NIWA
Taihoro Nukurangi

Indicators for Environmental Domain Reporting

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Executive summary

The Ministry for the Environment (MfE) is working in conjunction with Statistics New Zealand to produce a series of indicators for reporting across several environmental domains. Air quality is one of those domains. In order to produce effective indicators, MfE requires up-to-date information on the state and impacts of air quality and the pressures on it. Specifically, this includes the current concentrations of PM_{10} in New Zealand, the total estimated health costs of poor air quality in New Zealand's towns and cities, the total emissions from New Zealand's traffic and the contribution of natural sources to PM_{10}.

This report defines five indicators intended to be used in MfE's Air Domain report. There are three indicators of pressure: a national road vehicles emission inventory, contribution of natural sources of PM_{10} and meteorological conditions relevant to air quality. There is one indicator of state: the national average PM_{10} concentration, and one indicator of impact: health outcomes and costs from anthropogenic PM_{10}.

This report identifies data sources and provides the method for quantification of the indicators. Results are presented for the year 2012 (represented by the 2013 census). Results for the preceding 6 years (in the case of PM_{10} state and impact) or 12 years (in the case of the meteorological indicator and vehicle emissions) are also evaluated to provide context and commentary. Comparisons are also made with the results of the 2012 Update of the Health and Air Pollution in New Zealand (HAPINZ) study, upon which much of this work is based.

Two of the indicators are presented with the recommendation that the data with which they are calculated is insufficient to fully meet criteria set down by MfE and Stats NZ, and further research is necessary to ensure their robustness in future updates. They are considered interim indicators in this report. They are the Indicator of pressure: meteorological conditions and Indicator of pressure: contribution of natural sources.

The indicators for the 2014 Air Domain report are:

	Indicator	2012 Value
Indicator of Pressure:	National road vehicle emissions inventory	
	Carbon Monoxide (CO)	177 Gg[1]
	Carbon Dioxide (CO_2)	9,467 Gg
	Volatile Organic Compounds (VOC)	10 Gg
	Nitrogen Oxides (NO_x)	30 Gg
	Particulate Matter (PM_{10})	1.9 Gg
	Particulate Matter ($PM_{2.5}$)	1.8 Gg
	Vehicle Kilometres Travelled (VKT)	39,971 Km
Indicator of State:	Population weighted annual mean PM_{10} concentrations	15.6 $\mu g\ m^{-3}$
Indicator of impact:	Estimated number of health incidents related to PM_{10} exposure:	
	Mortality Adults age 30+	1003 cases
	Mortality Adults Maori age 30+	160 cases
	Mortality Babies age 0 – 1	3.4 cases
	Cardiac Hospital Admissions: All ages	197 cases
	Respiratory Hospital Admissions: All ages	319 cases
	Restricted Activity Days	1,348,479 days

The development of this work has led to the identification of areas for improvement in the generation of these indicators for future Domain reports. Recommendations for further research and development are provided in section 7 of the report.

[1] 1 Gg is equivalent to 1 kilotonne, or 1,000,000 kg

1 Introduction

The Ministry for the Environment (MfE) is working in conjunction with Statistics New Zealand (Stats NZ) to produce a series of indicators for reporting across several environmental domains. Air quality is one of those domains. These indicators fall into three categories:

- Indicators of Pressure, which describe the human activities and natural processes that influence the environment,
- Indicators of State, which describe the biophysical condition of the environment and how this is changing over time,
- Indicators of Impact, which explain what the State and changes in the State mean in terms of consequences for New Zealand society.

Five indicators are intended to be used in MfE and Stats NZ's Air Domain report:

- three Indicators of Pressure:
  - a national road vehicles emission inventory,
  - contribution of natural sources of PM_{10},
  - meteorological conditions relevant to air quality
- one Indicator of State:
  - the national average PM_{10} concentration
- one Indicator of Impact:
  - health outcomes and costs from anthropogenic PM_{10}.

In order to produce effective indicators, MfE and Stats NZ requires up-to-date information on the state and costs of air quality. Specifically, the current concentrations of PM_{10} in New Zealand, the total estimated health costs of poor air quality in New Zealand's towns and cities, the total emissions from New Zealand's traffic and the contribution of natural sources to PM_{10}.

