is that of the 230 early childhood centres in Auckland City, approximately 65% (which provide early childhood education for approximately 6,000 children) are located alongside a busy or standard road and that while it is anticipated that PM_{10} levels at many of these centres may exceed the WHO guideline value, it would not be feasible to remove licences from those early childhood centres not complying with these requirements, since this would cease their operation.

It may therefore be preferable to impose a licensing condition similar to that imposed by the US National Resource Centre for Health and Safety in Child Care. In this case a licensing condition may state that children shall play outdoors daily only when air quality conditions do not pose a significant health risk.

A problem with taking this approach is that outdoor play, so essential to the learning and self-development of the child, could be curtailed in order to maintain licensing requirements. It also means there has to be ongoing daily monitoring by an independent authority and the capacity to act should there be an exceedence.

An alternative approach might be to use the Resource Management Act 1991 with regard to consented planning permission for the development and therefore the location of early childhood centres. Territorial local authorities, as consenting authorities, could incorporate rules into their District Plans restricting the location of new early childhood centres in areas where air quality is compromised, *e.g.* alongside busy roads.

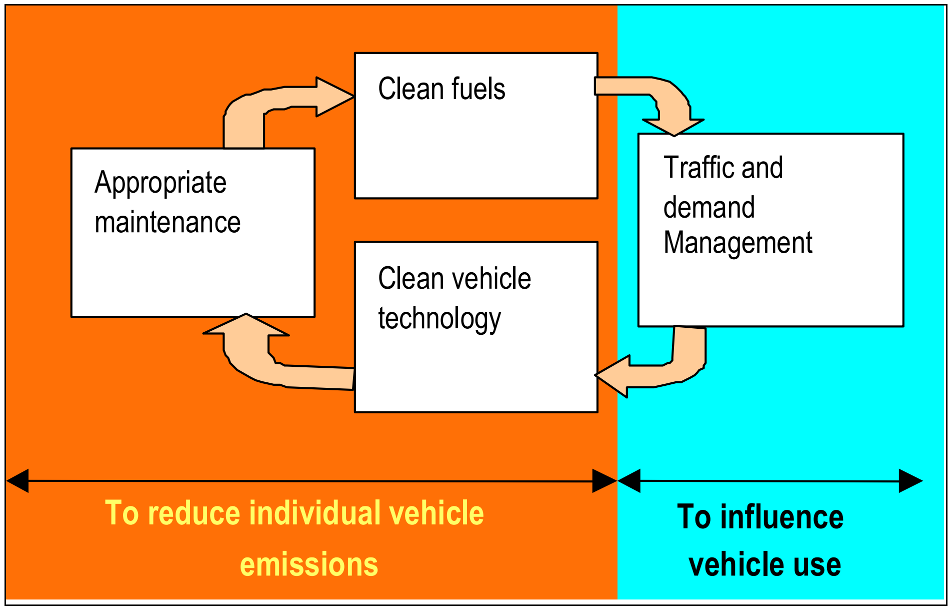
Current Policies

At present, policies for reducing the health impacts of vehicle emissions revolve around source reduction. New Zealand faces a challenge in this regard as it has the second highest vehicle ownership rate in the world next to the USA. There are approximately 2.8 million vehicles for a population of approximately 4.0 million. There is also a trend of an increase in the number of vehicles with larger engines, and the number of SUVs (sport utility vehicles) as well as more diesel vehicles.[130]

Effective management of vehicle emissions requires a four-pronged approach (Figure 74):

1. Appropriate vehicle maintenance
2. Clean fuels
3. Clean vehicle technology
4. Traffic and demand management.

Figure 74: The management of vehicle emissions [130]



In March 2001, the Ministry of Transport introduced the 10-second rule, providing the Police with the ability to fine owners of vehicles which emit excessive smoke or vapour for more than 10 seconds.

From October 2006, a 5-second visible smoke check was introduced for vehicles as part of warrant of fitness (WoF) and certificate of fitness inspections. This check is part of every vehicle's certificate or warrant of fitness. By running the vehicle for five seconds, warrant of fitness inspectors check for smoke coming out of the vehicle's exhaust while the engine idles, and again when the engine speed is increased to half its maximum (at about 2,500 revs per minute).

In late 2001, the Ministry of Economic Development (MED) reviewed the petrol and diesel specifications and in August 2002 new specifications were introduced to deliver cleaner petrol and cleaner diesel. The MED is currently considering a timetable for further fuel improvements.

