Updated Health and Air Pollution in New Zealand Study

Volume 1: Summary Report

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Disclaimer

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Executive Summary

This report estimates the health impacts and social costs[1] associated with air pollution in New Zealand for 2006[2].

Although air pollution is a complex mixture of contaminants and particles, this report is based on particulate matter less than 10 micrometres in size – commonly known as PM_{10} - because the majority of health effects in New Zealand are associated with this pollutant and it is a good indicator of the sources and effects of other air pollutants.

Air pollution health effects in New Zealand were first comprehensively assessed in the Health and Air Pollution in New Zealand (HAPINZ) study undertaken by Fisher *et al*. (2007). In this original study, health effects were evaluated for 67 urban areas based on the 2001 population and ambient monitoring data. The resulting social costs were presented in NZ$ as at June 2004. The authors estimated that air pollution from all sources in New Zealand was responsible for approximately 1,400 premature deaths per year, of which 1,100 premature deaths were attributed to anthropogenic (human-caused) sources.

Since the release of the original HAPINZ study, both the data availability and the understanding of air pollution health effects have improved. In particular, air quality monitoring is now undertaken in most urban locations in New Zealand – largely in response to the introduction of a national environmental standard for ambient PM_{10} concentrations in September 2005.

This report was commissioned to update the original study and is based on existing published work (detailed below), as new research was not conducted for this update:

- population data taken from the 2006 census
- recent monitoring, inventory and source apportionment data collected across New Zealand covering (or representing) ambient PM_{10} concentrations experienced in 2006 (averaged over 2006-2008)
- recent epidemiological results for the main health impacts of air pollution exposure for key population sub-groups, e.g. Māori and children, as well as for the whole population and
- updated social costs (in NZ$ as at June 2010), particularly the use of a transport risk (road safety) based value of a statistical life (VOSL), but not including any loss of life quality due to prolonged pain and suffering.

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[1] Costs here are referred at as social costs rather than health costs because they denote the total costs to society of the health effects which are more than just the costs incurred by the health system.

[2] 2006 was chosen as it is the year of the most recent census.

The update estimates annual average PM_{10} concentrations for each census area unit (CAU) across New Zealand and determines health effects and social costs associated with a range of air pollution sources, including:

- domestic fires used for home heating
- motor vehicles[3]
- industry
- open burning
- natural sources, e.g. sea spray and windblown dust.

We have developed a *Health Effects Model*, based on an Excel spreadsheet, which allows end-users to output results nationally, regionally, by Territorial Local Authority (TLA[4]), by Statistics NZ urban areas, or by airshed. End-users are also able to run scenarios for comparison with the base case, by selecting from a range of plausible input values of population, exposure and epidemiological exposure-response functions. The scenario option can be used to undertake sensitivity testing to test the effects of different assumptions, evaluate the effects of population and emissions trends, or review the effectiveness of different air quality management options.

Key Findings from the Update

The primary health impact resulting from air pollution (in terms of social costs) is premature mortality in adults. More than 2,300 New Zealanders are estimated to die prematurely each year due to exposure to PM_{10} pollution from all sources, with just over half associated with anthropogenic sources.

The total health impacts associated with **anthropogenic air pollution** in New Zealand each year are:

- 1,175 premature deaths in adults and babies
- 607 extra hospital admissions for respiratory and cardiac illnesses
- 1.49 million restricted activity days (days on which people cannot do the things they might otherwise have done if air pollution was not present).

[3] This source includes on road vehicles only – off road vehicles, aviation, marine and rail are not included.

[4] Note the number of TLAs is based on those that were in existence for the 2006 census. In 2010, there was an amalgamation of the eight Auckland councils so the number of TLAs is now 67 (excluding the Chatham Islands).

The total social costs associated with **anthropogenic air pollution** in New Zealand are estimated to be $4.28 billion per year or $1,061 per person, with the following overall contributions attributed to each source:

- 56 per cent due to domestic fires
- 22 per cent due to motor vehicles
- 12 per cent due to open burning
- 10 per cent due to industry.

Domestic fires dominate the health impacts associated with anthropogenic air pollution in every location across New Zealand, except the Auckland region (most particularly in the TLA of Auckland City where motor vehicle health impacts are nearly twice those of domestic fires). However, not being able to robustly assess NO_2 exposure means that the results of this update most likely under-estimate the health impacts of motor vehicle-related air pollution.

The remaining TLAs in the Auckland region show more or less equal proportions of effects attributed to domestic fires and motor vehicles. Other TLAs which are also more heavily impacted by motor vehicle emissions than the average include Hamilton City, Lower Hutt City, New Plymouth District, Tauranga City, and Wellington City.

Open burning is an appreciable air pollution source in all locations, rivalling motor vehicles and industry in its effects in many areas.

The effects associated with industry impacts vary significantly across New Zealand because the siting of many industries depends on access to particular resources which are often location-specific.

Māori are disproportionately represented in the adult premature mortality figures (18.3 per cent of deaths, but are only 8.7 per cent of adult population). This is not unexpected because the exposure-response function for Māori is nearly three times that of the whole adult population. However, the confidence intervals for the Māori adult and all adult response functions overlap so this finding may not be statistically significant. Regardless, it is of concern as this subgroup already experiences poorer health outcomes.

For the respiratory hospital admissions, one third of the cases occur in children aged 1 to 4 years – again a disproportionate effect given the population in that sub-group.

The overall health impacts in the update are comparable to those found in the original study (allowing for increases in population and changes in the exposure-response functions) but with a much greater proportion of health impacts found to be attributed to natural sources (taken from a number of source apportionment studies) and the emergence of a new but significant anthropogenic source – open burning. However, it should be noted that open burning has been banned in many airsheds since 2006 and is unlikely to feature as prominently as a source requiring intervention in future updates. The other major difference is in the social costs. The update estimates a higher cost from air pollution than previously because we have adopted a VOSL based on transport (road safety) risk to be consistent with the approach taken by overseas jurisdictions.

The information will be useful in cost-benefit analyses for a range of applications, such as:

- weighing benefits of health improvements against the costs of (various) air pollution reduction initiatives
- evaluating the effectiveness of existing policy initiatives (back-casting)
- assessing the likely effects of current population and business as usual trends (forecasting)
- developing targeted strategies for reducing the air pollution exposure of particularly vulnerable groups in the population.

Link to the other material as follows:

This report summarises the main findings of the updated Health and Air Pollution in New Zealand (HAPINZ) study and describes the workings of the *Health Effects Model*. It is intended for a general audience.

All of the technical reports (in their entirety) that were prepared as part of the updated HAPINZ study are presented in the *Updated Health and Air Pollution in New Zealand Study Volume 2 – Technical Reports* for those readers who would like more detailed information on the methodology. This report is supported by a detailed *Exposure Model* which contains all data, calculations and assumptions used to derive PM_{10} exposure for each CAU by source.

Contents

1. Introduction

1.1 Background

In 2003, the Ministry for the Environment, the Ministry of Transport and the Health Research Council of New Zealand (with in-kind support from the Ministry of Health and regional councils) commissioned the Health and Air Pollution in New Zealand (HAPINZ) study. In 2007, the HAPINZ study was published (Fisher *et al*. 2007). This represented New Zealand's first study on the national health impacts of air pollution.

HAPINZ examined 67 urban areas and included 73 per cent of New Zealand's population. The HAPINZ study linked anthropogenic (human-caused) air pollution with approximately 1,100 premature deaths each year. HAPINZ further estimated other illnesses caused by anthropogenic air pollution in New Zealand to include (annually):

- 700 extra hospital admissions for respiratory and cardiac illnesses
- 1.9 million restricted activity days[5]

The bulk of effects were associated with particulate pollution (PM_{10}), but there were also effects associated with other pollutants, such as nitrogen dioxide, carbon monoxide and benzene. The total economic cost of anthropogenic air pollution in New Zealand (from both premature death and adverse health impacts) was estimated at $1.1 billion per year or $421 per person (in NZ$ as at June 2004).

HAPINZ further attributed health effects to major emission sources (domestic, transport, industry and background). The primary sources were home heating nationally, followed by vehicles in central Auckland, and industry.

In order to judge the extent of health impacts in a given population likely to be caused by an exposure in the environment, scientists use the results of epidemiological studies that have been carried out separately, perhaps in other countries, along with estimates of the degree of exposure (see page 8 for further details). The most severe category of health impacts estimated in the HAPINZ study was premature mortality resulting from chronic (long-term) exposure to PM_{10}. The number of premature deaths was estimated by multiplying an exposure-response relationship by the estimated exposure. In the HAPINZ study, the exposure-response relationship assumed a 4.3 per cent increase in premature mortality for every 10 $\mu g/m^3$ increase in annual PM_{10} concentrations. This was based on American studies of effects of air pollution exposure (Künzli *et al*. 2000). The HAPINZ study noted that, based on more recent studies, the true figure could be in the range of 4 to 8 per cent but it concentrated on providing a basis for comparison with a previous pilot study for the Ministry of Transport (Fisher *et al*. 2002).

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[5] A restricted activity day is a day on which people cannot do the things they might otherwise have done if air pollution was not present.

1.2 Reasons for this Update

Since HAPINZ was published in 2007, a number of issues have been raised with the original methodology[6] and the study has also dated quickly. The authors themselves noted that by the time the original study was published, the population within their study areas had increased by 17 per cent from the base census year of 2001, which would similarly increase health impacts associated with air pollution.

Accordingly in 2010, the Ministry for the Environment, the Ministry of Transport, the New Zealand Transport Agency and the Health Research Council of New Zealand (with in-kind support from the Ministry of Health and Auckland Council) commissioned this update to HAPINZ[7]. The purpose of the update was to:

- update the base data for New Zealand to the 2006 census year
- assess the suitability, and update if appropriate, of exposure relationship(s) for PM_{10} with mortality and morbidity
- assess the suitability, and update if appropriate, of exposure relationship(s) for other key pollutants with mortality and morbidity
- review the use of a transport risk (road safety) based value of a statistical life (VOSL) and other jurisdictional approaches and, if appropriate, update this method and/or value
- update average medical costs
- review ambient air quality monitoring data since 2001 and, if appropriate, update HAPINZ calculations
- review published source apportionment studies since 2001 and, if appropriate, update HAPINZ calculations
- review published emissions inventories since 2001 and, if appropriate, update HAPINZ calculations and
- undertake sensitivity analyses for key parameters to query the robustness of results.

Another important feature of the update was the development of user-friendly spreadsheets and/or databases to show all underpinning calculations, data and

[6] Many air quality practitioners noted inconsistencies and errors in the spreadsheets developed for the original HAPINZ study, in particular the over-estimation of benzene cancer cases, the use of arithmetic rather than population weighted averages, and the under-estimation of natural source contributions. Whilst unfortunate, these errors were found on investigation to largely counter each other resulting in the social costs remaining essentially the same. However, greater attention to quality assurance was highlighted as a critical requirement for future HAPINZ updates (Kuschel & Mahon 2010).

[7] New research was not commissioned for this update and data are from existing published work.

assumptions. The intent of these spreadsheets was to provide transparent, robust and defensible estimates of:

- exposure to PM_{10} air pollution by census area unit, attributed by source
- mortality impacts of PM_{10} exposure in adults for non-external causes for all ethnicities and separately for Māori
- morbidity impacts of PM_{10} and other air pollutants (if available data support robust estimates)
- annual social costs due to exposure to PM_{10} and other pollutants (if available data support robust estimates) and
- sensitivity of predicted outcomes to key assumptions.

1.3 Project Funding and Steering Committee

The updated study has been overseen by an Environmental Health Joint Research Partnership Steering Committee (Steering Committee) comprising representatives from:

- Health Research Council (both staff and independent representatives)
- Ministry for the Environment (initially staff; post April 2011 a seconded technical expert from Environment Canterbury)
- Ministry of Health
- Ministry of Transport
- National Air Quality Working Group (Auckland Council)
- New Zealand Transport Agency.

A number of representatives on the Steering Committee have air quality expertise and were involved with the original HAPINZ study.

1.4 Updated versus Original HAPINZ Study

The Health and Air Pollution in New Zealand (HAPINZ) study (Fisher *et al*. 2007) was published in 2007 with a base year of 2001 (for census data and air quality monitoring data) with costs estimated as at June 2004. The original study will be referred to in this report as the **original** HAPINZ study.

The present study has a base year of 2006 to align with the most recent census data and reflects trends in the national demographics since 2001, in particular:

- New Zealand's overall population has increased by 7.8 per cent.
- The urban population has grown by 8.1 per cent since 2001 while the rural population has grown by 6.0 per cent.
- The Māori population has increased by 7.4 per cent since 2001.

- The proportion of the population aged 65 years and over has increased from 12.1 per cent in 2001 to 12.3 per cent in 2006.

The update also uses monitoring data for 2006 to 2008 with costs as at June 2010 (to reflect the more recent publication date of 2011). This will henceforth, be referred to as the **updated** HAPINZ study.

Note: When this study commenced, the intention was to use the updated methodology to recalculate the health impacts later in 2012 when the March 2011 census results became available but, due to the Christchurch earthquakes, the census has now been delayed to March 2013 so this recalculation will not be able to be done until late 2014.

1.5 Report Layout

The report is structured as follows:

- Section 2 introduces the key steps involved in assessing air pollution health impacts
- Section 3 outlines the approach taken in this study to assess the exposure of New Zealanders to air pollution (PM_{10} exposure)
- Section 4 reviews the range of health outcomes chosen for this assessment
- Section 5 describes the estimates used to establish the resulting social costs
- Section 6 presents the results of this update together with an analysis of the sensitivity of the final figures to the assumptions made
- Section 7 reviews the overall conclusions of the updated HAPINZ study.

2. Assessing Air Pollution Health Impacts

Clean healthy air contributes to New Zealand's quality of life - not only people's health, but also the natural functioning of and the "*beauty of the natural and physical environment*" (MfE 2007). Air and air quality are both a taonga[8] and a part of the kaitiakitanga[9] for Māori.

Air pollution contains a complex mixture of gases and particles. The precise health impacts of exposure depend, in part, upon a range of subtle factors related to:

- the composition of the pollutant mixture
- the level and duration of exposure (effective dose) and
- the factors related to the exposed population, such as age, sex, ethnicity, pre-existing illnesses and access to health services (population sensitivity).

Health impacts assessments combine information on the profile of exposure in the population concerned (often based on air pollution monitoring) with external information on the health impacts that are expected given the level of exposure (based on evidence from separate epidemiological studies). In practice, because air pollution exposures are complex, it is necessary to simplify the assessment of air pollution effects by using summary indicators of exposure. The uncertainties involved in extrapolating health effects from one population to another are minimised when the exposures are estimated, and summarised, using comparable methods.

Particulate matter less than 10 micrometres in size[10] (PM_{10}) is the best available indicator of air pollution exposure currently in New Zealand. More extensive local observations are now available for PM_{10} than for other pollutants. In addition, relevant exposure-response functions outlining subsequent health effects of PM_{10} are available from New Zealand and international epidemiological studies. Although $PM_{2.5}$ rather than PM_{10} is increasingly used in overseas assessments, there is insufficient information currently available in New Zealand to undertake a robust assessment of $PM_{2.5}$ effects.

2.1 What are the Health Effects of PM_{10}?

PM_{10} comes from anthropogenic (human-caused) sources such as burning coal, oil, wood, petrol and diesel in domestic fires, motor vehicles and industrial processes. Natural sources of particles include sea spray, dust, pollens, volcanic activity and more recently earthquakes (liquefaction dust). In most places in New Zealand, levels of PM_{10} in the air

[8] A taonga in Māori culture is a treasured thing, whether tangible or intangible.

[9] A kaitiaki is a guardian, and the process and practices of protecting and looking after the environment are referred to as kaitiakitanga.

[10] A micrometre is a millionth of a metre and is represented by the symbol μm.

are at their highest during winter months, due to the higher frequency of calm conditions and increased solid fuel (wood and coal) burning for home heating.

There is a substantial body of evidence that inhaling particulate matter (PM) is harmful to human health, particularly smaller fractions such as PM_{10}, $PM_{2.5}$ and finer. PM_{10} is a more inclusive, but less specific measure of exposure than $PM_{2.5}$. PM_{10} includes $PM_{2.5}$ plus the coarser $PM_{2.5}$ to PM_{10} fraction. Generally larger particulate matter (between 2.5 and 10μm) deposits in the upper airways whereas smaller particulate matter (less than 2.5μm) lodges in the very small airways deep in the lung. Inhaled ultrafine particulate matter may even enter the bloodstream.

Particles of different sizes typically have different sources and different chemical and biological composition. The mechanisms of particle toxicity are complex and still not fully understood. For example, it is not yet certain which of the several classes of toxic effects observed in laboratory experiments are responsible for specific human health effects (Brook *et al*. 2010).

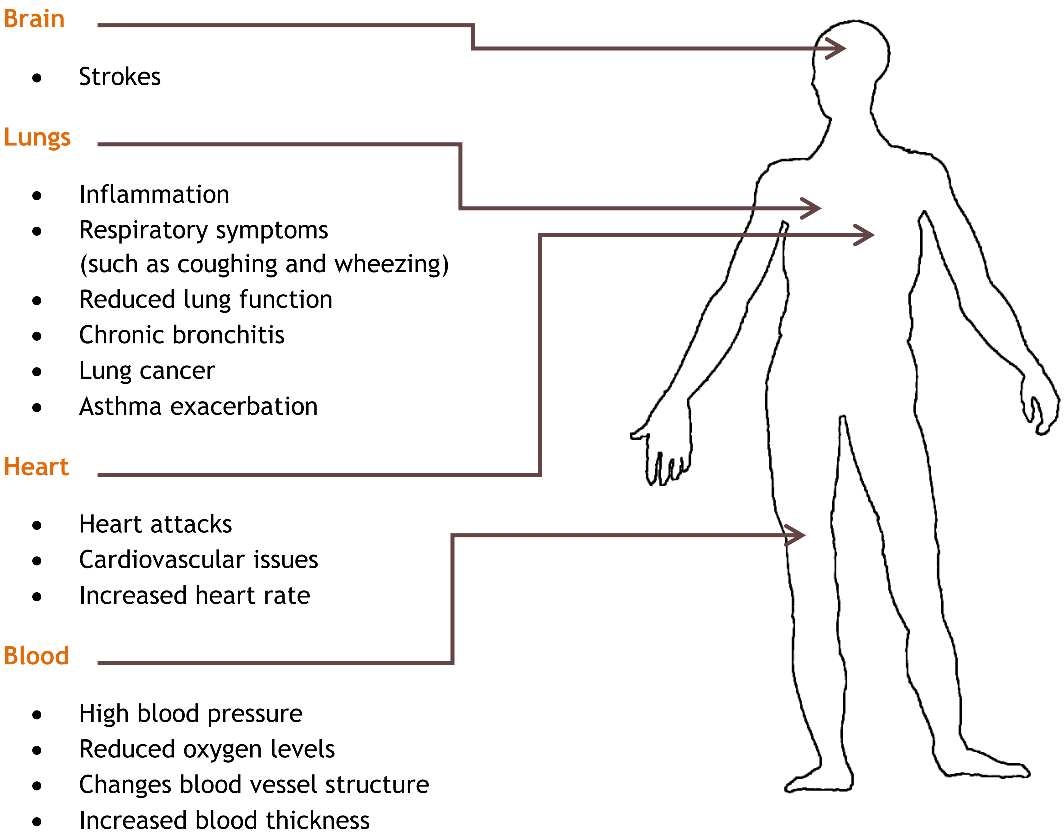
In laboratory experiments, human or animal cells exposed to particles from various sources show a range of inflammatory responses, which vary according to the source and composition of the particles. Particle characteristics including size, concentration, metal content, potential to cause oxidation and/or immunological responses have been shown to be important (Steenhof *et al*. 2011, Degobbi *et al*. 2010).