1.1 Scope of this report

The objectives of this work are to create three deliverables and a supporting report documenting the key statistics, method, assumptions and limitations for each deliverable. The deliverables are:

1. An update of the Health and Air Pollution in New Zealand (HAPINZ) model using 2012/13 data, including:
   - the public health effects impact (premature deaths, hospital admissions and restricted activity days) from anthropogenic sources only. This is to be a single figure for each component and not apportioned to the different anthropogenic sources,

- the public health effects costs (hospital admissions and restricted activity days, where restricted activity days relate to the cost of lost work days) from anthropogenic sources only. This is to be a single figure for each component and not apportioned to the different anthropogenic sources,
- a national annual average concentration of PM_{10}, as well as a spatial breakdown of PM_{10} concentrations,
- a comparison of the public health impacts and the national annual average concentration of PM_{10} over time. This comparison would be in a manner that provides an accurate comparison. The comparison would consider and document the reasons for any change - for example, whether it is due to changes in exposure due to population growth or changes in concentrations, the Canterbury earthquakes, etc.

2. A vehicle emissions inventory, showing changes in emissions, and the parameters feeding into the emissions, over time. The inventory is to cover the key ambient air quality pollutants produced from transport.
3. The quantification of the contribution natural sources make to PM_{10} concentrations, at a national level including regional examples where appropriate.

MfE's requirements for each are:

- Uncertainty estimates are to be included for each of the estimates in deliverables.
- Commentary on how much uncertainty is acceptable for the deliverable to be classified as an indicator or indicator component (based on expert judgement) is to be included in the report on each deliverable.
- All estimates are to be produced in line with the Ministry's draft indicator criteria, which will be provided to NIWA.

A supplementary task is to assess the feasibility of an indicator of the impact meteorological conditions have on air quality, specifically PM_{10} concentrations. That work is presented as a separate report (Somervell *et al*., 2014), the outcome of which is summarised here in Chapter 4.

1.2 Criteria

MfE and Statistics NZ list the following criteria for judging the suitability of indicators (Table 1-1).

Table 1-1: Criteria for judging the suitability of indicators. From Statistics New Zealand.

Criteria	Descriptor
Relevance	The degree to which the statistical product meets user needs in coverage, content and detail.
Accuracy	The degree to which the information correctly describes the phenomena it was designed to measure.
Timeliness	The degree to which data produced are up to date, published frequently and delivered to schedule.
Accessibility	The ease with which users are able to access and understand the statistical data and its supporting information.
Coherence/consistency	The degree to which statistical information can be successfully brought together with other statistical information within a broad analytical framework and over time.
Interpretability	The availability of supplementary information and metadata necessary to interpret and use the statistics effectively.

The criteria are intended to ensure that an indicator is both robust and representative. One of the overriding aims of this work is that a national air quality indicator should be representative of what it is intending to report on. Representativeness aims to ensure that the indicator is underpinned by a statistically valid dataset. This does not mean every site needs to be measured (as this is impractical in most circumstances), but that measured sites can be demonstrated to provide sufficient coverage of the phenomena under consideration.

The criteria Relevance and Accuracy are considered mandatory criteria and must always be met by an indicator included in the domain report. Of the remaining four criteria (Timeliness, Accessibility, Consistency and Interpretability) at least three must be partially met. This standard allows for the inclusion of realistically limited datasets and a way to track improvement or refinement of the indicators over time.

To allow an easy assessment of whether the indicators presented in this report meet the criteria, they have been listed in Appendix F. A traffic light colour coding has been applied: green = criteria met, amber = criteria partially met, red = criteria not met (see Figure 1-1). Each indicator included in the domain report must be green for Relevance and Accuracy and must have at least three oranges among the other criteria. As can be seen by Appendix F, all the indicators recommended for the domain report exceed this standard.

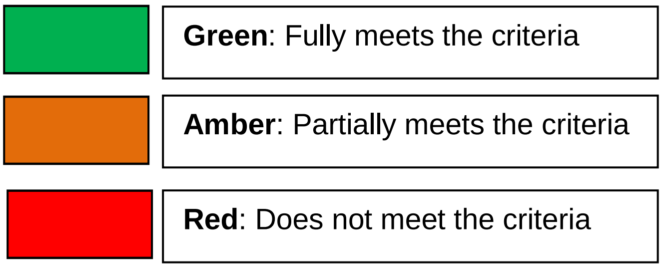


Figure 1-1: The traffic light system to interpret how indicators meet the criteria.

A consequence of this is that data or a method which may not in itself be robust enough to generate an indicator alone may, through incorporation with other data, be able to contribute to the generation of another indicator. It is a matter of the extent to which the indicator as a whole is dependent upon that data.

All data used in this report has been supplied by third parties and the authors have taken it on trust that appropriate quality assurance has been applied. The methods and calculations used by NIWA have been internally and externally reviewed and the report has met all of NIWA's quality assurance requirements.