From January 2004, all new vehicles entering New Zealand must meet minimum emissions standards, which are expected to tighten over time. While this rule does not currently apply to used imported vehicles, it is undergoing consideration to include all vehicles entering New Zealand, both new and used.

In 2005, a biodiesel standard was developed which allowed retail of blends of up to 100% and in 2006, biodiesel was trialled in buses.

Table 18: Summary of management of vehicle emissions policies

Strategy	Date
10-second smoke rule introduced	2001
Clean fuel specifications developed	2002
Minimum emissions standards developed for all new imported vehicles	2004
Biodiesel standard developed	2005
Biodiesel trialled in buses	2006
5-second WOF smoke check introduced	2006
Minimum emissions standards for all imported vehicles including used vehicles	Under consideration

Traffic and demand management focuses on the individual traveller and seeks to change travel behaviour through various initiatives (such as education and marketing). It includes a single network approach which seeks to optimise or reduce traffic flows, and a transport system approach which seeks to achieve modal shift (*i.e.* to low impact modes such as cycling and walking).

Strengths of the Study

Very little research has been carried out either in New Zealand or internationally on the air quality of outdoor play areas of early childhood centres in relation to motor vehicle emissions and childhood respiratory disease and asthma. The extent of monitoring is also limited and the amount of exposure data available in New Zealand relatively sparse, particularly in comparison with Europe.

The majority of previous studies have relied upon ambient (background) air quality results measured across the wider region and exposure assessments have not been based upon air quality monitoring of the specific target study areas, *e.g.* alongside a busy road, in a school playground, etc. Consequently, assessment of personal exposure to air pollutants in these studies will not be as accurate when compared to monitoring of the specific target study site.

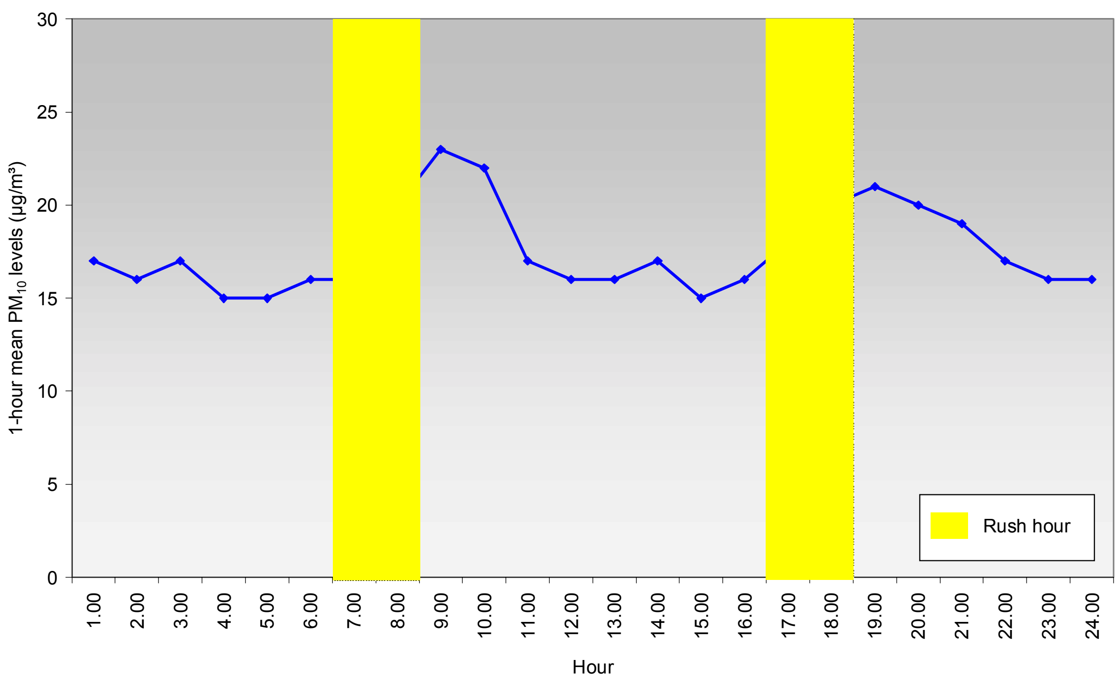
The same may be said of studies that have only relied upon the distance of the residential or school address to major roads as a measure of exposure to air pollution, while others have merely used traffic density data.

Consequently, in contrast to other similar studies, this study monitored air quality (PM_{10}) at the specific exposure site, *i.e.* the outdoor play area of the early childhood centre, and is therefore an improvement on those previous studies identified in the literature review.