Air pollution exposure can have two classes of epidemiological effects: short-term and long-term effects. Short-term exposure to urban air pollution can cause respiratory irritation even in healthy people. In clinical exposure studies, a range of acute (short-term) cardiovascular and respiratory effects have been shown in volunteers with or without pre-existing diseases. Some short-term effects (such as heart rhythm disturbances) are completely reversible, but others can cause chronic inflammation of the lungs and blood vessels, and eventually, following repeated exposure, lead to chronic diseases such as lung cancer and atherosclerosis (hardening of the arteries). Short-term effects can include premature death in susceptible individuals, but the major impact of air pollution exposure on life expectancy is through the gradual, cumulative effects on chronic disease.

In epidemiological studies, effects of air pollution exposures can be assessed in real world conditions. Such studies include irreversible effects of air pollution on health outcomes, including long and short-term effects on death and disease. However, epidemiological studies cannot study the precise pathological mechanisms leading to development of chronic cardiovascular and respiratory diseases that are the most important health outcomes of air pollution exposures.

Assessment of air pollution effects should ideally include an appraisal of the sum of scientific evidence from laboratory, clinical and epidemiological studies. However, that is a major task requiring years of work by large scientific teams, and is beyond the scope of this report.

Figure 2.1 outlines the potential health effects specifically associated with PM_{10} exposure.



Source: Based on Aphekom (2011)

Figure 2.1: Effects on health from PM_{10} exposure

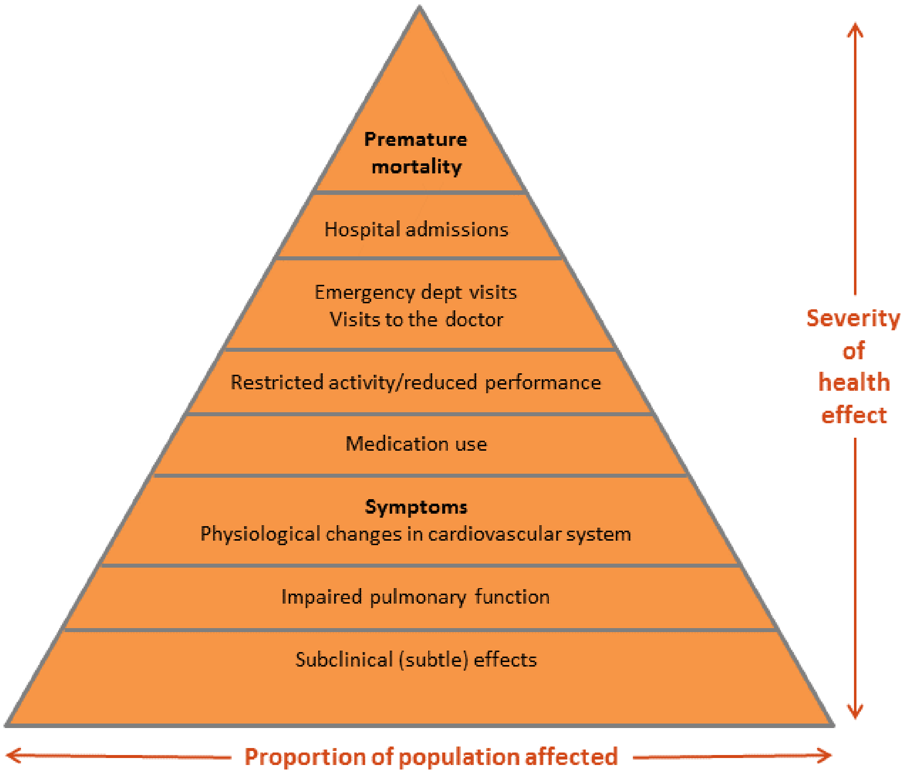
The health effects[11] of PM_{10} are predominantly respiratory and cardiovascular. The impacts range from functional changes (e.g., reduced lung function) to symptoms, impaired activities (e.g., school absenteeism, days off work), doctors' visits through to hospital admissions, reduced life expectancy and death.

Note: Studies generally do not support the hypothesis that PM_{10} pollution causes premature death by 'harvesting' those who would have died in a few days anyway. The health impact of long-term exposure to PM concentrations is typically much greater than that of short-term exposure in terms of social costs.

More people are affected by less severe health effects than the proportion affected by more severe health effects (see Figure 2.2). While there are a large number of

[11] Adverse health effects that involve increased illness or disease are generally referred to as 'morbidity' effects, while those involving premature death are classified as 'mortality' effects.

acute/transitory health effects due to PM_{10}, the fewer chronic impacts incur a much greater social cost.



Source: WHO (2006)

Figure 2.2: Pyramid of PM_{10} health effects

All PM_{10} is considered equally toxic

As already mentioned, there is a widespread consensus that air pollution causes adverse health effects. However, the link to individual sources is less clear. Particles from different sources (e.g., domestic fire emissions as opposed to sea spray) will have quite different chemical compositions, different physical characteristics and therefore potentially quite different toxicities but evidence from epidemiological studies is currently inconclusive. The World Health Organization (WHO 2006) states:

> **"The mass-based standards that have been proposed inherently assume that all airborne PM has the same potential to cause adverse health effects, regardless of chemical composition or physical characteristics.** *While both observational and experimental findings imply that particle characteristics are determinants of toxicity, definitive links between specific characteristics and the risk of various adverse health effects have yet to be identified."*

Note: This updated HAPINZ study assumes that **all PM_{10} is treated as equally toxic, irrespective of source**, which is consistent with the WHO approach, and uses the wording **"*causes*" for adverse effects linked to air pollution in general** but uses the wording **"*is associated with*" for adverse effects linked to specific sources of air pollution**, such as domestic fires.

2.2 How are the Health Effects of PM_{10} Assessed?

Health impacts resulting from exposure to air pollution (in this case to PM_{10}) are typically assessed in a step wise process as follows:

Assess people's exposure

Pollutants?
Base year?
Sources?
Spatial resolution?
Availability and quality of monitoring data?
Availability of population data?

↓

Select health outcomes

Long-term or short-term?
Age groups and gender?
Ethnicities?
Risk of double counting?
Availability of robust response-functions?
Availability of standardised incidence data?

↓

Estimate social costs

Base year for monetarisation?
Value of statistical life?
Medical costs?
Productivity losses?
Availability of supporting data?

For each area under assessment (e.g., a census area unit, CAU), the health impacts are generally calculated as follows:

$$\textbf{Health Effects (cases)} = \textbf{Exposure} * \textbf{ExposureResponse Function} * \textbf{Population Exposed}$$

Where ‘cases’ are the number of premature deaths, hospital admissions or restricted activity days etc. depending on the health outcome being assessed. These are usually assessed relative to a baseline rate that can vary significantly by population and region.

Note: We use the term ‘exposure-response’ rather than ‘concentration- or dose-response’ in this study. In this sense, ‘exposure’ refers to the exposure to ambient PM_{10} concentrations and does not take into account localised influences on personal exposure. This is appropriate because potential inaccuracies associated with higher or lower exposures are likely to balance out as they would have in the derivation of the dose/exposure-response relationships.

The social costs are then calculated as follows:

$$\textbf{Social Costs} = \textbf{Health Effects (cases)} * \textbf{Cost per case}$$

Results can be aggregated and reported for larger urban areas (such as towns and cities) or management areas (such as regions or airsheds) depending on physical and political boundaries.

The information is used in cost-benefit analyses for a range of applications, such as:

- weighing benefits of health improvements against the costs of (various) air pollution reduction initiatives
- evaluating the effectiveness of existing policy initiatives (back-casting)
- assessing the likely effects of current population and business as usual trends (forecasting)
- developing targeted strategies for reducing the air pollution exposure of particularly vulnerable groups in the population.

The following chapters deal with the major steps in the air pollution health impact assessment in more detail:

- Assessing people’s exposure (which contaminants we selected and why - see Chapter 3)
- Determining the resultant health effects (which health outcomes we selected and why - see Chapter 4)
- Estimating the overall social costs (which cost estimates we used and why - see Chapter 5).

3. Assessing PM_{10} Exposure

This section summarises the features of the approach taken to assess the exposure of the New Zealand population to PM_{10} air pollution in 2006 and the rationale behind the decisions made. The updated methodology is then compared with that used in the original HAPINZ study.

Readers seeking more information are directed to the following two reports contained in the *Updated Health and Air Pollution in New Zealand Study Volume 2 – Technical Reports:*

Appendix 1 which discusses the methodology for assessing PM_{10} exposure, including the approaches used for:

- Urban areas with air quality monitoring data
- Urban areas without air quality monitoring data
- Rural areas

Appendix 2 which reviews the results of various source apportionment studies undertaken in New Zealand in order to establish robust estimates of the contribution of natural sources to PM_{10} concentrations by census area unit (CAU).

3.1 Features of the PM_{10} Exposure Assessment

The features of the approach used to assess exposure in this update are summarised as follows:

- **Particulate matter (PM_{10})** is used as the best available indicator of air pollution exposure due to the wealth of monitoring data now available and the links to existing exposure-response functions developed from New Zealand and international epidemiological studies.
- **Actual monitoring data** are used in preference to modelling estimates and **averaged for 2006 to 2008** to reduce the influence of year to year variability in meteorological conditions.
- For unmonitored areas, annual concentrations are based on comparisons with monitored areas that have the same urban/rural classification[12].
- **PM_{10} data are corrected for gravimetric (HiVol) equivalency**[13] based on a combination of known relationships (applies to areas with 84 per cent of the

[12] As defined by Statistics New Zealand. See http://www.stats.govt.nz/census/about-2006-census/2006-census-definitions-questionnaires/definitions/geographic.aspx for details.

overall monitored population) and estimated relationships (remaining 16 per cent affected). These corrections are applied to the three-year annual averaged data.

- Concentrations are estimated for the following **sources** – domestic fires, motor vehicles, industry, open burning, and natural.
- Sources are allocated by estimating the natural source contributions (from source apportionment studies where available) and then allocating the remaining (anthropogenic) concentrations by emissions inventory proportions.
- **Results are estimated by census area units** as at 2006 (1,919 in total) but are able to be aggregated nationally, by regional council (16), by TLA (Territorial Local Authority, such as a city or district council) (74) [14], by urban area (139), and also by airshed (71).
- **Sensitivity analyses are undertaken for equivalency**, assuming the base case being all data adjusted for HiVol equivalency (1.0) with upper and lower bounds of 0.85 and 1.15 applied to the data respectively.

3.2 How was PM_{10} Exposure Assessed in this Update?

Mortality and morbidity impacts of air pollution exposure rely on annual or daily average concentration data. In New Zealand, PM_{10} monitoring data are now available for more than 40 urban areas. These areas range in size from Bluff to Auckland and in some locations PM_{10} data are available for a number of monitoring sites. Areas without monitoring data are typically small in size and have generally been deemed by regional councils as being low risk in terms of experiencing elevated PM_{10}.

In this update, we developed a national exposure model to determine PM_{10} concentrations for every CAU in New Zealand that were broken down by source. The model was based on actual monitoring data (averaged for 2006 to 2008) because the information was available for areas covering 83 per cent of the population living in urban areas and 73 per cent of the population overall in 2006. This is an important feature of the update because it gives confidence that estimates of health impacts for the majority of people were based on real monitoring data as an indicator of exposure.

All monitoring data were corrected for gravimetric (HiVol) equivalency as recommended by European Environment and Health Information System (ENHIS) Methodological Guidelines for Health Impact Assessment (2007). This provides a solid basis for

[13] HiVol refers to the joint Australian/New Zealand standard reference method for particulate monitoring that employs a high volumetric sampling rate to determine concentration of particulate on a weight (gravimetric) basis.

[14] Note the number of TLAs is based on those that were in existence for the 2006 census. In 2010, there was an amalgamation of the eight Auckland councils so the number of TLAs is now 67 (excluding the Chatham Islands).

comparisons and ensures we are comparing 'apples' with 'apples'. It further ensures that there is no under-estimation of the impacts of PM_{10} (as may be the case with uncorrected data). Most data were corrected using known relationships whilst the remaining data were corrected using a default factor. We then undertook sensitivity testing to determine health impacts for locations without known correction factors based on a lower bound representing no correction (0.85) and an upper bound representing additional correction required (1.15). The base case with all data corrected is 1.0.

In unmonitored areas, PM_{10} concentrations were estimated based on comparison with monitored areas that had the same Statistics New Zealand urban/rural classification.

Sources were assessed on a monthly basis as the relative contributions vary with seasons (e.g., domestic heating is greater in winter). Emissions from domestic heating, open burning and industry were estimated for each CAU using either inventory data or household wood/coal use data (domestic heating), household numbers and inventory derived relationships (open burning). Vehicle emissions were estimated from Ministry of Transport vehicle kilometres travelled (VKT) data by CAU[15] and emission factors from the Vehicle Emission Prediction Model version 3.0 (Metcalfe *et al.* 2009).

Previous New Zealand source apportionment[16] studies were reviewed to identify the contribution of natural sources to PM_{10} concentrations in urban areas. The review found an average natural source contribution of 6.8 µg/m^3. This value was used as a default for areas without source apportionment data. Average seasonal profiles were also established to account for seasonal variability.

PM_{10} concentrations were allocated by source by subtracting the estimated natural sources contribution (such as wind-blown dust and sea spray) and any major industry concentrations[17] from the monthly PM_{10} concentrations. The remaining monthly concentrations were then allocated to the other sources – domestic fires, motor vehicles, open burning and the remainder of industry - based on the relative contribution to total anthropogenic emissions (less major industry) for that month.

For example,

$$\textbf{Domestic fire concentration } (\mu g/m^3) = \frac{\textbf{Domestic fire emissions } (kg/km^2/day)}{\textbf{Total anthro less industry with tall stacks emissions } (kg/km^2/day)}$$

[15] The VKT data by CAU were corrected by 0.9 on advice of the Ministry of Transport to align the overall total with the actual total in the NZTA Motor Vehicle Registration Statistics database.

[16] Source apportionment studies involve collecting particulate such as PM_{10} or $PM_{2.5}$ on filters and then using chemical or elemental signatures to determine the relative fractions coming from different emission sources, e.g., sea spray is high in sodium and chlorine.

[17] Major industries – designated 'tall stack' industries in the Volume 2 report – were separated out to better account for their dispersion characteristics. Most of these sites emit from stacks that are well above ground level (typically 20 metres and higher).

The relative contributions of sources to monthly average PM_{10} concentrations were determined and these contributions were averaged for each year to provide a more robust assessment of the resulting contributions to annual average concentrations.

3.3 Why Only PM_{10} and not Other Pollutants?

Based on a review of the monitoring data available across New Zealand for 2006 to 2008, PM_{10} is the best available indicator of air pollution exposure. PM_{10} has more extensive local observations than any other pollutant. In addition, exposure-response functions outlining subsequent health effects of PM_{10} are available from New Zealand and international epidemiological studies.

International assessments increasingly use $PM_{2.5}$ rather than PM_{10} as the exposure metric. However, we were unable to undertake a robust assessment of the primary health effects due to the dearth of $PM_{2.5}$ monitoring data available in New Zealand in 2006. However, we did undertake a broad brush sensitivity analysis for one health outcome - mortality for all adults aged 30 years and over - using an estimated fraction of $PM_{2.5}$ in the PM_{10} annual average as a cross check (discussed in Chapter 6.3).

Basing the update on PM_{10} rather than $PM_{2.5}$ means that proportion of air pollution health impacts attributed to anthropogenic sources, in particular motor vehicles and domestic fires used for home heating, will be lower as these sources make a greater contribution to finer particulate fractions than natural sources.

In addition, there is evidence that both proximity to busy roads and nitrogen dioxide (NO_2) exposure have important health impacts (especially respiratory symptoms in children). However, it was not possible to quantify these exposures for the present study. In New Zealand, routinely available health outcome information is geocoded to CAUs, which means it is not sufficiently accurate for studies based on proximity to roads. There is insufficient representative NO_2 monitoring data on which to base an assessment of human exposures.

Not being able to robustly assess NO_2 exposure means that the results of this update most likely under-estimate the health impacts of motor vehicle-related air pollution.

Carbon monoxide (CO) and benzene were included in the original HAPINZ study. However, these were not included in the exposure assessment due to concerns about potential ‘double-counting’ of health effects (for CO) or due to low levels and low exposure-response functions (for benzene).

Note: Basing the assessment on PM_{10} does not mean that all health effects are attributed to PM_{10} alone as urban air pollution is a complex mixture of gases and particles.

3.4 What about Other Sources?

The following sources were included in the update:

- domestic fires used for home heating

  primarily wood burners, coal burners and open fires etc. but some gas-fired appliances where reported in the regional inventories

- motor vehicles

  on road only transport such as petrol and diesel cars, vans, trucks and buses

- industry

  stationary facilities for manufacturing products or generating energy that release process or combustion emissions

- open burning

  burning of biomass (e.g., tree trimmings) or waste outdoors

- natural sources

  primarily sea spray and windblown dust

From the inventory data, domestic fires used for home heating are the most widespread and significant source of anthropogenic PM_{10} in New Zealand, with emissions coming principally from solid-fuel (wood and coal) burning.

Emission estimates for other sources (e.g., other transport including aviation, shipping, rail, as well as off-road construction, farming and agriculture vehicles) are not reported consistently in emission inventories across New Zealand so were not included. However, in most areas, the first four sources – domestic fires, motor vehicles, industry and open burning – are likely to represent at least 95 per cent of all possible anthropogenic PM_{10} emissions.

As an example, the urban area of Auckland is one of the few places with significant 'other transport' sources but these sources have been estimated to only amount to 3.4 per cent of anthropogenic PM_{10} (AC 2011). Consequently, we estimate that the omission of other anthropogenic sources would likely result in only a minimal error (potentially up to 3 per cent of total anthropogenic emissions).