1.3 The structure of this report

This report describes five indicators for use in MfE's air quality domain report. Each indicator is described in one chapter and one appendix, with the exception of the meteorological indicator, which has a chapter in this report and an independent report (Somervell *et al*., 2014).

Chapters two to six each describe and report an indicator and follow the same general structure:

1. Defining the indicator
2. Documenting data sources
3. Describing the method used to calculate the indicator
4. Commentary on how the indicator meets MfE's criteria for indicators
5. Reporting the results for the indicator for 2012
6. The limitations and assumptions that should be kept in mind
7. Commentary for future updates of the indicator.

Chapter seven summarises the recommendations to develop or strengthen the indicators for future domain reports and to facilitate updates.

The appendices offer detailed commentary for each indicator on the calculation, assumptions made and sensitivity analyses performed. They highlight where improvements may be made for future reporting.

2 Indicator: National road vehicle emissions inventory

2.1 The indicator

The indicator chosen to represent the pressure from the national road vehicle fleet on the quality of the air in the country is **total annual emissions [Gg/yr]**[2] **of selected primary pollutants (CO, CO_2, VOC, NO_x, PM_{10} and $PM_{2.5}$) from road transport**. This indicator is based on the vehicle travel statistics (MoT indicator TV001), fleet composition (MoT indicator TV034), vehicle speed (MoT indicator SS008) and congestion (MoT indicator NR002) as inputs to the Vehicle Emission Prediction Model (VEPM), which is the best available information in New Zealand.

2.2 Data sources

A description of the data used in this indicator follows:

Vehicle travel statistics (TV001). Annual estimate of the road vehicle kilometres travelled (VKT) from odometer readings at warrant or certificate of fitness. The indicator's metadata indicates that the national totals are the best VKT estimates available. The regional estimates suffer from variability in maintenance cycles and are not as accurate, nor internally consistent as the national estimate (Stuart Badger - MoT, pers. comm. 20-Dec-2013).

http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv001/

Fleet composition (TV034). Annual estimate of the VKT from odometer readings, classified by fuel and vehicle type. The vehicle types that are used here broadly correspond to the classifications used by VEPM for light duty vehicles but only a single estimate is available for heavy duty vehicles.

http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv034/

Vehicle speed (SS008). Observed unimpeded speed choice by car drivers on open (100km/h speed limit) and urban (50 km/h speed limit) roads. It is used to estimate the actual speed that vehicles travel in areas without congestion.

http://www.transport.govt.nz/ourwork/tmif/safetyandsecurity/ss008/

Congestion (NR002). Observed reliability of travel time (Congestion index) as minutes delay per km of travel, compared to travel at the speed limit in the surveyed area.

http://www.transport.govt.nz/ourwork/tmif/networkreliability/nr002/

Vehicle Emission Prediction Model (VEPM). Average speed emission **model** that predicts emission factors under typical road, traffic and operating conditions for a given New Zealand fleet-year. It provides **estimates** of CO, VOC, NO_x, CO_2 and PM based on international emission factor databases and New Zealand information. It corresponds to the best available source of emission factor estimates for the New Zealand fleet.

http://air.nzta.govt.nz/predictions/nz-vepm

[2] Gg/yr is equivalent to Kilotonne/yr. Gg is used here as it is the SI unit.

2.3 Method

Full details of how to generate this indicator can be found in Appendix A and the accompanying spreadsheets but in simple terms, the indicator is calculated by multiplying the vehicle kilometres travelled (VKT) for the vehicle types by the estimated emission factor (EF) for that vehicle class and the corresponding average speed. National VKT data is taken directly from the TV001 indicator that comes from warrant of fitness data. Regional estimates, which come from the Road Assessment and Maintenance Management (RAMM) data, are scaled to the TV001 data for consistency. Fleet composition is also taken directly from TV034. For the regional estimates, the vehicle fleet composition is assumed to be constant.

The travel speed is estimated in two steps. First, indicator SS008 gives the non-congested speed both for urban (50 km/hr) and open (100 km/hr) roads. This unimpeded speed is corrected applying the congestion index (NR002) to estimate the **congested speed** of the vehicles in **urban roads**. The congestion index is calculated as the VKT weighted average of the regional congestion index and applied to both light and heavy vehicles.

The fleet composition and speed is then used with VEPM to predict the vehicle emission factors that are then used with the VKT to estimate the total emissions for the different pollutants.