Limitations

The monitoring method used in this study is regarded as a cheaper, low-level instrumental method that is not as accurate or precise as other methods. The method is generally used for simple surveys to obtain a snap-shot of pollution levels in an area of interest. However, the Ministry for the Environment accepts that manual methods such as those used in this study are sufficient for monitoring particulate levels.[112]

Figure 75: Daily cycle of PM_{10} levels, Mount Eden [131]



In this study, the monitoring equipment used provided only weekly PM_{10} levels and did not identify variations in PM_{10} levels that occur during a 24-hour period, particularly those caused by rush hour traffic (Figure 75). High precision instruments would provide continuous monitoring of PM_{10} concentrations over long periods of time but are extremely expensive to install.

While the MiniVol used to carry out the monitoring is not classified as a reference method sampler, it is accepted by USEPA that it gives results that closely approximate reference method air quality data.[127] Furthermore, it has been designated by the Ministry for the Environment as an equivalent reference method.[103]

Since this study was based upon a preliminary survey of eight early childhood centres, it may be assumed that the chosen method was suitable for its purpose, although it is recommended that further monitoring is carried out using more reliable equipment which would require significant funding.

It is important to note that the results obtained take into consideration night-time PM_{10} levels, which are generally lower than daytime levels due to less traffic. Night-time levels may be higher in winter due to PM_{10} emissions from domestic heating but since monitoring was not carried out during the winter months this was not a consideration in this study. This is of significance since it may suggest that children attending early childhood centres are exposed to greater PM_{10} levels than those recorded because they are only exposed during the daytime, when levels are higher.

Finally, most research into traffic-related air pollution and its effects has focused on PM_{10} and the epidemiological evidence which exists clearly links respiratory disease to PM_{10} pollution. Consequently, PM_{10} was chosen as the indicator for this study. However, more recently it has been suggested that it is probably the finer particles ($PM_{2.5}$) within PM_{10}

which cause the greatest effects since these smaller particles have the ability to penetrate deeper into the lungs.

However, it should be noted that the New Zealand National Environmental Standards for Air Quality does not set a standard for $PM_{2.5}$ although the WHO *recommends* a guideline value of $10\mu g/m^3$ (annual mean). It is therefore suggested that further research may be carried out to measure levels of $PM_{2.5}$ in similar locations to those in this study.

It is also recommended that any such further monitoring uses more reliable and precise equipment, which would provide hourly and 24-hour mean results for both PM_{10} and $PM_{2.5}$.

8: CONCLUSIONS

This pilot study provides preliminary evidence that children attending early childhood centres located alongside busy roads have greater exposure to traffic-related PM_{10} pollution than those attending early childhood centres located away from a quiet road or adjacent to a very quiet road.

Prevention of exposure is the single most effective means of protecting children against environmental threats. Overall, there is sufficient evidence that exposure to traffic-related air pollution levels has deleterious respiratory health effects in children.

Environmental factors play an important role in altering host resistance to respiratory diseases in childhood. At a young enough age, exposure to poor air quality can give rise to immediate and late manifestations as a result of the disturbed development and maturation of organ systems and their altered response to environmental stressors.

Children attending early childhood centres located alongside busy roads are at risk from the adverse health effects caused by traffic-related air pollution. However, these children must play outdoors for learning and self-development.

Several policy implications are suggested, to reduce the risk to those children attending early childhood centres located alongside busy roads, such as restricting a child's outdoor play when air quality is compromised and controlling the location of newly established early childhood centres, and that information for parents, ongoing PM_{10} monitoring and processes for issuing PM_{10} advisories when limits are exceeded, are made available to existing early childhood centres that are adjacent to busy roads.

Further research is suggested to confirm the findings in this small sample of air quality around early childhood centres in a larger sample, using high precision instruments which would provide more reliable and precise data, and possibly to undertake an epidemiological study to confirm the link to health effects, including the prevalence of respiratory disease and asthma (including cough, wheeze, use of medication, number of sick days and doctor/hospital visits) in those children attending early childhood centres.

All of the suggested further research would require substantial funding, which was not possible within the scope of this study.

APPENDIX 1: SEARCH STRATEGY

The Information Search Process

IDENTIFYING THE INFORMATION NEED

What do I need to know? What questions need answering?

PLANNING THE STRATEGY

- **What type of information** or data do I require? (review, law, statistical?)
- **Which sources hold this type of information?** (journals, books, online?)
- **Where & how will I locate** the sources of information ? (free Internet, online Library resources, Library, home?)
- **Organising the work**: How much time do I allocate to various aspects of the project, like data and/or information collection, analysing information & communicating results?