The main natural sources of PM_{10} in New Zealand are sea spray (referred to as 'marine aerosol') and windblown dusts (referred to as 'soil'). Other sources such as volcanic eruptions and trans-Tasman emissions from bush fires and dust storms in Australia can be significant but are infrequent occurrences and are difficult to quantify. Only marine aerosol and soil were considered in this update.

3.5 How does the Update compare with the Original HAPINZ?

Table 3.1 compares the main features of the update and the original HAPINZ studies.

Table 3.1: Comparison of exposure assessment methodologies used in the updated HAPINZ study versus the original HAPINZ study

Parameter	Update	Original
Base year	2006	2001
Areas	16 regions, 74 TLAs, 139 'urban' areas and 71 airsheds by CAU	67 'urban' areas by CAU
Population	4,027,902 covering 100 per cent of 2006 pop'n	2,803,215 covering 73 per cent of 2001 pop'n
Pollutants	PM_{10} only	PM_{10} plus CO, NO_2, benzene
Exposure assessment methodology	Actual monitoring data 2006-2008 covering 73 per cent 2006 pop'n with proxy monitoring in remaining areas	Land based regression model to supplement limited actual monitoring data
Sources	Natural sources, Domestic fires Motor vehicles, Industry and Open burning	Natural sources, Domestic fires, Motor vehicles and Industry
Natural source PM_{10} contributions	3.6 to 9.5 μg/m^3 from source apportionment studies (default average 6.8 μg/m^3)	2 to 16 μg/m^3 estimates (average 3.3 μg/m^3)

4. Selecting Health Outcomes

This section summarises the health outcomes assessed and the rationale behind the decisions made. The health outcomes used in the update are then compared with those used in the original HAPINZ study.

Readers seeking more information are directed to the following report contained in the *Updated Health and Air Pollution in New Zealand Study Volume 2 – Technical Reports:*

Appendix 3 which outlines the recommendations and justification for the following components of the health effects assessment methodology:

- exposure-response functions and methodology for estimation of mortality from PM_{10} exposure
- whether to specifically assess $PM_{2.5}$ effects based on literature and available $PM_{2.5}$ data
- exposure-response functions and methodology for morbidity effects of PM pollution based on review of recent meta-analyses
- review of meta-analyses and available data for other pollutants
- confirmation of methodology to quantify health effects for Māori and other sub-groups.

4.1 Features of the Health Outcome Selection

The health outcomes and exposure-response estimates selected for assessment in this update are as follows:

- **Premature mortality** from long-term exposure (PM_{10} annual mean)
  - Adults, aged 30 years and over: 7% (3% to 10%) per 10 μg/m^3
  - Babies, aged 1 month to 1 year: 5% (2% to 8%) per 10 μg/m^3
- **Hospital admissions** from short-term exposure (PM_{10} daily mean)
  - cardiac hospital admissions, all ages: 0.6% (0.3% to 0.9%) per 10 μg/m^3
  - respiratory hospital admissions, all ages: 1.0% (0.6% to 1.7%) per 10 μg/m^3
- **Restricted activity days** from long-term exposure ($PM_{2.5}$ annual mean[18])
  - restricted activity days, all ages: 0.9 (0.5-1.7) per 10 μg/m^3

[18] Assuming that 60 per cent of annual PM_{10} in urban areas and 40 per cent of annual PM_{10} in rural is $PM_{2.5}$

- **Population sub-group impacts**
  - premature mortality for Māori adults, aged 30 years and over: 20% (7% to 33%) per 10 µg/m^3 (PM_{10} annual mean)
  - respiratory hospital admissions for children aged 1 to 4 years: 1% (0.6% to 1.7%) per 10 µg/m^3 (PM_{10} daily mean)
  - respiratory hospital admissions for children aged 5 to 14 years: 3% (0% to 5%) per 10 µg/m^3 (PM_{10} daily mean)
- **Sensitivity analyses** are conducted on the 95% confidence intervals or upper and lower bounds of the selected exposure-response functions.
- As a cross check, a comparison is also undertaken for one health outcome - mortality for all adults aged 30 years and over - using an indicative exposure-response function for $PM_{2.5}$ as opposed to PM_{10} follows:
  - all adults, aged 30 years and over: 9% per 10 µg/m^3 ($PM_{2.5}$ annual mean)

4.2 How were the Health Outcomes Selected?

Particulate matter (PM_{10}) was chosen as the best available indicator of air pollution exposure for the purposes of this update. More extensive local observations are available for PM_{10} than for other pollutants. In addition, major New Zealand and international epidemiological studies have used PM_{10} as one of the exposure metrics.

The health outcomes selected were based on the need to provide policy-relevant estimates supported by well-established epidemiological results, while avoiding double-counting of effects, and including some less substantial evidence relevant to social justice and equity. They included:

1. an estimate of effects of long-term exposure on mortality in adults (found to be the dominant health impact in previous studies)
2. separate estimates of effects of long-term exposure on mortality in sensitive subpopulations, including infants and Māori
3. estimates of the effects of short-term exposure on hospital admissions for cardiovascular and respiratory diseases and
4. an estimate of restricted activity days.

We did not undertake a full literature review but examined the health outcomes included in recent assessments (particularly meta-analyses) including:

- a nationally representative New Zealand cohort study (Hales *et al*. 2010)
- a US assessment of $PM_{2.5}$ (USEPA 2010)
- the Global Burden of Disease Assessment (Cohen *pers. comm*. 2011)
- one European health impact assessment guide (ENHIS 2007) and

- one global impact assessment guide (Ostro 2004).

Premature mortality in adults was assessed based on Hales *et al.* (2010) who reported substantially different air pollution effects in different ethnic groups in a cohort study undertaken in New Zealand. These differences were numerically substantial (20% in Māori as compared to 7% in all ethnicities combined). However, the authors cautioned that the ethnic differences were not statistically significant (i.e., there is overlap between the plausible range of these estimates for the two groups).

For relatively wealthy countries such as New Zealand, the strongest evidence for effects on mortality in children relates to the post neonatal period (ages 1 month to 1 year). We assessed the impact of air pollution on post-neonatal mortality based on the meta-analysis by Lacasaña *et al.* (2005) as cited in a European guide to air pollution impact assessment (ENHIS 2007). There was insufficient evidence on which to base estimates of mortality impacts of long-term exposure in older children and young adults (aged under 30 years).

We included estimates of effects on hospital admissions for respiratory diseases in children, based on the results of a multi-city Australasian study (Barnett *et al.* 2005) and the effect on hospital admissions in adults, based on the results of a European meta-analysis, APHEIS (2004), as cited in a European guide to air pollution impact assessment (ENHIS 2007).

Some New Zealand and international studies have also estimated restricted activity days (in which air pollution exposure causes symptoms sufficient to prevent usual activities such as attendance at work or study). We included an estimate of restricted activity days, for all ages (ALA 1995 based on Ostro 1987).

The proposed health outcomes and exposure-response estimates selected are consistent with recommendations of other recent or current international studies of air pollution effects (Cohen *pers. comm.* 2011).

As discussed earlier, many international studies recommend use of $PM_{2.5}$ as the exposure metric but we were unable to do this in the update due to a lack of monitoring data currently. However, we did undertake a rudimentary cross-check for the most significant health effect - premature mortality in all adults aged 30 years and over. The New Zealand-specific relationship determined by Hales *et al.* (2010) for PM_{10} was scaled using a ratio based on the premature mortality exposure-response functions for $PM_{2.5}$ to PM_{10} seen in overseas studies to develop an **indicative relationship for $PM_{2.5}$ exposure** of

$$\mathbf{1.09\ (=1.07*1.06/1.043)\ per\ 10\ \mu g/m^3\ PM_{2.5}}$$

This was applied to estimates of $PM_{2.5}$ concentrations across New Zealand (largely taken from source apportionment work) to check the figures derived based on PM_{10}.

4.3 What are the Exposure-Response Functions?

We assumed linear, no threshold exposure-response functions for all endpoints. This assumes that health effects are detectable at any concentration above zero and that the increase in the effect is proportional to the increase in concentration. This is in line with current thinking for exposures in the range typically experienced in New Zealand (Schwartz *et al*. 2002, Schwartz *et al*. 2008). As discussed in Chapter 2, all PM_{10} was treated as equal in terms of its health effects, i.e. the exposure-response functions are the same for each health effects irrespective of the PM_{10} source.

Health effects were calculated by CAU and then aggregated to give national or regional or airshed etc. estimates as follows:

4.3.1 Overall for all Health Effects (Except Restricted Activity Days)

$$\mathbf{Cases_{Total} = Cases_{Base} + Cases_{AP}}$$

Where:

$Cases_{Total}$ is the total number of cases observed in the population of interest

$Cases_{Base}$ is the number of baseline cases that would have occurred without exposure to air pollution

$Cases_{AP}$ is the number of extra cases that arise due to exposure to air pollution

$Cases_{AP}$ is calculated as follows for pollutants (such as PM_{10}) that do not have a threshold:

$$\mathbf{Cases_{AP} = Cases_{Base} * (RR - 1) * E}$$

Where:

RR is the relative risk per unit of pollution (selected from epidemiological studies)

E is the exposure for the population of interest (available from monitoring data)

From above

$$\mathbf{Cases_{Total} = \left(\frac{Cases_{AP}}{(RR - 1) * E}\right) + Cases_{AP}}$$

Therefore:

$$\mathbf{Cases_{AP} = \frac{Cases_{Total}}{(1 + \left(\frac{1}{(RR - 1) * E}\right))}}$$

Table 4.1: Summary of the parameters and data sources used in the exposure-response functions in the updated HAPINZ study

Health Outcome	Relative Risk (RR)[7]	$Cases_{Total}$	Exposure (E)
1 Premature mortality, all adults, all ethnicities	**1.07** (1.03-1.10) Hales *et al.* (2010)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006
1a Premature mortality, all adults, Māori-only[1,2]	**1.20** (1.07-1.33) Hales *et al.* (2010)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006
2 Premature mortality, babies, all ethnicities[3,4]	**1.05** (1.02-1.08) Lacasaña *et al.* (2005)	MoH data national only 2005-2007	Annual pop'n wtd average PM_{10}÷10 for 2006
3 Cardiac hospital admissions, all ages all ethnicities[5]	**1.006** (1.003-1.009) APHEIS (2004)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006
4 Respiratory hospital admissions, all ages all ethnicities[5]	**1.01** (1.006-1.017) APHEIS (2004)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006
4a Respiratory hospital admissions, children all ethnicities, aged 1-4 years[5,6]	**1.02** (1.01-1.04) Barnett *et al.* (2005)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006
4b Respiratory hospital admissions, children all ethnicities, aged 5-14 years[5,6]	**1.03** (1.00-1.05) Barnett *et al.* (2005)	MoH data by CAU 2005-2007	Annual average PM_{10}÷10 for 2006

Note:

1. This is a subset of the premature mortality, all adults, all ethnicities health effect and must not be added to the overall results.
2. The confidence intervals for the relative risk factors for 'all ethnicities' and 'Māori-only' overlap. The 'Pacific-only' group is not included as Hales *et al.* (2010) did not find any significant effects in this group (but this was probably due to low numbers of cases in that ethnic group).
3. For this health outcome, the total cases data are only available as a single national total. To get estimates by CAU the national total has been pro-rated by the number of babies in each CAU versus the total number of babies nationally.
4. These numbers have been multiplied by the population weighted annual average concentrations.
5. The daily average PM_{10} increments are calculated from the annual average concentrations, assuming 365 days in a year.
6. This is a subset of the 'respiratory hospital admissions, all ages' health effect and must not be added to the overall results.
7. Relative risks are per 10μg/m^3 PM_{10}.

4.3.2 Restricted Activity Days

$$\mathbf{Cases_{RADs} = Pop\ by\ CAU * RF * E}$$

Where:

RF = **0.9** (0.5-1.7) days per person per year per 10 µg/m^3 annual $PM_{2.5}$ (ALA 1995 based on Ostro 1987)

E = annual $PM_{2.5}$ average in µg/m^3 figure per CAU divided by 10 (assuming $PM_{2.5}$ is 0.6*PM_{10} in urban areas and 0.4*PM_{10} in rural areas)

Pop by CAU is the 2006 census population for all ages, all ethnicities (Stats NZ census data)

Note: RADs are not calculated relative to a baseline incidence; hence a risk factor (RF) of 0.9 is used.

4.4 What about Other Health Outcomes such as Asthma?

We considered a number of other health outcomes but did not include them in the updated HAPINZ study for the following reasons:

- **Short-term PM_{10} effects on mortality** were not included because they are largely included as part of the assessment of long-term effects and would lead to 'double counting'.
- **Adverse reproductive outcomes, stroke incidence, chronic obstructive pulmonary disease (COPD) and asthma *incidence*** were not included due to limited scientific consensus on the relationships with air pollution. Note **there is a distinction between the incidence of disease and worsening of pre-existing disease**. Effects of air pollution on stroke and exacerbations of respiratory diseases, including respiratory infections, asthma and chronic airways diseases are partly accounted for in the assessment of morbidity (hospital admissions and RADs).
- **Nitrogen dioxide (NO_2) exposure** was not included due to limited data. There is increasing evidence linking proximity to busy roads and nitrogen dioxide (NO_2) exposure with adverse health effects, especially for respiratory symptoms in children. However, it was not possible to quantify these exposures in New Zealand due to limited continuous monitoring data.
- **Benzene cancer risk** estimates from the original HAPINZ study were not updated because ambient concentrations have dropped significantly in response to reductions in the benzene content of petrol and the very low relative risk factors[19].
- **Premature mortality associated with carbon monoxide (CO)** was not included because it is impossible to separate this effect from mortality due to PM_{10} and its inclusion would run the risk of 'double counting'.

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[19] There was an error in the benzene cancer risk estimates in the original HAPINZ study which over-estimated cancer cases by a factor of 79.

4.5 How does the Update compare with the Original HAPINZ?

Table 4.2 compares the main features of the update and the original HAPINZ studies.

Table 4.2: Comparison of health outcomes used in the updated HAPINZ study versus the original HAPINZ study

Health Outcome	Factor used in Update	Factor used in Original
Premature mortality (PM_{10}) adults, aged 30 yrs & over all ethnicities	**1.07** (1.03-1.10)	**1.043** (1.026-1.061)
Premature mortality (PM_{10}) adults, aged 30 yrs & over Māori	**1.020** (1.07-1.33)	**not included**
Premature mortality (PM_{10}) babies, aged 1 mth to 1 yr all ethnicities	**1.05** (1.02-1.08)	**not included**
Cardiac admissions (PM_{10}) all ages all ethnicities	**1.006** (1.003-1.009)	**1.01**
Respiratory admissions (PM_{10}) all ages all ethnicities	**1.01** (1.006-1.017)	**1.013**
Respiratory admissions (PM_{10}) children, aged 1 to 4 yrs all ethnicities	**1.02** (1.01-1.04)	**not included**
Respiratory admissions (PM_{10}) children, aged 5 to 14 yrs all ethnicities	**1.03** (1.00-1.05)	**not included**
Restricted activity days ($PM_{2.5}$) all ages all ethnicities	**0.9** (0.5-1.7)	**0.912**
COPD (PM_{10}) all ages, all ethnicities	**not included** due to lack of consensus in international literature	**1.214**
Premature mortality (CO) all ages, all ethnicities	**not included** due to double counting concerns	**1.079**
Cancer (Benzene) all ages, all ethnicities	**not included** due to emissions reductions and low RR	**1.0000759**

5. Estimating Social Costs

This section firstly presents the key social cost estimates and then presents the rationale behind the decisions made. The updated estimates are then compared with those used in the original HAPINZ study.

Readers seeking more information are directed to the following report contained in the *Updated Health and Air Pollution in New Zealand Study Volume 2 – Technical Reports:*

Appendix 4 which outlines the recommendations and justification for the following cost estimates:

- value of statistical life (VOSL) for premature mortality
- social costs for morbidity effects.

5.1 Features of the Social Costs Estimation

The approach used to estimate the social cost estimates in this update are as follows:

- All costs are estimated in New Zealand dollars as at June 2010.
- A **transport risk (road safety) based Value of Statistical Life (VOSL) of NZ$3.56 million** is used for all cases of premature mortality due to air pollution.
- Average costs of **NZ$6,350 (cardiovascular)** and **NZ$4,535 (respiratory)** are used for all **hospital admissions**. These include medical costs and loss of output during hospitalisation but do not include loss of life quality due to prolonged pain and suffering.
- Restricted activity days are valued at **NZ$62**, based on the average loss of output per day (irrespective of a working or non-working day).
- **Sensitivity analyses** are conducted using a VOSL twice as high to reflect higher international values for air pollution risk and using a range of likely loss of life quality and medical costs for the morbidity effects.

5.2 How were the Social Costs Estimated?

Air pollution results in mortality and morbidity health consequences. This amounts to loss of life and life quality of people exposed to pollution. Once the health consequences were estimated, our task was to estimate the total cost to society (the 'social costs') resulting from these consequences.

In this update we estimated the social costs arising from the following health outcomes (selected in Chapter 4):

- premature mortality (all cases, irrespective of age, gender or ethnicity)
- cardiac hospital admissions
- respiratory hospital admissions
- restricted activity days.

Like any other risk area, air pollution increases the risk of death to those exposed to the pollution. The value of a change in risk is generally measured by society's willingness to pay (WTP) for that change. The amount of money a society is willing to pay to reduce the risk of death so that **one premature death is prevented** is known as WTP-based value of statistical life (VOSL)[20]. The official VOSL in New Zealand used by the transport sector and many others is regularly updated by the Ministry of Transport. The VOSL at June 2010 prices was $3.56 million (MoT 2010) and this was adopted for the update.

The total costs per hospitalisation were based on the medical costs and the loss of output only incurred for each health effect – in this case respiratory hospital admissions and cardiovascular hospital admissions.

For the medical costs, we reviewed the hospitalisation data and found that the average length of hospitalisation was 5 days for cardiovascular diseases and 3.3 days for respiratory diseases. An NZIER (2009) report estimated the average medical cost per hospitalisation as $7,700 at 2008 prices, based on an average length of hospitalisation of 12.6 days for traffic accidents and 6.8 days for PM_{10} pollution (MfE 2004). Using the latest MoT (2010) estimates for hospitalisation of $8,500 as at June 2010, the total medical cost for these two diseases was estimated at $6,040 and $4,330 respectively for cardiovascular and respiratory diseases.

For the loss of output, the average loss per day in hospital was estimated as the average weekly income divided by 7. Statistics New Zealand survey data was used to calculate the average income per person per week as at June 2010 ($436). This gave $62 per day (irrespective of a working or non-working day). Therefore the average loss of output per cardiovascular hospital admissions was $310 (=5*$62) and per respiratory hospital admission was $205 (=3.3*$62).