2.4 Does the indicator meet MfE criteria?

We consider that this indicator meets all of the criteria set by MfE. The data used in this indicator provide complete and consistent national coverage and are regularly updated by the NZTA and the Ministry of Transport. Thus, the data are guaranteed to be timely, available and accessible to the widest possible audience. The accuracy of the indicator is limited by the accuracy of the Vehicle Emission Prediction Model and the assumptions about the vehicle fleet, however, given it aligns with international best practice, regularly updated to include new research and is based on/validated real life testing the accuracy is considered appropriate to meet the indicator criteria. VEPM provides the best information available on vehicle emission factors in New Zealand and the use of odometer readings provides the best, nationally consistent, information available. Finally, the indicator is compatible with those used internationally and reported in the scientific literature[3].

2.5 Results

Table 2-1 shows the total VKT and emissions for 2009-2012 and the percentage change between 2001 and 2012. In general, over the past ten years, even though vehicle travel has increased by 11%, the total emissions from road transport have decreased between 25% and 50% with the exception of CO_2 which has increased by more than 10%. However, during the last four years, when VKT have barely changed, emissions of CO, NO_X, VOC and PM have decreased by only 20% while CO_2 emissions have stopped increasing and have reduced by 3%. Figure 2-1 shows the ten year time series of estimated VKT and road transport emissions for CO_2, CO, VOC, NO_X and PM.

[3] http://www.epa.gov/ttn/chief/trends/index.html#tables
http://www.eea.europa.eu/publications/air-quality-in-europe-2013

Table 2-1: Annual estimates for VKT (million vehicle kilometres) and emissions from road transport in Gg (10^9g) and percentage change between 2001 and 2012.

Species	2001 [Gg]	2009 [Gg]	2010 [Gg]	2011 [Gg]	2012 [Gg]	Change from 2001 to 2012
Carbon Monoxide (CO)	290	227	213	187	177	-39%
Carbon Dioxide (CO_2)	8,354	9,705	9,651	9,476	9,467	+13%
Volatile Organic Compounds (VOC)	20	13	12	11	10	-49%
Nitrogen Oxides (NO_x)	46	33	32	31	30	-36%
Particulate Matter (PM_{10})	2.6	2.2	2.1	2.0	1.9	-25%
Particulate Matter ($PM_{2.5}$)	2.2	2.1	2.0	1.9	1.8	-26%
Vehicle Kilometres Travelled (VKT)	36,168	39,997	39,951	39,674	39,971	+11%