TOPIC SELECTION, CONCEPTUALISATION & FORMULATING KEY THEMES

- Explore & discuss ideas with others, browse library for ideas eg books, reference materials (eg encyclopaedias)
- Conceptualise topic (what is the topic about? what questions need answering?)
- Develop range of keywords to use for search

COLLECTING INFORMATION

- **Build search strategy** using keywords and Boolean operators
- **Conduct searches** using a range of databases, Library catalogue and Internet
  - Preliminary searches give some idea of what information is available and what other keywords to try
  - Preliminary results help to predict outcomes of possible foci
  - If necessary, re-focus topic & re-examine key concepts. May need to combine or split themes.
  - Consult Librarians, if required
- Take notes and keep track of article and resource citation for bibliography

EVALUATING & USING INFORMATION

- Examine & analyse information critically, decide what information should be kept
- Weave own ideas & others into writing by acknowledging use of others' ideas through citing
- Re-visit library databases and re-think search strategy if there is insufficient information
- Compile a list of references cited in appropriate style (eg APA)
- Present the completed piece of work – research paper, oral presentation etc…

This model is based on the ideas of:

1. Atton, C., *Using critical thinking as a basis for library user education,* Journal of Academic Librarianship 1994; 20: 310-313.
2. Kuklthau, C., *Seeking meaning: a process approach to library and information services*, Norward, N.J.: Ablex Publshing Corp, 1993.

DATABASES

- Medline
- EMBASE
- ENVIROnetBASE
- PubMed
- ERIC
- Scirus
- EVA
- Google Scholar

KEY WORDS

- Particulates
- Particulate matter
- PM_{10}
- Air pollution
- Traffic
- Vehicles
- Emissions
- Health effects
- Respiratory disease
- Respiratory disorders
- Asthma
- Children
- Child
- Early childhood centres
- Day care centres

SEARCH STRATEGY

Box A: Exposure

1. Air pollution/
2. Particulate matter/
3. Particulate$.tw
4. PM_{10}.tw
5. Emission$.tw
6. Vehicle emissions/
7. Vehicles/
8. Traffic.tw
9. Or/1-8

The forward slash (/) denotes Medline Subject Heading (MeSH) term, the suffix .tw denotes a text word or words found in the title or abstract

Box B: Outcomes

1. Respiratory disease$.tw
2. Respiratory disorders/
3. Asthma/
4. Health effect$.tw
5. Or/1-4

Box C: Settings/Participants

1. Early childhood centre$.tw
2. Day care centres/
3. Children.tw
4. Child/
5. Or/1-4

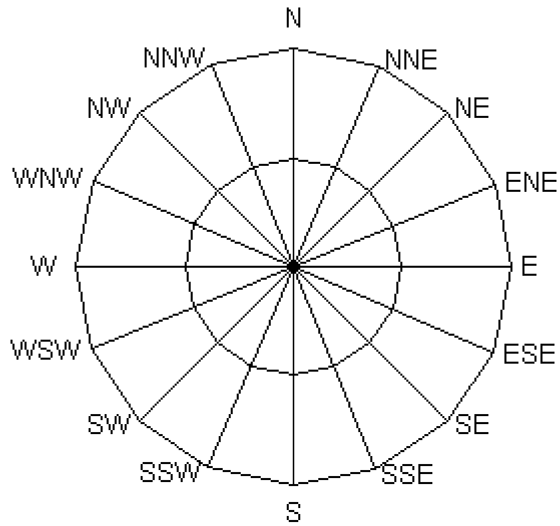
Search Query

Combined A.9 and B.5 and C.5

APPENDIX 2: WIND DIRECTION CALCULATOR

Wind Direction and Degrees

Cardinal Direction	Degree Direction
N	348.75 - 11.25
NNE	11.25 - 33.75
NE	33.75 - 56.25
ENE	56.25 - 78.75
E	78.75 - 101.25
ESE	101.25 - 123.75
SE	123.75 - 146.25
SSE	146.25 - 168.75
S	168.75 - 191.25
SSW	191.25 - 213.75
SW	213.75 - 236.25
WSW	236.25 - 258.75
W	258.75 - 281.25
WNW	281.25 - 303.75
NW	303.75 - 326.25
NNW	326.25 - 348.75



Source: The Minnesota Climatology Working Group, *Wind Direction and Degrees,* http://climate.umn.edu/snow_fence/Components/winddirectionanddegreeswithouttable3.htm (10 January 2008)

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