Combined these gave the total costs for medical costs and loss of output (during hospitalisation) at $6,350 and $4,535 (in June 2010 prices) for cardiovascular and respiratory diseases respectively. [21]

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[20] The VOSL is not a value of an identified individual life. It is the value society as a whole is willing to pay to prevent a premature death. Therefore the subsequent social cost includes the cost to society of premature deaths due to pollution.

[21] This does not include the value to society of loss of life quality due to any long term impairment.

Restricted activity days (RADs) were estimated for the whole population, not just those employed. So RADs refer to loss of activity related to earning as well as non-earning time. Thus average loss per RAD was related to the average loss per affected person. We followed the same methodology as for loss of output during hospitalisation to estimate the loss of income per RAD at $62 per day (irrespective of a working or non-working day) and assuming that the loss per RAD applies to the whole day on average.

5.3 Why value Statistical Lives and not Life Years Lost?

In the original HAPINZ study (Fisher *et al*. 2007), the value used for prevention of mortality was $750,000 at 2004 prices when the VOSL used by the Ministry of Transport was $2.725 million. This was based on the assumption that about 5 years of life would be lost on average when a person died due to air pollution.

The estimated value was derived based on the assumption that the average age at death in road traffic crashes was 35 years and the average loss of life years was 44 years. Using a 6 per cent discount rate the study estimated the value per life year from the assumption that the discounted present value over 44 years would be $2.725 million. That would give the discounted present value over five years (only) at 6 per cent discount rate of about $750,000. Fisher *et al*. (2007) used this as the value to society of preventing one premature death.

We consider the approach used in the original study inappropriate because the value per life year is not necessarily constant. If it was constant, the VOSL would decline by age. We have no evidence of a decline trend of VOSL by age. Besides, once a person is diagnosed with a heart disease or cancer, the level of trauma suffered by the person and their close ones is very high. In addition, an OECD study recommends use of the same value for all ages (OECD 2010). We have used the official VOSL for the value to society of preventing an air pollution-related mortality.

5.4 How does our VOSL Compare with Overseas VOSLs?

The current WTP-based VOSL used for transport safety evaluations was based on people's willingness to pay for improvement in road safety risks. As noted by NZIER (2009) in response to a question raised on the validity of using transport risk-based VOSL for evaluating mortality risk changes from air quality improvements, there is no particular reason why the VOSL in the present context should differ drastically from VOSL estimated from traffic crash risk changes, except the possibility for **higher** values due to prolonged pain and suffering before death in some cases. In addition, it is not practical to estimate the WTP based VOSL for every risk environment due to the very high cost of conducting contingent valuation surveys.

As noted in NZIER (2009), pollution exposure results in some chronic diseases and many suffer for a long time before death. In such cases, the social costs of death can be much higher than social costs of death due to traffic crashes. It is not surprising that in many jurisdictions the VOSL used for evaluating prevention of mortality due to environmental effects is much higher than the value used for prevention of mortality due to traffic crashes.

While many countries use WTP based VOSL only limited information is available on separate values for environmental effects and transport safety. Many countries use the same value for convenience or in the absence of separate estimates. The difficulty in comparing VOSLs from overseas is that they are expressed in different currencies and also refer to prices of different years.

Table 5.1 shows the VOSLs used in different countries. To avoid complication, we converted all available values to prices in 2009, using per capita GDP as an indexing factor and then expressed them in NZ$. For better comparison between countries, exchange rate was expressed in purchasing power parity (PPP).

Table 5.1: VOSL in different countries in 2009 NZ$ PPP

Country	VOSL in 2009 NZ$ PPP	
	Transport	**Environment**
New Zealand	$3.50M	
USA	$9.0M	$11.1M
Australia	$3.2M	$7.1M
Canada	$8.0M	
UK	$3.5M	
Austria	$5.4M	
France	$2.5M	
Germany	$2.6M	

Table 5-1 shows that the air pollution VOSL adopted for our update (NZ$3.56 million in 2010) is, if anything, at the low end of the range of values adopted by overseas countries. This is especially true for those countries, such as Australia and the USA, who differentiate between a transport and an environmental VOSL.

5.5 How does the Update compare with the Original HAPINZ?

Table 5.2 compares the main features of the update and the original HAPINZ studies.

Table 5.2: Comparison of social costs used in the updated HAPINZ study versus the original HAPINZ study

Social Cost	Update	Original
Basis for costs	**NZ$ as at June 2010**	**NZ$ as at June 2004**
Premature death all cases	**$3.56 million** based on full value of Road Safety VOSL of $3.56M	**$750,000** based on discounted value of Road Safety VOSL of $2.73M
Cardiac admissions all cases	**$6,350** based on 5 days hospitalisation plus medical costs & lost productivity	**$3,675**
Respiratory admissions all cases	**$4,535** based on 3.3 days hospitalisation plus medical costs & lost productivity	**$2,700**
Restricted activity days all cases	**$62** per day irrespective of whether a working or non-working day	**$92** only estimated for working days

6. Results and Discussion

6.1 National Impacts

6.1.1 Overall

Table 6.1 presents the health impacts of air pollution for New Zealand in 2006 by source and effect (costs in NZ$ as at June 2010).

Table 6.1: Total air pollution health impacts for New Zealand in 2006 by source and effect

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	653	255	123	139	1,136	2,307	8,211
Premature Mortality (babies)	2	1	0	1	5	9	31
Cardiac Admissions (all)	131	51	21	29	217	449	3
Respiratory Admissions (all)	203	91	34	47	356	731	3
Restricted Activity Days (all)	817,600	352,300	128,900	187,700	1,440,000	2,926,500	181
Total Social Costs ($million)							**8,429**

Note the social costs can be pro-rated across the table by source.

The primary health impact resulting from air pollution (in terms of social costs) is premature mortality in adults. More than 2,300 New Zealanders are estimated to die prematurely each year due to exposure to PM_{10} pollution from all sources, with just over half associated with anthropogenic (human-caused) sources.

The total health impacts associated with **anthropogenic air pollution** in New Zealand each year are:

- 1,175 premature deaths in adults and babies
- 607 extra hospital admissions for respiratory and cardiac illnesses
- 1.49 million restricted activity days (days on which people cannot do the things they might otherwise have done if air pollution was not present).

Table 6.2 presents the social costs of air pollution for New Zealand in 2006 by source and effect (in NZ$ as at June 2010).

Table 6.2: Total air pollution costs for New Zealand in 2006 by source

Health Effect	Social Costs by Source ($million)						Anthropogenic Fraction
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	2,324	909	440	494	4,046	8,211	51%
Premature Mortality (babies)	8	3	1	2	17	31	46%
Cardiac Admissions (all)	1	0	0	0	1	3	52%
Respiratory Admissions (all)	1	0	0	0	2	3	51%
Restricted Activity Days (all)	51	22	8	12	89	181	51%
Total	**2,385**	**934**	**449**	**508**	**4,155**	**8,429**	**51%**

As with the health impacts, just over half of the social costs from air pollution are associated with anthropogenic sources.

Nationally, the dominant anthropogenic source is domestic fires (used for home heating in winter) followed by motor vehicles and appreciable contributions from open burning and industry.

The total social costs associated with **anthropogenic air pollution** in New Zealand are estimated to be $4.28 billion per year or $1,061 per person, with the following contributions attributed to each source:

- 56 per cent due to domestic fires
- 22 per cent due to motor vehicles
- 10 per cent due to industry
- 12 per cent due to open burning.

6.1.2 By Population Subgroup

Table 6.3 presents the health impacts of air pollution in New Zealand in 2006 for key population sub-group outcomes by source (costs in NZ$ as at June 2010).

Table 6.3: Total air pollution health impacts and costs for New Zealand in 2006 by source and effect for key population subgroups

Health Effect	Cases per Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	653	255	123	139	1,136	2,307	8,211
Premature Mortality (Māori adults)	105	41	19	31	228	422	1,504
Respiratory Admissions (all)	203	91	34	47	356	731	3
Respiratory Admissions (children 1-4)	67.5	31.5	11.4	15.7	121.5	247.6	1
Respiratory Admissions (children 5-14)	41.6	18.4	6.9	9.9	75.0	151.8	1

Note these health effects are a sub-group of the shaded categories and should not be added on to the health effects or costs as this would be ‘double-counting’.

Māori are disproportionately represented in the adult premature mortality figures (18.3 per cent of deaths, but are only 8.7 per cent of adult population). However, this is not unexpected because the exposure-response function for Māori is nearly three times that of the whole adult population.

For the respiratory hospital admissions, one third of the cases occur in children aged 1 to 4 years – again a disproportionate effect given the population in that sub-group.

6.2 Regional and Local Impacts

Detailed results by region, TLA, airshed and Statistics NZ urban area are summarised in Appendix 1.

6.2.1 Variation in Anthropogenic versus Natural Fraction

Overall for New Zealand, the anthropogenic fraction of the air pollution health impacts is just over half, at 51 per cent on average. However, this fraction varies with the scale of the area under assessment.

As seen in the tables in section A1-6 of Appendix 1, the anthropogenic fractions can range from 26 per cent to 76 per cent depending on the location and the resolution. Finer scales (e.g., Statistics NZ urban areas) show a greater range in values.

Urban areas tend to have a higher proportion of impacts associated with anthropogenic sources (due to a greater population density and air pollution emitting activities) than rural areas but this trend is not consistent. It should be noted that the natural contributions are estimated from source apportionment data but this information is not available for all areas. Many of the smaller locations rely on using a default value of 6.8 $\mu g/m^3$ rather than actual data and therefore may considerably under- or over-estimate the natural fraction.

6.2.2 Variation in the Relative Anthropogenic Sources

Nationally, the overall breakdown in anthropogenic air pollution health impacts is:

- 56 per cent due to domestic fires
- 22 per cent due to motor vehicles
- 12 per cent due to open burning
- 10 per cent due to industry.

On average, domestic fire impacts are 2.5 times those of motor vehicles. However, these anthropogenic proportions vary with location.

The relative contribution of each source is estimated based on the results of source apportionment studies and emission inventories. It is important to note that the accuracy of these relative contributions is limited by the accuracy of these methods. However, the results are based on the best available information and provide a good indication of relative contributions.

As seen in the tables in section A1-6 of Appendix 1, **domestic fires dominate the health impacts associated with anthropogenic air pollution in <u>every location</u> across New Zealand, <u>except</u> the Auckland region (most particularly the TLA of Auckland City where motor vehicle health impacts are nearly twice those of domestic fires).** The remaining TLAs in the Auckland region show more or less equal proportions of effects attributed to domestic fires and motor vehicles. Other TLAs which also have a higher proportion of motor vehicle emissions than the average[22] include Hamilton City, Lower Hutt City, New Plymouth District, Tauranga City, and Wellington City.

Emissions from domestic fires are on average 2.5 times greater than emissions from motor vehicle sources nationally. However, in most South Island and central North Island

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[22] The ratio of motor vehicle impacts to domestic fire impacts nationally is 39 per cent on average (= 22/55). Therefore domestic fire impacts are greater than 2.5 times those for motor vehicles on average.

locations, impacts from domestic fires are well in excess of the 2.5 average, with values from domestic fires ranging from 3.8 times greater than for motor vehicles in Christchurch City to 16 in Central Otago District (with many TLAs around 10).

Open burning is an appreciable air pollution source in all locations, rivalling motor vehicles and industry in its effects in many areas.

The effects associated with industry vary significantly across New Zealand. This is because the siting of many industries depends on access to particular resources which are not readily available in all locations.

6.3 Sensitivity Testing

Sensitivity testing was undertaken on key assumptions and for cross-checking using the scenario option in the *Health Effects Model* as follows:

- high and low values for the HiVol correction factor
- upper and lower bounds/confidence intervals for the exposure-response functions
- cross-check on adult premature mortality using $PM_{2.5}$ instead of PM_{10}
- upper and lower bounds for the cost estimates
- back-cast to 2001 to compare with 2006.

The results are presented in Appendix 2 and discussed in the following sections. The full list of default (base case) parameters with their typical ranges are listed in Table A3.1 in Appendix 3.

Note: A detailed analysis of uncertainty, often undertaken in overseas assessments of air pollution health impacts, was beyond the scope of and resources available for this update. However, the sensitivity testing undertaken in this section highlights which parameters have the most effect on the outcome of the health impacts assessment and therefore which would warrant refinement in future.

Based on the sensitivity testing, focus on refining the confidence intervals for the exposure-response-functions (for premature mortality, in particular) or the upper/lower bounds for the social cost estimates (for VOSL, in particular) would have the greatest impact on increasing confidence in the estimated impacts.

6.3.1 Effect of HiVol Correction Factor

The base case is all data adjusted for HiVol equivalency (1.0) as outlined in Chapter 4. Realistic upper (1.15) and lower (0.85) correction factors are applied to the data in the sensitivity testing. See Appendix A2.1 for detailed results.

Increasing the HiVol correction factor (i.e., increasing the PM_{10} concentration in each CAU) by 15 per cent increases the impacts by just over 13 per cent relative to the base case.

Decreasing the HiVol correction factor (i.e., decreasing the PM_{10} concentration in each CAU) by 15 per cent decreases the impacts by just under 14 per cent relative to the base case.

Overall effect: Within these two bounds, air pollution health impacts are still predicted to be between \$7.27 and \$9.56 billion (relative to the base case of \$8.43 billion).

The number of premature deaths for adults ranges between 1,989 and 2,615 (relative to the base case of 2,307).

Note: Changing the correction factor from the default of 1.0 (in the model) is only valid for those CAUs which have PM_{10} data that is not already HiVol equivalent or with a known correlation. **In reality, this only affects 16 per cent of the monitored areas and would therefore be expected to have a very minor effect overall**.

6.3.2 Effect of Exposure–Response Values

The base case uses the best estimates for all exposure-response functions/risk factors as outlined in Chapter 5. Published 95% confidence intervals or realistic upper and lower bounds for these factors are applied to the data in the sensitivity testing. See Appendix A2.2 for detailed results.

Using the highest likely values for the exposure-response functions increases the impacts by just over 38 per cent relative to the base case.

Using the lowest likely values for the exposure-response functions decreases the impacts by just over 54 per cent relative to the base case.

Overall effect: Within these two bounds, air pollution health impacts are still predicted to be between \$3.84 and \$11.67 billion (relative to the base case of \$8.43 billion).

The number of premature deaths for adults ranges between 1,046 and 3,165 (relative to the base case of 2,307).

6.3.3 Cross-check on Adult Premature Mortality Using $PM_{2.5}$

The base case uses the best estimate for adult premature mortality due to exposure to PM_{10} as outlined in Chapter 4. High (0.6) and low (0.4) proportions of PM_{10} as $PM_{2.5}$ are combined with the indicative $PM_{2.5}$ exposure-response function in the sensitivity testing as a cross-check. See Appendix A2.3 for detailed results.

Using the indicative $PM_{2.5}$ exposure-response function together and assuming $PM_{2.5}$ is 40 per cent of PM_{10} (typical of rural areas) predicts fewer premature deaths by 46 per cent than the base case using PM_{10}.

Using the indicative $PM_{2.5}$ exposure-response function together and assuming $PM_{2.5}$ is 60 per cent of PM_{10} (typical of urban areas) predicts fewer premature deaths by 21 per cent than the base case using PM_{10}.

Overall effect: Within these two bounds, the number of adult premature deaths is still predicted to be between 1,244 and 1,819 (relative to the base case using PM_{10} of 2,307).

Note: The $PM_{2.5}$ relationship used is only *indicative* yet predicts results comparable to those in the base case. Recent epidemiological research suggests that there may be separate effects for the $PM_{2.5}$ to PM_{10} fraction in addition to the $PM_{2.5}$ fraction (Brunekreef *pers. comm.* 2011). This would make the comparison even closer. Regardless, the cross-check as it stands confirms the magnitude of the effect.

6.3.4 Effect of Social Cost Estimates

The base case uses the best estimates for social costs for the range of health effects investigated as outlined in Chapter 5. Realistic upper and lower estimates for these costs are applied to the data in the sensitivity testing. **Note**: the lower estimate for VOSL is the same as the best estimate of VOSL ($3.56 million as at June 2010) whilst the upper estimate is double that at $7.12 million. See Appendix A2.4 for detailed results.

Using the upper bounds for the social cost estimates increases the impacts by just over 103 per cent relative to the base case.

Using the lower bounds for the cost estimates decreases the impacts by only 1 per cent relative to the base case.

Overall effect: Within these two bounds, air pollution social costs are still predicted to be between $8.35 and $17.16 billion (relative to the base case of $8.43 billion).

Note: The majority of the increase in the high cost scenario is due to factoring in loss of life quality due to prolonged illness and suffering which is not included in the base case. As seen in Table 5.1 many overseas jurisdictions use a specific environmental VOSL which is considerably higher than a transport (road safety) risk VOSL to adequately account for loss of life quality costs.

6.3.5 Back-cast to 2001 to Compare with 2006

Table 6.4 compares the air pollution health effects for New Zealand for 2006 (from this update) with an estimate for 2001 (using the same methodology). This scenario is based on the actual change in population and the estimated change in emissions for domestic fires and motor vehicles (industry, open burning and natural are assumed to be the same) going from 2006 to 2001 as outlined in Appendix A2.5.

All anthropogenic sources <u>except</u> motor vehicles show a predicted increase in health impacts between 2001 and 2006, largely in response to the increase in population combined with minimal or no estimated changes in emissions. The reduction in motor vehicle impacts reflects the significant and genuine improvements made in fuel quality and emissions standard requirements introduced in earnest after 2001.

Comparable improvements have occurred in domestic fire emissions in response to the introduction of the woodburner standards and various insulation and clean heat retrofit programmes with areas such as Christchurch and Nelson showing significant reductions in PM_{10} concentrations between 2001 and 2006 but changes in most areas are subsequent to 2006. The full impact of these changes is expected to be evident in any future update. This was originally intended to be based on 2011 to align with the census but the March 2011 census has now been postponed to March 2013, due to the disruption caused by the February 2011 Christchurch earthquake.

Open burning has been banned in many regions since 2006 and the impact of this source is also expected to reduce in future HAPINZ updates.

Table 6.4: Comparison of air pollution effects in 2006 versus 2001

Variable	2006	2001	Change
Population (all)	4.03 million	3.74 million	**+7.8%**
Premature Mortality (all sources)	2,316	2,181	**+6.2%**
Premature Mortality (anthropogenic only)	1,175	1,123	**+4.6%**
Total Social Costs (NZ$ at June 2010)	$8.43 billion	$7.96 billion	**+5.9%**
Social Costs (domestic fires)	$2.38 billion	$2.24 billion	**+6.3%**
Social Costs (motor vehicles)	$0.93 billion	$0.98 billion	**-5.1%**
Social Costs (industry)	$0.45 billion	$0.41 billion	**+9.8%**
Social Costs (open burning)	$0.51 billion	$0.47 billion	**+8.5%**
Social Costs (natural)	$4.15 billion	$3.86 billion	**+7.5%**

7. Conclusions and Recommendations

7.1 Key Findings

The primary health impact resulting from air pollution (in terms of social costs) is premature mortality in adults. More than 2,300 New Zealanders are estimated to die prematurely each year due to exposure to PM_{10} pollution from all sources, with just over half associated with anthropogenic sources.

The total health impacts associated with **anthropogenic air pollution** in New Zealand each year are:

- 1,175 premature deaths in adults and babies[23]
- 607 extra hospital admissions for respiratory and cardiac illnesses
- 1.49 million restricted activity days (days on which people cannot do the things they might otherwise have done if air pollution was not present).

The total social costs associated with **anthropogenic air pollution** in New Zealand are estimated to be $4.28 billion per year or $1,061 per person, with the following contributions attributed to each source:

- 56 per cent due to domestic fires
- 22 per cent due to motor vehicles
- 10 per cent due to industry
- 12 per cent due to open burning.

Domestic fires dominate the health impacts associated with anthropogenic air pollution in every location across New Zealand, except the Auckland region (most particularly in the TLA of Auckland City where motor vehicle health impacts are nearly twice those of domestic fires). However, not being able to robustly assess NO_2 exposure means that the results of this update most likely under-estimate the health impacts of motor vehicle-related air pollution.

The remaining TLAs in the Auckland region show more or less equal proportions of effects associated with domestic fires and motor vehicles. Other TLAs which are also more heavily impacted by motor vehicle emissions than the average include Hamilton City, Lower Hutt City, New Plymouth District, Tauranga City, and Wellington City.

[23] There were 28,245 deaths in New Zealand in 2006 (Census 2006), with 393 deaths resulting from road accidents.

Emissions from domestic fires are on average 2.5 times greater than emissions from motor vehicle sources nationally. However, in most South Island and central North Island locations, impacts from domestic fires are well in excess of the 2.5 average, with values from domestic fires ranging from 3.8 times greater than for motor vehicles in Christchurch City to 16 in Central Otago District (with many TLAs around 10).

Open burning is an appreciable air pollution source in all locations, rivalling motor vehicles and industry in its effects in many areas.

The effects associated with industry impacts vary significantly across New Zealand because the siting of many industries depends on access to particular resources which are often location-specific.

Māori are disproportionately represented in the adult premature mortality figures (18.3 per cent of deaths, but are only 8.7 per cent of adult population). This is not unexpected because the exposure-response function for Māori is 20%, nearly three times that of the whole adult population. However, the confidence intervals for the Māori adult and all adult response functions overlap so this finding may not be statistically significant. Regardless, it is of concern as this subgroup already experiences poorer health outcomes.

For the respiratory hospital admissions, one third of the cases occur in children aged 1 to 4 years – again a disproportionate effect given the population in that sub-group.

7.2 Policy Implications

The large fraction of health impacts associated with air pollution from natural sources is a challenge but highlights the critical importance of effective air quality policy and practices.

Air quality management can only realistically address anthropogenic sources. If nearly half of the adverse effect is associated with sources that cannot be managed then those sources that can be managed must be monitored and controlled more closely.

All anthropogenic sources except motor vehicles show a predicted increase in health effects between 2001 and 2006, largely in response to the increase in population combined with minimal or no estimated changes in emissions. The reduction in motor vehicle impacts reflects the significant and genuine improvements made in fuel quality and emissions standard requirements introduced after 2001.

Comparable improvements have occurred in domestic fire emissions in response to the introduction of the woodburner standards and various insulation and clean heat retrofit programmes but the majority of the impact occurs subsequent to 2006. However, the full impact of these changes will not be able to be quantified until the next HAPINZ update (which is likely to be after the March 2013 Census and subject to funding).

Open burning has been banned in many regions since 2006 and the impact of this source is also expected to reduce in future HAPINZ updates.

In the interim, the *Health Effects Model* developed for this update can be used to assist policy makers with designing and evaluating effective air quality management programmes.

7.3 Recommendations for Future Work

This health effects assessment was based on PM_{10} only. However, it is likely that there are separate and independent health effects resulting from other air pollutants – in particular exposure to NO_2. There would be value in designing and undertaking a **pilot NO_2 exposure assessment** in an area already identified as being impacted by motor vehicle emissions given that roadways are also the dominant source of NO_2 emissions. The most obvious location would be in the urban area of Auckland where existing continuous NO_2 monitoring data are already available and correlations may be able to be undertaken with the NZTA's national passive sampling network.

Internationally, air pollution health effect assessments are increasingly being based on $PM_{2.5}$ rather than PM_{10}. We would have preferred to use $PM_{2.5}$ in this update but there were only limited data available. **Future HAPINZ updates should consider opting for $PM_{2.5}$ but this will only be possible if additional ambient monitoring is undertaken.** Currently, New Zealand has a 'reporting only' guideline as opposed to a mandatory requirement for monitoring of $PM_{2.5}$ across the country. A number of submissions during the recent review of the national environmental standards for air quality called for the Ministry for the Environment to consider amending the current air quality regulations to include a standard for $PM_{2.5}$. A significant advantage of shifting to $PM_{2.5}$ is that it is easier to manage the sources as the majority of PM_{10} emitted by anthropogenic sources is smaller than 2.5 μm whilst the majority of natural sources of PM_{10} are within the range of 2.5 μm to 10 μm.

Open burning has emerged in this update as an appreciable air pollution source in all locations. In many areas across New Zealand, open burning effects rival those from motor vehicles and industry. However, emissions from open burning are difficult to quantify with confidence owing to difficulties in establishing the quantities of material burnt and because emission factors are sourced from overseas. **Work is needed to develop a set of robust open burning emissions factors and activity data for New Zealand so this potentially significant source can be better quantified and managed.**

A number of sources have not been included in the source apportionment because consistent emissions inventory data are unavailable. This includes emissions from shipping, aviation, rail and other off-road vehicles such as construction and agricultural vehicles. As only half of the diesel in New Zealand is used on-road, off-road diesel transport is one source that is very likely to influence emissions in urban areas and should be considered in future assessments. **Work is needed to develop a set of robust off-road transport (including vehicles, marine, and aviation) emissions factors and activity data for New Zealand so these potentially significant sources can be better quantified and managed.**

The New Zealand-specific exposure-response relationships used in this update were based on the original HAPINZ exposure model. Therefore, **we recommend that this study**

(Hales *et al*. 2010) be repeated using the 2006 exposure estimates in this report, along with appropriate mortality data from the New Zealand Census Mortality study. This research is particularly important in view of the inconclusive evidence that there are ethnic differences in sensitivity to the life-shortening effects of long term air pollution exposure (Hales *et al*. 2010). The availability of improved exposure estimates for recent years will increase the statistical power of future epidemiological studies, allowing more precise estimates of air pollution effects to be made.

The estimates undertaken in this update for the population subgroups, in particular those for Māori, indicate the potential for air pollution to further compound the effects of existing health inequalities. **More work needs to be undertaken to refine the exposure-response functions for Māori and other ethnic subgroups such as Pacific Islanders to ensure that appropriate policies are in place to minimise their air pollution risks.**

One of the critical parameters identified in the sensitivity testing that affects the outcome of any air pollution health impacts assessment is the value of statistical life (VOSL). In the absence of appropriate data, this update uses a published transport safety risk-based VOSL for the environmental risk-based VOSL. Given the likelihood that the environmental risk VOSL should be valued much higher to reflect the suffering and loss of life quality caused by air pollution (as it is in many overseas countries), **we recommend that a study be carried out to estimate the relativity between these two types of VOSL specifically for New Zealand**.

Another important issue is the loss of life quality for non-fatal cardiovascular and respiratory diseases, as well as cancer. The first two are covered in this update and therefore **we recommend that a study also be carried out to estimate the relativity between loss of life quality in serious transport injuries and these non-fatal diseases**.

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Glossary

Term	Definition
AC	Auckland Council
acute	short-term duration but severe
airshed	a geographic area established to manage air pollution within the area as defined by the AQNES
ALA	American Lung Association
anthropogenic	generated by human activities, such as the combustion of fuels or processing of raw materials
AQNES	National Environmental Standards for Air Quality
ARC	Auckland Regional Council (now known as Auckland Council)
cardiovascular	of, pertaining to, or affecting the heart and blood vessels
CAU	Census Area Unit
CHA	cardiovascular hospital admission
chronic	long-term duration or constantly recurring
CO	carbon monoxide
coarse particulate	particles in the $PM_{2.5}$ to PM_{10} fraction
COPD	chronic obstructive pulmonary disease, which includes a range of conditions such as bronchitis, chronic bronchitis, emphysema, bronchiectasis, extrinsic allegoric alveolitis, and chronic airways obstruction
domestic fire	a solid-fuel heating appliance which is intended primarily to heat a residential dwelling
fine particulate	particles in the $PM_{2.5}$fraction
HAPINZ	Health and Air Pollution in New Zealand
kaitiakitanga	in Māori culture, a kaitiaki is a guardian, and the process and practices of protecting and looking after the environment are referred to as kaitiakitanga
kg	kilogram
m	metre
MfE	Ministry for the Environment
MoH	Ministry of Health
morbidity	ill health or suffering
mortality	death
MoT	Ministry of Transport
motor vehicles	vehicles registered to travel on public roads, including cars, light commercial vehicles, trucks, buses and motorcycles
natural	generated by natural activities, such as wind-blown dust, sea spray, vegetation, animals or volcanoes

NO_2	nitrogen dioxide
NZIER	New Zealand Institute for Economic Research
NZTA	New Zealand Transport Agency
OECD	Organisation for Economic Cooperation and Development
open burning	burning of biomass and waste in the outdoors
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 µm in diameter, sometimes referred to as *fine* particulate – also known as *respirable* particulate because it deposits deeper in the gas-exchange region including the respiratory bronchioles and alveoli
PM_{10}	particulate matter less than 10 µm in diameter, includes *fine* particulate (less than 2.5 µm) and *coarse* particulate (2.5 to-10 µm) - also known as *thoracic* particulate because it deposits within the lung airways and the gas-exchange region, including the trachea, bronchi, and bronchioles
RADs	restricted activity days are days on which people cannot do the things they might otherwise have done if air pollution was not present.
respiratory	of, pertaining to, or affecting the lungs and airways
RHA	respiratory hospital admission
solid fuel	coal and wood (including wood pellets)
taonga	in Māori culture, a taonga is a treasured thing, whether tangible or intangible
TLA	Territorial Local Authority, such as city or district council
µg	microgram, one millionth of a gram
$\mu g/m^3$	microgram per cubic metre, a unit of concentration
µm	micrometre, one millionth of a metre
VKT	vehicle kilometres travelled
VOSL	value of statistical life
WHO	World Health Organization
woodburner	a domestic heating appliance that burns wood but which is not an open fire or a multifuel heater, a pellet heater or a coal burning heater or a cooking stove
WTP	willingness to pay

Appendix 1: Tables of Results

A1.1 Premature Mortality (Adults) by Region by Source

Table A1-1: Premature mortality for all adults aged 30 years and over in 2006 by source and by region

Region	Premature Mortality for all adults (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	112	126	22	31	320	611	2,177
Bay of Plenty	35	14	10	10	83	153	545
Canterbury	187	45	40	6	156	435	1,548
Gisborne	4	0	0	2	15	21	75
Hawke's Bay	41	7	9	12	44	113	402
Manawatu-Wanganui	30	7	0	11	75	123	439
Marlborough	14	2	1	5	8	31	111
Nelson	11	3	2	0	10	26	91
Northland	17	5	8	8	50	88	314
Otago	58	11	19	3	60	151	536
Southland	23	1	2	1	29	55	197
Taranaki	18	6	0	10	36	71	252
Tasman	9	1	2	0	12	25	88
Waikato	44	12	9	17	104	187	664
Wellington	43	13	0	19	122	197	701
West Coast	7	1	0	1	11	20	71
Outside	0	0	0	0	0	0	0
National	**653**	**255**	**123**	**139**	**1,136**	**2,307**	**8,211**

Table A1-1a: Premature mortality for Māori adults aged 30 years and over in 2006 by source and by region

Region	Premature Mortality for all Māori adults (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	18	20	3	5	51	97	347
Bay of Plenty	14	5	5	3	34	60	213
Canterbury	10	3	2	0	9	23	82
Gisborne	3	0	0	2	13	19	66
Hawke's Bay	13	2	2	4	14	36	126
Manawatu-Wanganui	7	1	0	2	16	27	97
Marlborough	2	0	0	1	1	3	12
Nelson	0	0	0	0	0	1	4
Northland	8	2	3	3	26	42	150
Otago	2	0	1	0	2	5	19
Southland	2	0	0	0	3	5	19
Taranaki	3	1	0	1	6	10	37
Tasman	0	0	0	0	1	1	4
Waikato	16	4	2	6	35	63	226
Wellington	6	2	0	3	16	27	96
West Coast	0	0	0	0	1	1	5
Outside	0	0	0	0	0	0	0
National	**105**	**41**	**19**	**31**	**228**	**422**	**1,504**

A1.2 Premature Mortality (Babies) by Region by Source

Table A1-2: Premature mortality for all babies aged 1 month to 1 year in 2006 by source and by region

Region	Premature Mortality for all babies (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	0.6	0.6	0.1	0.2	1.6	3.0	11
Bay of Plenty	0.1	0.0	0.0	0.0	0.3	0.6	2
Canterbury	0.4	0.1	0.1	0.0	0.4	1.0	4
Gisborne	0.0	0.0	0.0	0.0	0.1	0.1	0
Hawke’s Bay	0.1	0.0	0.0	0.0	0.1	0.3	1
Manawatu-Wanganui	0.1	0.0	0.0	0.0	0.3	0.5	2
Marlborough	0.0	0.0	0.0	0.0	0.0	0.1	0
Nelson	0.0	0.0	0.0	0.0	0.0	0.1	0
Northland	0.1	0.0	0.0	0.0	0.2	0.3	1
Otago	0.1	0.0	0.0	0.0	0.2	0.3	1
Southland	0.1	0.0	0.0	0.0	0.1	0.2	1
Taranaki	0.1	0.0	0.0	0.0	0.1	0.2	1
Tasman	0.0	0.0	0.0	0.0	0.1	0.1	0
Waikato	0.2	0.1	0.0	0.1	0.5	0.9	3
Wellington	0.2	0.0	0.0	0.1	0.6	0.9	3
West Coast	0.1	0.0	0.0	0.0	0.2	0.3	1
Outside	0.0	0.0	0.0	0.0	0.0	0.0	0
National	**2.2**	**1.0**	**0.3**	**0.6**	**4.7**	**8.8**	**31**

A1.3 Cardiac Hospital Admissions by Region by Source

Table A1-3: Cardiac hospital admissions for all New Zealanders in 2006 by source and by region

Region	Cardiac Hospital Admissions for all ages (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	25.7	28.2	3.8	7.2	70.0	134.9	1
Bay of Plenty	8.3	2.3	2.1	2.4	16.2	31.2	0
Canterbury	32.2	6.8	6.3	1.4	26.1	72.7	1
Gisborne	0.5	0.1	0.0	0.3	2.3	3.2	0
Hawke’s Bay	9.8	1.6	1.7	3.0	9.1	25.2	0
Manawatu-Wanganui	6.8	1.2	0.0	2.4	15.1	25.7	0
Marlborough	3.1	0.5	0.3	1.1	1.9	6.8	0
Nelson	2.7	0.8	0.4	0.0	2.4	6.3	0
Northland	3.9	1.2	1.6	1.8	10.0	18.4	0
Otago	11.7	2.4	2.6	0.7	10.1	27.5	0
Southland	3.5	0.1	0.2	0.2	4.3	8.4	0
Taranaki	3.0	0.9	0.0	1.7	5.5	11.3	0
Tasman	1.4	0.1	0.4	0.0	1.9	3.8	0
Waikato	8.2	2.5	1.7	3.3	18.2	33.8	0
Wellington	8.2	2.0	0.0	3.5	21.6	35.3	0
West Coast	1.8	0.1	0.0	0.3	1.9	4.1	0
Outside	0.0	0.0	0.0	0.0	0.0	0.0	0
National	**130.8**	**50.9**	**21.1**	**29.3**	**216.5**	**448.6**	**3**

A1.4 Respiratory Hospital Admissions by Region by Source

Table A1-4: Respiratory hospital admissions for all New Zealanders in 2006 by source and by region

Region	Respiratory Hospital Admissions for all ages (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	50.4	57.0	7.6	14.9	138.2	268.1	1
Bay of Plenty	14.7	3.9	4.2	3.9	27.2	53.9	0
Canterbury	47.9	10.3	9.3	1.7	39.0	108.3	1
Gisborne	1.2	0.2	0.0	0.6	5.3	7.3	0
Hawke’s Bay	11.5	1.6	2.0	3.4	10.1	28.6	0
Manawatu-Wanganui	9.6	1.7	0.0	3.4	20.9	35.6	0
Marlborough	3.0	0.5	0.3	1.0	1.8	6.5	0
Nelson	3.3	1.0	0.5	0.0	2.8	7.7	0
Northland	5.9	1.8	2.5	2.8	14.9	28.0	0
Otago	15.6	4.0	3.9	0.7	13.6	37.8	0
Southland	4.8	0.2	0.4	0.3	6.0	11.6	0
Taranaki	4.6	1.4	0.0	2.6	8.3	16.9	0
Tasman	1.4	0.1	0.4	0.1	2.1	4.2	0
Waikato	12.8	4.0	2.4	5.6	27.2	52.0	0
Wellington	13.5	3.4	0.0	6.1	35.9	58.8	0
West Coast	2.5	0.1	0.0	0.3	2.5	5.5	0
Outside	0.0	0.0	0.0	0.0	0.0	0.0	0
National	**202.7**	**91.2**	**33.5**	**47.4**	**356.0**	**730.8**	**3**

Table A1-4a: Respiratory hospital admissions for all children aged 1 to 4 years in 2006 by source and by region

Region	Respiratory Hospital Admissions for children aged 1-4 years (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	18.0	20.4	2.8	5.5	49.7	96.4	0
Bay of Plenty	5.8	1.4	1.8	1.4	10.4	20.8	0
Canterbury	16.9	3.6	3.3	0.5	13.9	38.2	0
Gisborne	0.6	0.1	0.0	0.3	2.4	3.3	0
Hawke's Bay	3.5	0.4	0.6	1.0	2.9	8.4	0
Manawatu-Wanganui	2.8	0.5	0.0	1.0	6.2	10.5	0
Marlborough	0.7	0.1	0.1	0.2	0.5	1.6	0
Nelson	1.3	0.4	0.2	0.0	1.0	2.8	0
Northland	1.7	0.5	0.7	0.8	4.5	8.3	0
Otago	3.8	0.9	0.9	0.2	3.4	9.2	0
Southland	1.7	0.1	0.1	0.1	2.1	4.1	0
Taranaki	1.1	0.4	0.0	0.6	2.1	4.2	0
Tasman	0.5	0.0	0.1	0.0	0.7	1.3	0
Waikato	3.7	1.3	0.7	1.8	8.0	15.6	0
Wellington	4.8	1.2	0.0	2.2	13.0	21.2	0
West Coast	0.7	0.0	0.0	0.1	0.7	1.6	0
Outside	0.0	0.0	0.0	0.0	0.0	0.0	0
National	**67.5**	**31.5**	**11.4**	**15.7**	**121.5**	**247.6**	**1**

Table A1-4b: Respiratory hospital admissions for all children aged 5 to 14 years in 2006 by source and by region

Region	Respiratory Hospital Admissions for children aged 5-14 years (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	10.4	11.4	1.5	3.1	28.6	55.0	0
Bay of Plenty	3.6	0.9	1.1	0.9	6.6	13.1	0
Canterbury	10.1	2.1	2.0	0.4	8.5	23.0	0
Gisborne	0.3	0.0	0.0	0.2	1.4	2.0	0
Hawke's Bay	2.5	0.3	0.4	0.7	2.1	6.1	0
Manawatu-Wanganui	1.7	0.4	0.0	0.7	3.9	6.6	0
Marlborough	0.5	0.1	0.1	0.2	0.3	1.1	0
Nelson	0.9	0.3	0.2	0.0	0.8	2.2	0
Northland	1.1	0.3	0.5	0.5	2.8	5.3	0
Otago	2.2	0.5	0.6	0.1	2.1	5.5	0
Southland	1.2	0.0	0.1	0.1	1.5	2.9	0
Taranaki	0.8	0.3	0.0	0.5	1.6	3.3	0
Tasman	0.3	0.0	0.1	0.0	0.5	1.0	0
Waikato	2.4	0.7	0.4	1.1	5.2	9.9	0
Wellington	3.2	0.8	0.0	1.4	8.5	13.9	0
West Coast	0.4	0.0	0.0	0.1	0.5	1.0	0
Outside	0.0	0.0	0.0	0.0	0.0	0.0	0
National	**41.6**	**18.4**	**6.9**	**9.9**	**75.0**	**151.8**	**1**

A1.5 Restricted Activity Days by Region by Source

Table A1-5: Restricted activity days for all New Zealanders in 2006 by source and by region

Region	Restricted Activity Days for all ages (cases)						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	191,590	214,980	30,810	55,320	534,340	1,027,050	64
Bay of Plenty	43,310	10,130	10,020	12,570	84,370	160,400	10
Canterbury	210,410	46,660	38,880	7,770	176,890	480,600	30
Gisborne	3,270	510	0	1,500	13,940	19,220	1
Hawke's Bay	45,080	6,250	7,500	13,550	44,520	116,890	7
Manawatu-Wanganui	32,810	6,350	80	12,370	74,190	125,810	8
Marlborough	12,150	1,750	1,130	4,420	9,100	28,550	2
Nelson	19,770	4,960	3,050	0	15,590	43,360	3
Northland	16,620	4,550	6,370	7,790	44,200	79,530	5
Otago	66,790	17,780	16,660	3,390	64,290	168,920	11
Southland	21,420	850	1,620	1,330	27,630	52,850	3
Taranaki	18,470	4,700	0	10,610	34,280	68,060	4
Tasman	9,040	1,020	2,460	410	13,520	26,450	2
Waikato	56,550	15,420	10,120	24,960	125,360	232,410	14
Wellington	61,810	15,840	40	30,500	168,020	276,210	17
West Coast	8,460	610	120	1,210	9,590	19,980	1
Outside	40	0	0	10	140	190	0
National	**817,580**	**352,340**	**128,860**	**187,710**	**1,439,980**	**2,926,470**	**181**

A1.6 Total Social Costs by Source

Table A1-6: Total social costs from PM_{10} air pollution in 2006 by source and by region

Region	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Auckland	1,303,029	411.8	465.7	79.0	115.0	1,181.6	2,253.1	48%
Bay of Plenty	257,382	128.8	52.4	35.9	37.6	303.0	557.7	46%
Canterbury	521,847	680.9	164.2	145.5	23.4	568.0	1,582.1	64%
Gisborne	44,508	13.2	1.5	0.0	6.5	55.8	77.0	28%
Hawke's Bay	147,777	148.1	24.3	32.7	44.4	161.4	410.9	61%
Manawatu-Wanganui	222,411	110.2	25.8	0.16	39.8	272.5	448.4	39%
Marlborough	42,564	51.2	6.5	5.3	19.6	30.7	113.2	73%
Nelson	42,897	38.9	11.9	6.4	0.0	36.6	93.8	61%
Northland	148,482	62.5	19.5	28.1	29.4	181.0	320.5	44%
Otago	193,782	212.0	40.9	67.1	11.6	216.5	548.1	61%
Southland	90,873	83.3	2.5	5.9	4.9	104.7	201.2	48%
Taranaki	104,118	65.8	22.3	0.0	36.6	131.9	256.7	49%
Tasman	44,634	32.1	3.2	9.0	1.3	44.7	90.3	50%
Waikato	382,701	161.2	43.9	33.0	62.6	381.6	682.3	44%
Wellington	448,947	156.9	48.1	0.2	70.5	445.8	721.5	38%
West Coast	31,332	27.3	2.1	0.8	4.3	38.7	73.2	47%
Outside	618	0.1	0.0	0.0	0.0	0.2	0.2	26%
National	**4,027,902**	**2,384.2**	**934.8**	**448.8**	**507.7**	**4,154.7**	**8,430.3**	**51%**

16 in total (as at 2006)

Table A1-6a: Total social costs from PM_{10} air pollution in 2006 by source and by TLA

TLA	Pop'n	Social Costs ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Ashburton District	27,375	29.0	3.1	20.5	5.8	31.5	89.9	65%
Auckland City	404,637	137.2	204.6	41.0	38.3	428.4	849.5	50%
Buller District	9,699	14.8	0.8	0.6	2.6	20.2	39.0	48%
Carterton District	7,101	2.1	1.4	0.0	0.4	9.9	13.7	28%
Central Hawke's Bay District	12,957	3.7	0.6	0.0	1.2	13.9	19.5	29%
Central Otago District	16,644	23.4	1.5	0.0	2.0	21.8	48.8	55%
Chatham Islands Territory	609	0.0	0.0	0.0	0.0	0.2	0.2	26%
Christchurch City	348,450	490.5	126.8	105.8	2.3	391.8	1,117.2	65%
Clutha District	16,836	9.0	0.4	0.1	0.9	14.0	24.5	43%
Dunedin City	118,671	145.0	35.4	65.6	2.3	133.7	381.9	65%
Far North District	55,854	20.7	4.7	0.1	6.2	67.6	99.2	32%
Franklin District	58,929	13.4	7.2	3.9	2.1	44.0	70.7	38%
Gisborne District	44,472	13.1	1.5	0.0	6.5	55.8	77.0	28%
Gore District	12,105	14.4	0.4	1.5	0.6	14.7	31.5	53%
Grey District	13,221	9.7	0.8	0.2	1.3	10.2	22.3	54%
Hamilton City	129,246	64.4	26.7	14.8	42.3	121.1	269.4	55%
Hastings District	70,833	79.3	8.8	13.0	20.2	71.4	192.6	63%
Hauraki District	17,196	2.5	0.8	5.4	0.4	16.2	25.3	36%
Horowhenua District	29,868	16.9	4.3	0.0	3.7	46.6	71.5	35%
Hurunui District	10,473	9.1	1.0	0.0	2.7	15.5	28.3	45%
Invercargill City	50,322	62.7	1.4	4.1	3.3	69.3	140.8	51%
Kaikoura District	3,624	4.3	1.4	0.0	1.6	6.2	13.4	54%
Kaipara District	18,138	4.9	1.0	0.0	1.8	20.8	28.6	27%
Kapiti Coast District	46,194	25.2	2.8	0.0	4.9	63.0	95.9	34%
Kawerau District	6,921	0.6	0.0	0.5	0.1	1.1	2.4	52%
Lower Hutt City	97,710	28.2	11.5	0.0	17.7	118.4	175.8	33%
Mackenzie District	3,801	0.6	0.1	0.0	0.2	2.1	3.0	30%
Manawatu District	28,248	18.6	5.0	0.0	4.6	43.0	71.3	40%

TLA	Pop'n	Social Costs ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Manukau City	328,956	87.8	93.2	14.9	29.6	250.2	475.8	47%
Marlborough District	42,552	51.2	6.5	5.3	19.6	30.7	113.2	73%
Masterton District	22,620	17.3	1.5	0.2	4.0	24.6	47.6	48%
Matamata-Piako District	30,471	10.6	2.6	0.2	2.6	35.4	51.5	31%
Napier City	55,365	63.7	14.5	19.7	22.6	71.1	191.6	63%
Nelson City	42,897	38.9	11.9	6.4	0.0	36.6	93.8	61%
New Plymouth District	68,892	39.1	18.0	0.0	28.4	87.4	173.0	49%
North Shore City	205,608	68.0	69.5	5.6	20.7	185.9	349.7	47%
Opotiki District	8,976	3.3	0.7	0.0	1.3	12.6	17.9	29%
Otorohanga District	9,075	2.7	0.7	0.0	0.9	11.7	15.9	27%
Palmerston North City	75,546	30.5	9.9	0.0	21.5	73.7	135.6	46%
Papakura District	45,183	18.7	18.6	2.2	4.3	52.5	96.2	45%
Porirua City	48,543	18.8	6.0	0.0	6.9	36.6	68.3	46%
Queenstown-Lakes District	22,956	4.9	0.9	0.0	0.7	12.7	19.3	34%
Rangitikei District	14,715	3.6	0.6	0.0	0.9	8.5	13.6	37%
Rodney District	89,571	25.0	18.1	7.6	3.5	80.7	134.9	40%
Rotorua District	65,901	42.6	15.1	35.2	2.6	73.9	169.5	56%
Ruapehu District	13,572	9.9	0.9	0.0	2.9	13.7	27.5	50%
Selwyn District	33,663	10.8	1.9	0.5	2.4	18.8	34.5	45%
South Taranaki District	26,484	17.9	3.3	0.0	5.7	30.5	57.5	47%
South Waikato District	22,650	19.4	2.1	8.4	4.2	24.5	58.7	58%
South Wairarapa District	8,886	5.6	0.7	0.0	1.1	14.8	22.2	33%
Southland District	28,446	6.2	0.7	0.4	1.0	20.7	29.0	29%
Stratford District	8,892	8.8	1.0	0.0	2.4	14.1	26.4	46%
Tararua District	17,634	6.3	1.8	0.0	1.3	19.9	29.3	32%
Tasman District	44,634	32.1	3.2	9.0	1.3	44.7	90.3	50%
Taupo District	32,421	21.2	4.6	0.1	3.6	39.8	69.3	43%
Tauranga City	103,638	55.4	32.7	0.0	25.3	138.1	251.5	45%
Thames-Coromandel District	25,938	11.4	1.2	0.4	2.4	40.0	55.5	28%
Timaru District	42,876	106.0	22.9	12.5	3.8	63.2	208.4	70%

TLA	Pop'n	Social Costs ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Upper Hutt City	38,418	18.8	5.5	0.0	5.7	48.7	78.7	38%
Waikato District	43,947	7.3	2.0	0.1	1.6	23.0	34.0	32%
Waimakariri District	42,825	29.4	6.6	6.1	4.4	33.7	80.2	58%
Waimate District	7,209	1.0	0.3	0.1	0.2	4.3	6.0	28%
Waipa District	42,507	16.6	2.1	3.1	3.6	52.4	77.6	33%
Wairoa District	8,475	1.4	0.4	0.0	0.4	5.0	7.2	30%
Waitakere City	186,429	65.4	55.1	3.7	17.2	151.6	292.9	48%
Waitaki District	20,223	29.7	2.7	1.4	5.8	35.1	74.8	53%
Waitomo District	9,438	1.0	0.4	0.4	0.3	3.6	5.7	37%
Wanganui District	42,621	24.4	3.2	0.0	4.9	67.0	99.5	33%
Wellington City	179,460	40.9	18.6	0.0	29.9	129.9	219.3	41%
Western Bay of Plenty District	42,072	10.6	1.9	0.0	4.1	36.5	53.1	31%
Westland District	8,412	2.7	0.4	0.0	0.5	8.3	11.9	30%
Whakatane District	33,294	16.8	2.1	0.1	4.2	42.8	66.1	35%
Whangarei District	74,460	37.0	13.8	27.9	21.4	92.6	192.8	52%
Outside	417	0.0	0.0	0.0	0.0	0.0	0.0	22%
National	**4,027,902**	**2,384.2**	**934.8**	**448.8**	**507.7**	**4,154.7**	**8,430.3**	**51%**

74 in total (as at 2006)

Table A1-6b: Total social costs from PM_{10} air pollution in 2006 by source and by airshed

Airshed	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Alexandra, Clyde & Cromwell	13,104*	19.6	0.5	0.0	1.5	9.9	31.5	69%
Arrowtown & Queenstown	15,216*	3.0	0.3	0.0	0.4	5.8	9.5	39%
Ashburton	16,833	28.3	2.9	20.4	5.6	28.2	85.4	67%
Auckland Urban	1,197,948	380.0	446.4	67.8	110.5	1,077.6	2,082.3	48%
Balclutha & Milton	11,862*	6.0	0.2	0.1	0.4	3.7	10.5	64%
Beachlands & Maraetai	5,277*	0.3	0.1	0.1	0.0	0.8	1.3	38%
Blenheim	30,549	48.2	5.9	5.1	18.9	24.5	102.6	76%
Cambridge	15,060	8.6	1.0	0.0	1.6	23.2	34.4	33%
Christchurch	348,918	482.5	125.4	102.4	0.0	380.6	1,090.8	65%
Dargaville	9,162	1.1	0.3	0.0	0.3	3.9	5.5	30%
Dunedin (North, Central & South), Green Island & Port Chalmers	97,083*	120.7	32.5	57.3	0.4	108.2	319.1	66%
Geraldine	6,336	1.6	0.3	0.1	0.6	2.4	5.0	52%
Gore	8,967	12.1	0.3	1.3	0.5	12.4	26.7	53%
Hamilton City	144,114	67.0	27.2	14.8	42.6	127.9	279.5	54%
Hastings	31,125	52.1	5.4	6.8	12.4	31.2	107.9	71%
Hawea	1,596	0.3	0.1	0.0	0.1	1.3	1.8	26%
Helensville	5,508	0.6	0.4	0.1	0.1	1.9	3.0	38%
Huntly	8,877	1.2	0.5	0.1	0.7	2.8	5.3	47%
Invercargill	44,115	62.3	1.3	4.1	3.3	67.7	138.6	51%
Kaiapoi	11,430	17.7	4.2	2.8	1.5	13.2	39.4	67%
Kaitaia	8,910	5.0	0.8	0.1	1.2	12.4	19.5	36%
Kapiti Coast	46,317	25.3	2.9	0.0	4.5	62.5	95.3	34%
Karori	14,007	5.8	0.7	0.0	3.9	12.9	23.3	45%
Kerikeri	12,051	1.2	0.2	0.0	0.3	3.3	4.9	34%
Kingston	468	0.9	0.4	0.0	0.2	4.0	5.4	26%
Kumeu & Riverhead	9,555*	4.6	4.0	0.1	0.5	8.2	17.4	53%
Lower Hutt	83,820	24.2	11.0	0.0	16.7	107.6	159.5	33%

Airshed	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Marsden Point	8,730	0.9	0.5	0.0	0.4	5.0	6.8	27%
Matamata	9,105	2.6	0.8	0.1	1.2	5.0	9.6	48%
Morrinsville	9,129	5.6	1.2	0.0	0.9	20.3	28.0	28%
Mosgiel	11,961	22.1	2.1	7.4	1.6	18.3	51.5	64%
Napier	41,358	45.0	11.5	16.1	15.6	48.8	137.0	64%
Naseby & Ranfurly	1,857*	1.8	0.2	0.0	0.2	3.5	5.7	39%
Nelson A	10,878	11.1	2.3	0.5	0.0	5.8	19.7	70%
Nelson B	21,036	18.6	6.1	3.8	0.0	19.3	47.8	60%
Nelson C	10,980	9.3	3.5	2.1	0.0	11.5	26.3	56%
Ngaruawahia	12,198	1.3	0.4	0.0	0.3	5.1	7.1	29%
Oamaru	16,386	27.8	2.2	1.4	5.3	27.1	63.8	58%
Otorohanga	8,685	1.2	0.5	0.0	0.2	5.2	7.2	27%
Paeroa	7,137	0.7	0.3	0.0	0.1	2.9	4.0	27%
Palmerston	1,572	1.6	0.5	0.0	0.4	6.6	9.0	26%
Porirua	68,478	23.9	8.9	0.0	9.5	50.7	93.0	46%
Pukekohe	17,142	6.8	3.6	2.7	1.2	20.0	34.3	42%
Putaruru	7,920	5.0	0.5	7.8	0.3	9.9	23.6	58%
Rangiora	14,742	8.3	1.6	3.3	2.0	10.7	25.9	59%
Reefton	1,269	11.3	0.1	0.4	1.9	6.8	20.5	67%
Richmond	14,319	25.4	2.3	8.9	0.2	20.8	57.5	64%
Rotorua	51,594	34.5	12.3	31.2	1.8	57.0	136.8	58%
Roxburgh	1,683	2.0	0.8	0.0	0.3	8.5	11.5	26%
Snells Beach	4,167	1.0	0.3	0.3	0.2	3.4	5.2	35%
Taihape	4,563	0.4	0.3	0.0	0.1	1.9	2.6	28%
Taumarunui	6,639	8.1	0.5	0.0	2.6	9.6	20.9	54%
Taupo	19,569	16.8	3.9	0.1	2.6	24.0	47.4	49%
Te Aroha	10,593	0.9	0.2	0.0	0.1	3.2	4.4	28%
Te Awamutu & Kihikihi	14,028*	4.0	0.4	3.0	1.5	18.4	27.3	33%
Te Kuiti	7,011	0.6	0.1	0.4	0.2	1.5	2.8	48%
Thames	10,008	3.6	0.3	0.4	0.5	12.2	17.0	28%

Airshed	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Timaru	26,892	97.5	21.6	12.3	1.6	49.8	182.8	73%
Tokoroa	13,530	14.2	1.6	0.6	3.9	14.0	34.2	59%
Tuakau	7,131	0.6	0.3	0.0	0.2	2.0	3.1	34%
Turangi	5,232	0.6	0.1	0.0	0.1	1.9	2.7	30%
Upper Hutt	35,277	17.6	5.4	0.0	5.3	46.3	74.6	38%
Waiheke Island	7,689	0.5	0.2	0.1	0.1	1.7	2.6	35%
Waihi	4,500	1.1	0.1	5.4	0.1	9.4	16.0	41%
Waikouaiti	2,376	0.1	0.1	0.0	0.0	0.5	0.6	26%
Waimate	7,032	0.2	0.1	0.1	0.0	0.8	1.3	35%
Wainuiomata	17,214	5.3	0.6	0.0	1.3	13.2	20.4	35%
Wairarapa	38,607	24.9	3.7	0.2	5.5	49.3	83.5	41%
Waiuku	10,695	1.5	0.8	0.5	0.2	4.4	7.4	41%
Wanaka	5,409	0.7	0.1	0.0	0.1	1.6	2.4	36%
Warkworth	3,270	0.3	0.5	0.0	0.1	0.7	1.6	55%
Wellington	109,224	21.2	11.0	0.0	18.5	76.4	127.1	40%
Wellsford	1,671	0.2	0.1	0.0	0.0	0.7	1.1	39%
Whangamata	3,555	0.7	0.0	0.0	0.1	2.0	2.9	29%
Whangarei	60,069	33.6	12.6	26.7	20.0	80.5	173.4	54%
Whitianga	7,938	1.0	0.4	0.0	0.3	4.5	6.2	27%
Outside	1,037,646	480.4	132.1	29.3	170.6	1,214.3	2,026.7	40%
National	**4,027,902**	**2,384.2**	**934.8**	**448.8**	**507.7**	**4,154.7**	**8,430.3**	**51%**

There are officially 71 PM_{10} airsheds in New Zealand but 76 are shown in the table because Otago 1, 2, 3 & 4 have been split into specific town airsheds.

Airsheds shown highlighted are combined either because they occupy the same CAU or because the CAUs that apply to them cannot be easily separated. The population figures marked with * have been combined.

Airsheds are defined by meshblock boundaries whereas the HAPINZ update only has resolution down to CAU boundaries so some minor adjustments have been made.

Table A1-6c: Total social costs from PM_{10} air pollution in 2006 by source and by Stats NZ urban area

Stats NZ Urban Area	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Alexandra	4,824	1.3	0.0	0.0	0.1	0.5	1.9	74%
Arrowtown	2,148	0.5	0.0	0.0	0.1	0.2	0.8	75%
Ashburton	16,833	28.3	2.9	20.4	5.6	28.2	85.4	67%
Balclutha	4,062	1.7	0.0	0.0	0.1	1.1	2.9	62%
Blenheim	28,527	49.6	6.0	5.1	19.2	23.8	103.7	77%
Bluff	1,791	0.1	0.0	0.0	0.0	0.1	0.2	38%
Brightwater	1,794	0.1	0.0	0.0	0.0	0.3	0.4	29%
Bulls	1,659	0.3	0.1	0.0	0.1	0.5	0.9	47%
Cambridge Zone	15,195	9.0	1.1	0.1	1.6	24.2	36.0	33%
Carterton	4,122	0.5	0.0	0.0	0.1	0.6	1.2	47%
Central Auckland Zone	395,964	135.3	204.2	40.9	37.5	420.3	838.2	50%
Christchurch	360,783	509.2	130.5	105.2	3.7	401.7	1,150.2	65%
Coromandel	1,476	1.9	0.1	0.0	0.2	5.5	7.7	29%
Cromwell	3,588	14.3	0.4	0.0	1.2	7.2	23.1	69%
Dannevirke	5,520	1.8	0.2	0.0	0.4	2.5	4.8	47%
Darfield	1,482	3.7	0.3	0.0	0.9	3.4	8.4	59%
Dargaville	4,455	0.5	0.0	0.0	0.1	1.0	1.6	39%
Dunedin	110,991	144.1	35.2	65.6	2.1	130.0	376.9	66%
Edgecumbe	1,626	0.5	0.0	0.0	0.1	0.8	1.4	42%
Eltham	1,980	1.1	0.1	0.0	0.3	1.4	2.9	53%
Featherston	2,343	2.2	0.1	0.0	0.4	4.0	6.6	40%
Feilding	13,887	11.8	1.7	0.0	2.9	19.2	35.5	46%
Foxton Community	4,446	0.6	0.1	0.0	0.1	0.9	1.8	47%
Geraldine	2,244	1.3	0.1	0.1	0.5	1.0	3.1	66%
Gisborne	32,535	11.2	0.9	0.0	5.9	46.8	64.8	28%
Gore	9,645	14.2	0.3	1.5	0.6	13.8	30.4	55%
Greymouth	9,672	9.1	0.7	0.2	1.2	7.9	19.2	59%
Greytown	1,998	0.4	0.0	0.0	0.1	0.8	1.3	40%

Stats NZ Urban Area	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Hamilton Zone	155,253	70.5	27.6	14.8	43.0	136.5	292.4	53%
Hanmer Springs	729	7.1	0.4	0.0	2.1	6.6	16.2	59%
Hastings Zone	62,109	78.7	8.6	13.0	20.1	69.3	189.6	63%
Hawera	10,779	12.5	2.4	0.0	4.1	16.7	35.7	53%
Helensville	2,529	0.4	0.2	0.1	0.1	1.0	1.6	40%
Hokitika	3,540	0.7	0.0	0.0	0.1	0.6	1.4	58%
Huntly	6,834	1.0	0.3	0.1	0.6	1.6	3.6	57%
Inglewood	3,090	0.7	0.1	0.0	0.2	0.8	1.8	53%
Invercargill	46,770	62.4	1.3	4.1	3.3	68.5	139.6	51%
Kaikohe	4,113	0.7	0.0	0.0	0.1	1.4	2.2	38%
Kaikoura	2,175	3.7	0.9	0.0	1.5	2.8	8.8	68%
Kaitaia	5,205	4.3	0.5	0.0	0.9	8.7	14.4	39%
Kapiti	37,344	17.4	1.8	0.0	3.0	45.6	67.8	33%
Katikati Community	3,582	1.0	0.1	0.0	0.3	2.0	3.4	42%
Kawakawa	1,347	0.1	0.0	0.0	0.0	0.3	0.5	38%
Kawerau	6,921	0.6	0.0	0.5	0.1	1.1	2.4	52%
Kerikeri	5,859	0.9	0.1	0.0	0.2	1.9	3.1	38%
Leeston	1,296	1.8	0.1	0.0	0.5	1.6	4.0	59%
Levin	19,140	11.5	1.5	0.0	2.7	25.8	41.5	38%
Lincoln	2,727	0.7	0.1	0.0	0.2	0.7	1.8	60%
Lower Hutt Zone	97,158	27.8	11.4	0.0	17.5	116.7	173.5	33%
Manaia	924	0.3	0.0	0.0	0.1	0.4	0.9	53%
Mangakino	1,020	0.2	0.0	0.0	0.0	0.4	0.7	42%
Martinborough	1,326	1.1	0.0	0.0	0.2	1.9	3.2	40%
Marton	4,680	2.3	0.1	0.0	0.5	3.2	6.1	47%
Masterton	19,491	17.1	1.4	0.2	4.0	23.8	46.5	49%
Matamata	6,306	2.4	0.6	0.1	1.1	4.3	8.6	50%
Milton	1,884	4.1	0.1	0.1	0.2	1.5	5.9	75%
Moerewa	1,533	0.9	0.1	0.0	0.2	1.9	3.0	38%
Morrinsville	6,603	3.8	0.1	0.0	0.5	11.1	15.6	29%

Stats NZ Urban Area	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Motueka	7,128	3.4	0.2	0.1	0.3	10.6	14.6	27%
Murupara	1,836	4.5	0.2	0.0	0.8	7.6	13.1	42%
Napier Zone	56,295	64.1	14.5	19.7	22.7	72.0	192.9	63%
Nelson	56,370	64.2	14.1	15.2	0.2	57.3	151.1	62%
New Plymouth	49,272	30.7	16.5	0.0	25.8	68.8	141.8	51%
Northern Auckland Zone	248,121	79.7	79.2	10.2	22.7	230.0	421.9	45%
Oamaru	12,681	27.6	2.1	1.4	5.3	26.0	62.4	58%
Ohakune	1,101	0.4	0.0	0.0	0.1	0.5	1.0	47%
Opotiki	4,176	1.1	0.1	0.0	0.3	2.0	3.5	42%
Opunake	1,365	1.5	0.1	0.0	0.4	1.8	3.8	53%
Otaki	5,466	7.5	0.7	0.0	1.4	14.3	23.9	40%
Otorohanga	2,589	0.3	0.0	0.0	0.0	0.8	1.2	29%
Oxford	1,716	0.8	0.1	0.0	0.2	0.7	1.7	59%
Paeroa	3,978	0.3	0.0	0.0	0.0	0.9	1.2	29%
Pahiatua	2,562	1.3	0.1	0.0	0.2	2.4	3.9	40%
Paihia	1,770	0.5	0.1	0.0	0.2	1.1	1.8	38%
Palmerston North	76,035	33.7	11.9	0.0	22.1	80.8	148.6	46%
Patea	1,143	0.3	0.0	0.0	0.1	0.3	0.7	53%
Picton	4,083	0.3	0.0	0.0	0.0	0.9	1.3	28%
Pleasant Point	1,170	0.5	0.0	0.0	0.1	0.4	1.1	59%
Porirua Zone	48,393	18.8	5.9	0.0	6.9	36.1	67.7	47%
Pukekohe	22,512	7.2	3.7	2.7	1.3	20.7	35.6	42%
Putaruru	3,768	4.8	0.3	7.8	0.3	8.4	21.5	61%
Queenstown	10,422	2.5	0.3	0.0	0.3	5.2	8.2	37%
Raetihi	1,035	0.7	0.0	0.0	0.1	1.0	1.8	47%
Raglan	2,637	1.1	0.0	0.0	0.1	3.2	4.5	29%
Rangiora	11,865	8.2	1.5	3.3	2.0	10.0	25.0	60%
Reefton	948	11.3	0.1	0.4	1.9	6.8	20.4	67%
Riverton	1,512	0.5	0.0	0.0	0.0	2.0	2.5	21%
Rolleston	3,822	0.8	0.1	0.0	0.3	0.9	2.1	59%

Stats NZ Urban Area	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Rotorua	53,769	40.9	14.4	35.2	2.2	65.8	158.4	58%
Russell	819	4.3	0.3	0.0	0.9	8.8	14.3	38%
Shannon	1,368	1.6	0.2	0.0	0.3	2.3	4.4	47%
Snells Beach	3,234	0.1	0.0	0.0	0.0	0.2	0.3	38%
Southern Auckland Zone	371,649	105.9	111.5	17.1	33.8	300.6	568.9	47%
Stratford	5,337	7.8	0.4	0.0	2.2	9.2	19.7	53%
Taihape	1,788	0.1	0.0	0.0	0.0	0.1	0.2	50%
Taipa Bay-Mangonui	1,566	1.3	0.2	0.0	0.4	3.0	4.8	38%
Tairua	1,266	2.3	0.1	0.0	0.3	6.6	9.2	29%
Takaka	1,152	0.8	0.0	0.1	0.1	2.6	3.7	29%
Taumarunui	5,055	8.1	0.5	0.0	2.6	9.3	20.5	55%
Taupo	21,297	18.3	3.9	0.1	2.7	28.2	53.2	47%
Tauranga	108,888	57.1	32.8	0.0	25.7	140.7	256.4	45%
Te Anau	1,899	0.0	0.0	0.0	0.0	0.3	0.4	6%
Te Aroha	3,768	0.6	0.0	0.0	0.0	1.6	2.2	29%
Te Awamutu Zone	14,457	4.1	0.4	3.0	1.5	18.5	27.5	33%
Te Kuiti	4,419	0.5	0.0	0.4	0.2	0.7	1.7	61%
Te Puke Community	7,080	2.3	0.4	0.0	0.6	4.6	7.8	42%
Temuka	4,044	5.2	0.5	0.0	1.2	4.7	11.5	59%
Thames	6,756	3.5	0.3	0.4	0.5	11.5	16.1	29%
Timaru	26,892	97.5	21.6	12.3	1.6	49.8	182.8	73%
Tokoroa	13,530	14.2	1.6	0.6	3.9	14.0	34.2	59%
Turangi	3,240	0.5	0.0	0.0	0.1	1.2	1.8	31%
Twizel Community	1,017	0.2	0.0	0.0	0.0	0.1	0.3	59%
Upper Hutt Zone	36,405	18.2	4.7	0.0	5.6	44.1	72.5	39%
Waiheke Island	7,689	0.5	0.2	0.1	0.1	1.7	2.6	35%
Waihi	4,500	1.1	0.1	5.4	0.1	9.4	16.0	41%
Waihi Beach	1,776	0.2	0.0	0.0	0.1	0.5	0.8	42%
Waimate	2,835	0.1	0.0	0.1	0.0	0.1	0.3	59%
Waiouru	1,383	0.3	0.0	0.0	0.0	0.4	0.8	48%

Stats NZ Urban Area	Pop'n	Social Costs by Source ($million)						Anthropogenic Fraction
		Dom Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Waipawa	1,926	0.5	0.0	0.0	0.1	0.7	1.3	50%
Waipukurau	4,008	0.2	0.0	0.0	0.1	0.3	0.6	50%
Wairoa	4,272	0.4	0.0	0.0	0.1	0.6	1.2	50%
Waitara	6,291	5.5	0.4	0.0	1.8	6.8	14.5	53%
Waiuku	7,725	3.5	0.5	0.3	0.5	9.6	14.4	33%
Wakefield	1,878	0.3	0.0	0.0	0.0	1.0	1.4	27%
Wanaka	5,040	0.7	0.1	0.0	0.1	1.5	2.4	37%
Wanganui	38,973	24.1	3.1	0.0	4.8	65.7	97.7	33%
Warkworth	3,270	0.3	0.5	0.0	0.1	0.7	1.6	55%
Wellington Zone	178,671	40.4	18.5	0.0	29.8	128.0	216.7	41%
Wellsford	1,671	0.2	0.1	0.0	0.0	0.7	1.1	39%
Western Auckland Zone	192,327	71.3	59.8	4.2	17.8	164.3	317.4	48%
Westport	3,900	0.2	0.0	0.0	0.0	0.1	0.3	58%
Whakatane	18,207	9.6	1.2	0.1	2.6	24.1	37.6	36%
Whangamata	3,555	0.7	0.0	0.0	0.1	2.0	2.9	29%
Whangarei	49,080	32.2	12.1	27.9	19.6	69.4	161.1	57%
Whitianga	3,768	0.2	0.0	0.0	0.0	0.5	0.6	29%
Winton	2,088	0.9	0.0	0.0	0.1	1.2	2.3	46%
Woodend	2,616	0.4	0.0	0.0	0.1	0.4	0.9	59%
Outside (Rural)	564,726	125.5	47.1	8.7	34.9	556.1	772.3	28%
National	**4,027,902**	**2,384.2**	**934.8**	**448.8**	**507.7**	**4,154.7**	**8,430.3**	**51%**

139 areas in total = 138 urban areas and one amalgamated area (designated rural) for everything else.

The above table does not include Oceanic islands outside these areas.

Appendix 2: Sensitivity Analyses

A2.1 Effect of HiVol Corrections

Table A2-1a: Effect of low (0.85) HiVol correction factor

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	564	220	107	119	979	1,989	7,082
Premature Mortality (babies)	1.9	0.8	0.3	0.5	4.0	8	27
Cardiac Admissions (all)	111.4	43.3	18.0	24.9	184.3	382	2
Respiratory Admissions (all)	172.7	77.7	28.6	40.3	303.3	623	3
Restricted Activity Days (all)	694,940	299,490	109,530	159,550	1,223,980	2,487,500	154
Total Social Costs ($million)							7,268

Note: This scenario sets the PM correction factor to 0.85 for <u>all</u> CAUs which will significantly <u>under</u>-estimate the total health effects.
In reality, the correction factor only applies to those CAUs which are not already HiVol equivalent.

Table A2-1b: Effects of high (1.15) HiVol correction factor

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	739	289	140	157	1,290	2,615	9,309
Premature Mortality (babies)	2.5	1.1	0.3	0.7	5.4	10	36
Cardiac Admissions (all)	150.2	58.4	24.3	33.6	248.6	515	3
Respiratory Admissions (all)	232.5	104.6	38.5	54.4	408.5	838	4
Restricted Activity Days (all)	940,220	405,190	148,180	215,870	1,655,970	3,365,440	209
Total Social Costs ($million)							9,561

Note: This scenario sets the PM correction factor to 1.15 for <u>all</u> CAUs which will significantly <u>over</u>-estimate the total health effects.
In reality, the correction factor only applies to those CAUs which are not already HiVol equivalent.

A2.2 Effect of Exposure-Response Values

Table A2-2a: Effect of low exposure-response values

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	297	116	57	63	514	1,046	3,724
Premature Mortality (babies)	0.9	0.4	0.1	0.2	2.0	4	13
Cardiac Admissions (all)	65.7	25.6	10.6	14.7	108.7	225	1
Respiratory Admissions (all)	122.4	55.0	20.3	28.6	214.8	441	2
Restricted Activity Days (all)	454,210	195,750	71,590	104,280	799,990	1,625,820	101
Total Social Costs ($million)							3,841

Note: This scenario uses the lower bounds or confidence intervals for all of the exposure-response functions

Table A2-2b: Effect of high exposure-response values

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	893	350	168	191	1,563	3,165	11,268
Premature Mortality (babies)	3.4	1.5	0.5	0.9	7.2	13	48
Cardiac Admissions (all)	195.3	75.9	31.5	43.7	323.3	670	4
Respiratory Admissions (all)	340.7	153.3	56.3	79.7	599.1	1,229	6
Restricted Activity Days (all)	1,544,320	665,540	243,400	354,570	2,719,960	5,527,770	343
Total Social Costs ($million)							11,669

Note: This scenario uses the upper bounds or confidence intervals for all of the exposure-response functions

A2.3 Cross-check of Mortality Effects using $PM_{2.5}$

Table A2-3a: Cross check of adult mortality based on $PM_{2.5}$ assuming 0.4

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	353	138	67	75	611	1,244	4,430

Note: This scenario increases the response function for premature mortality to 0.09 and corrects the PM_{10} concentrations by 0.4 to reflect the proportion of $PM_{2.5}$ typical for rural areas which will be a potential under-estimate of total effects.

Note also: The splits shown will not be accurate as the proportions of $PM_{2.5}$ in natural versus anthropogenic sources vary greatly.

Table A2-3b: Cross check of adult mortality based on $PM_{2.5}$ assuming 0.6

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	516	202	98	109	895	1,819	6,477

Note: This scenario increases the response function for premature mortality to 0.09 and corrects the PM_{10} concentrations by 0.6 to reflect the proportion of $PM_{2.5}$ typical for urban areas which will be a potential over-estimate of total effects.

Note also: The splits shown will not be accurate as the proportions of $PM_{2.5}$ in natural versus anthropogenic sources vary greatly.

A2.4 Effect of Cost Estimates

Table A2-4a: Effect of low cost estimates

New Zealand	Social Costs ($million)						Anthropogenic Fraction
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	2,324	909	440	494	4,046	8,211	51%
Premature Mortality (babies)	8	3	1	2	17	31	46%
Cardiac Admissions (all)	1	0	0	0	1	3	52%
Respiratory Admissions (all)	1	0	0	0	2	3	51%
Restricted Activity Days (all)	28	12	4	6	49	100	51%
Total	2,362	924	445	502	4,115	8,348	51%

Note: This scenario uses the lower bounds or confidence intervals for all of the cost estimates and is likely to be an under-estimate of the total costs because loss of life quality due to prolonged pain and suffering is not included.

Table A2-4b: Effect of high cost estimates

New Zealand	Social Costs ($million)						Anthropogenic Fraction
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	4,648	1,818	879	987	8,092	16,423	51%
Premature Mortality (babies)	16	7	2	4	34	63	46%
Cardiac Admissions (all)	47	18	8	10	77	160	52%
Respiratory Admissions (all)	72	33	12	17	127	260	51%
Restricted Activity Days (all)	71	31	11	16	125	255	51%
Total	4,854	1,907	912	1,034	8,455	17,161	51%

Note: This scenario uses the upper bounds or confidence intervals for all of the cost estimates and does include loss of life quality due to prolonged pain and suffering.

A2.5 Estimate of 2001 Air Pollution Health Impacts

Table A2-5: Estimate of total air pollution health impacts for New Zealand in 2001 using the update methodology

Health Effect	Cases by Source						Social Costs ($million)
	Domestic Fires	Motor Vehicles	Industry	Open Burning	Natural	Total	
Premature Mortality (adults)	611	267	113	128	1,054	2,173	7,737
Premature Mortality (babies)	2.3	1.0	0.4	0.5	4.0	8.3	30
Cardiac Admissions (all)	119.1	52.1	22.0	25.0	205.3	423.3	3
Respiratory Admissions (all)	193.8	84.8	35.9	40.7	334.4	689.5	3
Restricted Activity Days (all)	836,320	343,940	154,760	175,600	1,443,470	2,976,220	185
Total Social Costs ($million)							7,958

Note: This scenario is based on the actual change in population and the estimated change in emissions for domestic fires and motor vehicles (industry, open burning and natural are assumed to be the same) going from 2006 to 2001.

Based on the census data, the population is multiplied by 0.928 relative to 2006.

Based on the number of households and the proportion using wood, domestic fires emissions are assumed to increase by 1.011 relative to 2006. Based on the total fleet travel and the average fleet emission factors, motor vehicle emissions are assumed to increase by 1.123 relative to 2006. With the other emissions kept the same, total PM_{10} emissions are therefore assumed to increase by 1.017 relative to 2006.

This results in estimated splits for 2001 of 28.1% domestic fires, 12.3% motor vehicles, 5.2% industry, 5.9% open burning, and 48.5% natural as shown above.

Appendix 3: Users' Guide to the Health Effects Model

The *Health Effects Model* consists of the following worksheets:

About This Model

1 Introduction

2 Base case Input

3 Scenario Input

4 Base case Output

5 Scenario Output

6 Comparison

7 Base case Results

8 Scenario Results

9 All Base Data

Report Tables - Base case

Maps

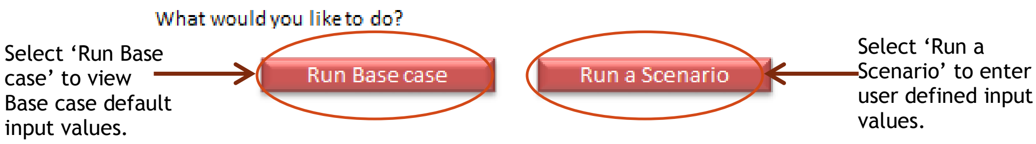
About This Model

The *Health Effects Model* opens with an 'About This Model' page. This page lists the organisations who commissioned and funded the project, those who assisted in providing the base data, and the project team members who developed the model.

Click on the 'Next' button to proceed to the Introduction page.

1 Introduction

The Introduction page provides a brief background and outline of the structure of the model and allows users to select whether to run base case analysis or select a scenario by requesting a response to:



Select 'Run Base case' to view the base case inputs (this proceeds to **2 Base case Input**) and then run the model or 'Run a Scenario' to select user-defined inputs and then run the model (proceeds to **3 Scenario Input**).

2 Base case Input

All base case input values used to run a base case analysis are displayed and **input values cannot be changed** by the user. An error message is displayed if a value is entered on this page.

Input values for PM_{10} and population are multipliers but are set to a default value of 1.00 for the base case analysis (as the base case analysis is for the set year of 2006 with set PM_{10} data).

Click on 'Run Base case' to run the model. When the run is complete, the model will go to **4 Base case Output** and display the results.

3 Scenario Input

In this sheet, a user can define the input values to run their own scenarios. For example, this function could be used by Councils to assess the likely change in health costs resulting from emission reduction scenarios[24].

As with the Base case Input, input values for PM_{10} and population are multipliers and the user can set different values for the scenario. For example, if a PM_{10} value of 1.20 is set, this will increase the PM_{10} concentrations by 20 per cent. Similarly, if a high population scenario is to be assessed, the user can set a value of 2.00 for population which will double the 2006 base population.

Click on 'Run Scenario' to run the model. When the run is complete, the model will go to **5 Scenario Output** and display the results.

4 Base case Output

This sheet displays the summary base case output table. The default results presented are the national results. Results can be selected by region, TLA, airshed or urban area (as defined by Stats NZ).

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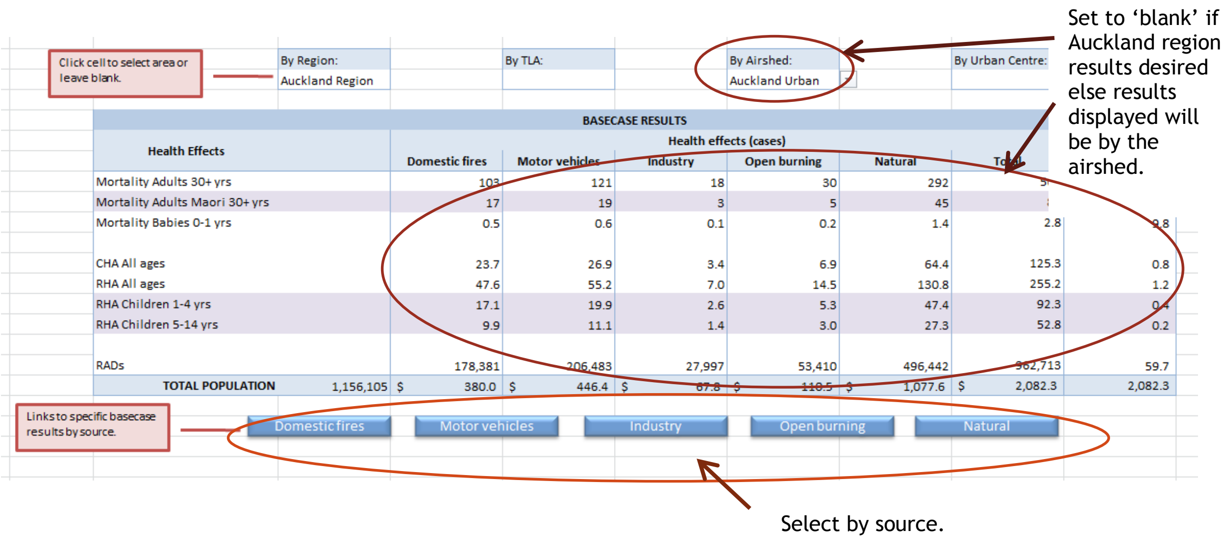
[24] It is important to note that the *Health Effects Model* is based on annual average PM_{10} concentrations. The model does not directly allow users to estimate the effect of changes in 24 hour average concentrations (e.g., to meet the requirements of the National Environmental Standard for PM_{10}). However, this could be undertaken in locations where the relationship between peak 24 hour average concentrations and annual average concentration has been estimated.

To select by specific area, click in the desired box and select area from the drop down menu. Note: a dropdown menu does not appear automatically. The cell must be selected first.

A dependent selection is not available in this model, so **only one area type can be selected at a time**. For example, if the user has viewed results for the Auckland Urban airshed, and wants to view results for the Auckland region, the airshed field must be cleared (set to blank).

The blank option for each area selection is the first option in the drop down menu (the text 'blank' does not actually appear).



BASECASE RESULTS								
Health Effects		Health effects (cases)						
		Domestic fires	Motor vehicles	Industry	Open burning	Natural	Total	
Mortality Adults 30+ yrs		103	121	18	30	292	[illegible]	
Mortality Adults Maori 30+ yrs		17	19	3	5	45	[illegible]	
Mortality Babies 0-1 yrs		0.5	0.6	0.1	0.2	1.4	2.8	9.8
CHA All ages		23.7	26.9	3.4	6.9	64.4	125.3	0.8
RHA All ages		47.6	55.2	7.0	14.5	130.8	255.2	1.2
RHA Children 1-4 yrs		17.1	19.9	2.6	5.3	47.4	92.3	0.4
RHA Children 5-14 yrs		9.9	11.1	1.4	3.0	27.3	52.8	0.2
RADs		178,381	206,483	27,997	53,410	496,442	962,713	59.7
TOTAL POPULATION	1,156,105	$ 380.0	$ 446.4	$ 67.8	$ 110.5	$ 1,077.6	$ 2,082.3	2,082.3

Options are also provided to view detailed base case results by specific source as indicated above.

Note: Some airsheds have been combined together due to the size of the underlying census area unit (CAU) with two exceptions:

- Te Awamutu & Kihikihi –is actually one airshed in reality
- Dunedin – is not an airshed but is named as such in this model and includes the actual airsheds of North Dunedin, Central Dunedin, South Dunedin, Green Island and Port Chalmers.

5 Scenario Output

This sheet displays the summary scenario output table. Functionality and conditions are the same as those presented in **4 Base case Output**.

If no scenario is selected, then the base case results are presented by default.

6 Comparison

This sheet presents both the summary base case and scenario output tables on the same page for comparison. Results displayed here are the same as those displayed in **4 Base case Output** and **5 Scenario Output**.

Note: To compare results the user must ensure that the areas selected in the Base case Output table and the Scenario Output table are the same.

7 Base case Results

This sheet presents the results and calculations performed in the model for the base case analysis by CAU. Health effects and costs are also broken down by source contribution on this page.

Note: Results are presented by CAU but the detail shown (e.g., decimal places) implies a level of accuracy which is not necessarily justifiable and therefore must be treated with caution. Data are imported from the *Exposure Model*, which uses ambient monitoring, source apportionment studies and emission inventories to estimate PM_{10} concentrations by source by CAU. The exposure data are then multiplied by population information, exposure-response functions and costs estimates in the *Health Effects Model* to determine air pollution health impacts by source by CAU.

Results can be filtered by region, TLA, airshed or urban centre to view the each CAU's result for the selection. A 'filtered total' and 'national total' summary is provided at the bottom of the sheet to compare summary results between the selection and national results.

8 Scenario Results

This sheet presents the results and calculations performed in the model for the scenario analysis. Health effects and costs are also broken down by source contribution on this page as per the **7 Base case Results**.

Note: Results are presented by CAU and the same caution as with **7 Base case Results** applies.

Note: Results can be filtered using the same parameters as indicated in **7 Base case Results**.

9 All Base Data

All base data used for all calculations are presented on this page.

- Population data obtained from Census 2006, Statistics New Zealand.
- Health data and base incidence rates are the three year average of data provided by Ministry of Health.
- PM_{10} concentrations are from the *Exposure Model*

Note: Statistics New Zealand do not supply data for CAUs where confidentiality may be breached. Data for these CAUs are represented with a '..C'. For the purposes of the model calculations, when this occurs, the data are assumed to be zero.

Note: For the premature mortality cases related to babies, information on the total cases is only available as a national total. To get estimates by CAU, the national total has been pro-rated by the number of babies in each CAU over the total number of babies nationally. These numbers have been multiplied by the population weighted annual average concentrations but only for the 0-1 year population.

Report Tables - Base case

This page contains all the tables for the base case presented in the *Updated Health and Air Pollution in New Zealand Study Volume 1 - Summary Report*. These tables are only provided as a reference and **cannot be changed.**

Maps

The following section outlines the steps required to create a map using the data from the *Health Effects Model* (from sheets '7 Base case Results' and '8 Scenario Results').

1. Obtain the spatial file of the 2006 Census from Statistics New Zealand, or from your organisation's GIS team.

Prepare the Excel table

1. Tidy up data in sheets '7 Base case Results' or '8 Scenario Results' from the *Health Effects Model* by deleting all the extra information from the table that is not required.

Tip: Copy and paste into a new Excel workbook the Base case or Scenario Output sheets. Ensure to paste special as 'values' in the new workbook so that none of the original data is lost and the formulas are not embedded into this sheet.

2. Remove any blank rows or columns, including any between the heading and data.
3. Ensure each column has a heading. This will correspond as the *field name* in GIS. Headings cannot have spaces, cannot start with a number and must be 10 characters or less.

4. Do NOT delete the Census Area Unit Code (2006 Areas) column. These numbers will be needed to match the data in the Excel file with the GIS spatial file. Sort the numbers in ascending order.
5. Remove all formatting in the table and save the file (.xls or .xlsx).

Adding the Excel Table to ArcMap

1. In ArcMap, click the **Add Data** button, browse to the location of the Excel file and double click the name.
2. Choose the data sheet to add (usually the first sheet on the list) and click **Add**.
3. **Open** the **attribute table** for both the Excel file and the 2006 Census spatial layer.
4. Check that the CAU number column in the data table matches the content a column in the spatial layer. The heading names do not need to match, but the content in each column does need to match. The data in the table will be joined using this common column.

Join the Excel Table to the Spatial Layer

1. **Right-click** on the 2006 Census spatial data.
2. From the menu, in **Joins and Relates**, click **Join**.
3. The **Join Data** dialog box appears.
4. At '**What do you want to join to this layer?**' Select **Join attributes from a table** from the drop down menu.
5. Select the following at:

   '1. Choose the field this layer that the join will be based on:'

   Select the field name of the data in the 2006 Census spatial layer that matches the data in the Excel table.

   '2. Choose the table to join to this layer, or load the table from disk:'

   Select the sheet of the Excel file (usually Sheet 1 which will appear as Sheet1$)

   '3. Choose the field in the table to base the join on:'

   Select the column name from the Excel table which matches that of the 2006 Census spatial layer.
6. Under **Join Options**, select the **Keep all records** option.

Verify that the Join worked

1. Right click the 2006 Census spatial data.
2. Click **Open Attribute Table**
3. Scroll to the right of the attribute table to check if the columns from the Excel file have been added.

Creating a map

1. Right click on the spatial layer in ArcMap.
2. Select **Properties** from the drop down menu.
3. In the **Symbology** tab, under **Show**, click **Quantities** then click **Graduated colors**.
4. In the ‘Fields’ section, at ‘Value’, choose a field from the 2006 Census spatial file to be displayed on the map from the drop down menu. Leave the normalization field blank.
5. This will display the data in five classification breaks using ‘Natural Breaks (Jenks)’ classification as the default. This can be changed by clicking on **Classify** and selecting another classification option.
6. Click **OK**.

The data should be displayed by CAU in ArcMap. Additional data can be added to the map in Map Layout (such as legend, scale, map title etc.).

Range of Values for Sensitivity Analysis

A list of the range of values available to the user in the Scenario Input page, and those used in the Sensitivity Analysis are listed below.

Table A3-1: Default values and typical ranges for the parameters used in the Health Effects Model

PM_{10} Data		Default Value	Typical Range
1	Data as supplied by councils and corrected for HiVol equivalency	1.00	(0.85-1.15)
2	Population data as per 2006 Census	1.00	(1.00-1.00)
Health Outcomes		**Default Value**	**Typical Range**
3	Premature mortality, all adults (30 yrs +) per 10 μg/m^3 annual PM_{10}	0.07	(0.03-0.10)
3a	Premature mortality, Maori adults (30 yrs +) per 10 μg/m^3 annual PM_{10}	0.20	(0.07-0.33)
4	Premature mortality, all children (0-1 yrs) per 10 μg/m^3 annual PM_{10}	0.05	(0.02-0.08)
5	Cardiac hospital admissions, all ages per 10 μg/m^3 daily PM_{10}	0.006	(0.003-0.009)
6	Respiratory hospital admissions, all ages per 10 μg/m^3 daily PM_{10}	0.01	(0.006-0.017)
6a	Respiratory hospital admissions, all children (1-4 yrs) per 10 μg/m^3 daily PM_{10}	0.02	(0.01-0.04)
6b	Respiratory hospital admissions, all children (5-14 yrs) per 10 μg/m^3 daily PM_{10}	0.03	(0.00-0.05)
7	Restricted activity days, all ages per 10 μg/m^3 daily $PM_{2.5}$	0.9	(0.5-1.7)
Social Costs (in NZ$ as at June 2011)		**Default Value**	**Typical Range**
8	Premature mortality, all adults (30 yrs +) per 10 μg/m^3 annual PM_{10}	$3.56M	($3.56M-$7.12M)
8a	Premature mortality, Maori adults (30 yrs +) per 10 μg/m^3 annual PM_{10}	$3.56M	($3.56M-$7.12M)
9	Premature mortality, all children (0-1 yrs) per 10 μg/m^3 annual PM_{10}	$3.56M	($3.56M-$7.12M)
10	Cardiac hospital admissions, all ages per 10 μg/m^3 daily PM_{10}	$6,350	($6,350-$356,000)
11	Respiratory hospital admissions, all ages per 10 μg/m^3 daily PM_{10}	$4,535	($4,535-$356,000)
11a	Respiratory hospital admissions, all children (1-4 yrs) per 10 μg/m^3 daily PM_{10}	$4,535	($4,535-$356,000)
11b	Respiratory hospital admissions, all children (5-14 yrs) per 10 μg/m^3 daily PM_{10}	$4,535	($4,535-$356,000)
12	Restricted activity days, all ages per 10 μg/m^3 daily $PM_{2.5}$	$62	($34-$87)