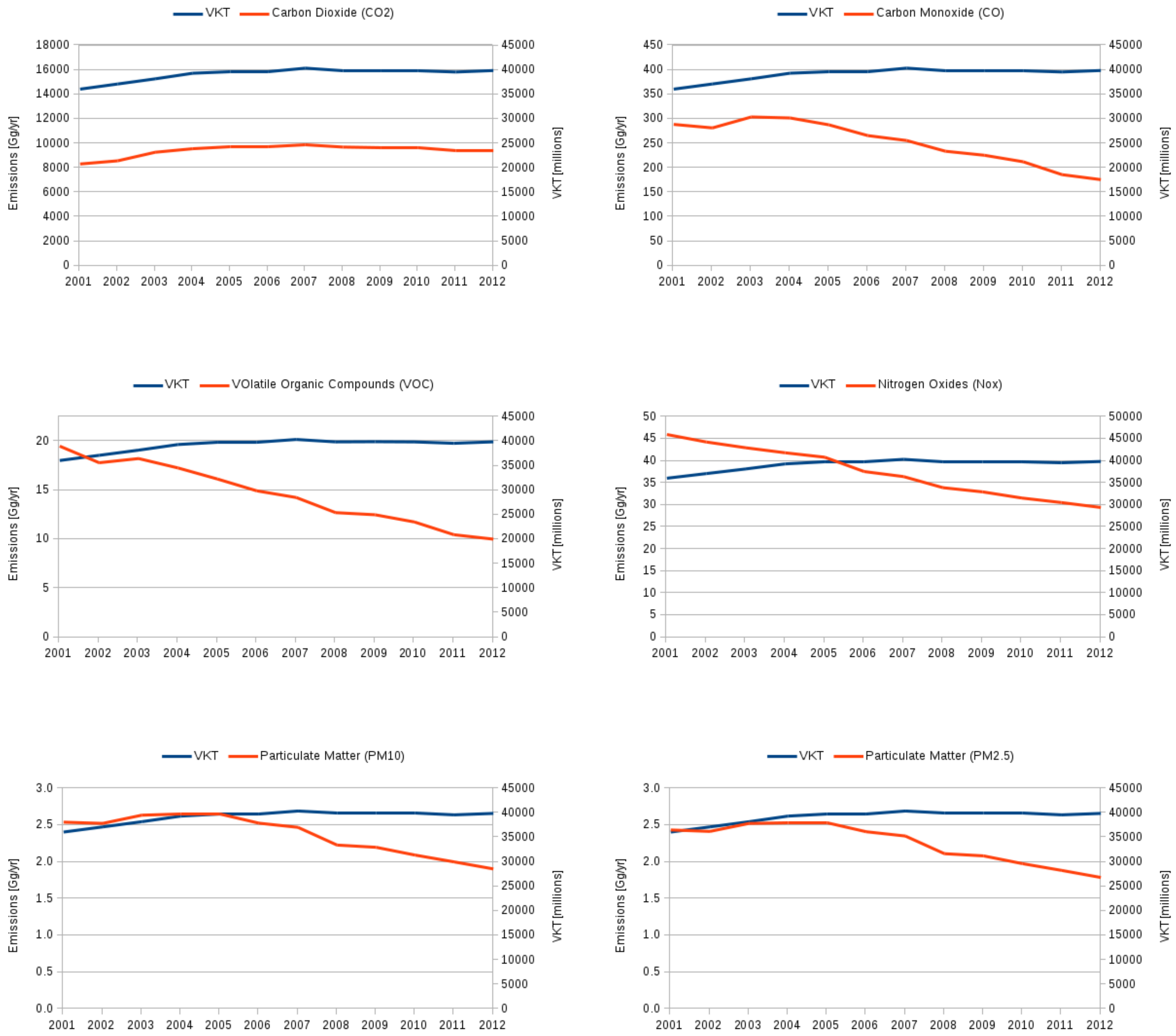
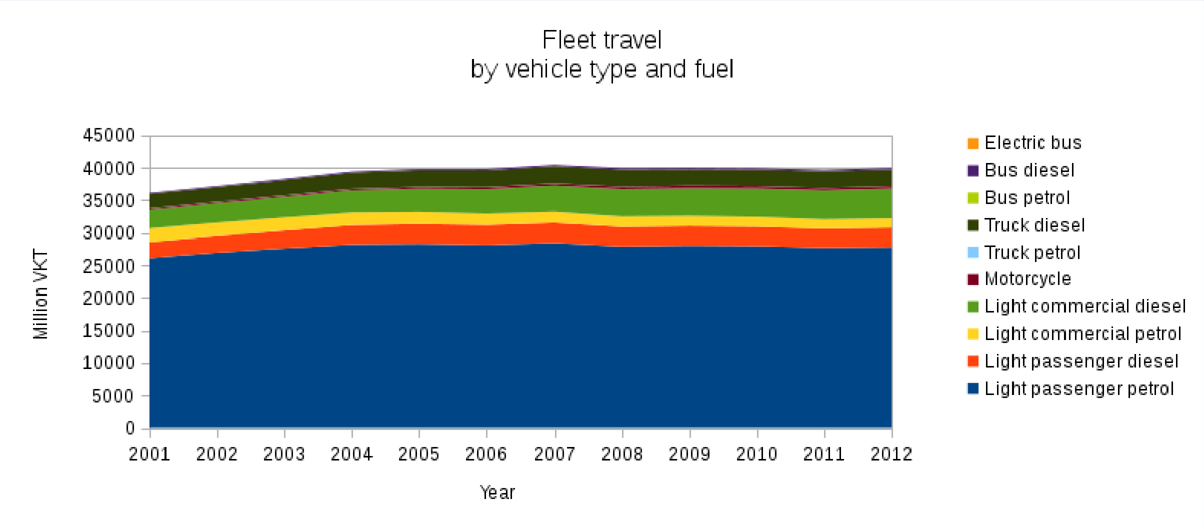


Figure 2-1: Ten year time series of national VKT and road transport emissions.

Technological advances have had a significant impact on the emissions of individual vehicles, therefore even though there have been significant increases in VKT during the past decade, the total emissions have still decreased.

The determinants of the total road transport emissions are the fleet travel (VKT) and its composition. Figure 2-2 shows that since 2001 most vehicle classes have increased their kilometres travelled, except light commercial **petrol** vehicles that have decreased their travel by 35%. This has been offset by the 65% increase in light commercial **diesel** vehicle travel. Private travel has increased less than 10% since 2001 but most of that increase has been due to a shift towards **diesel** vehicles that have increased their travel by almost 25%. However, focusing on the past four years, with the exception of bus and light commercial vehicles, the national VKT have remained constant (less than 1% change).



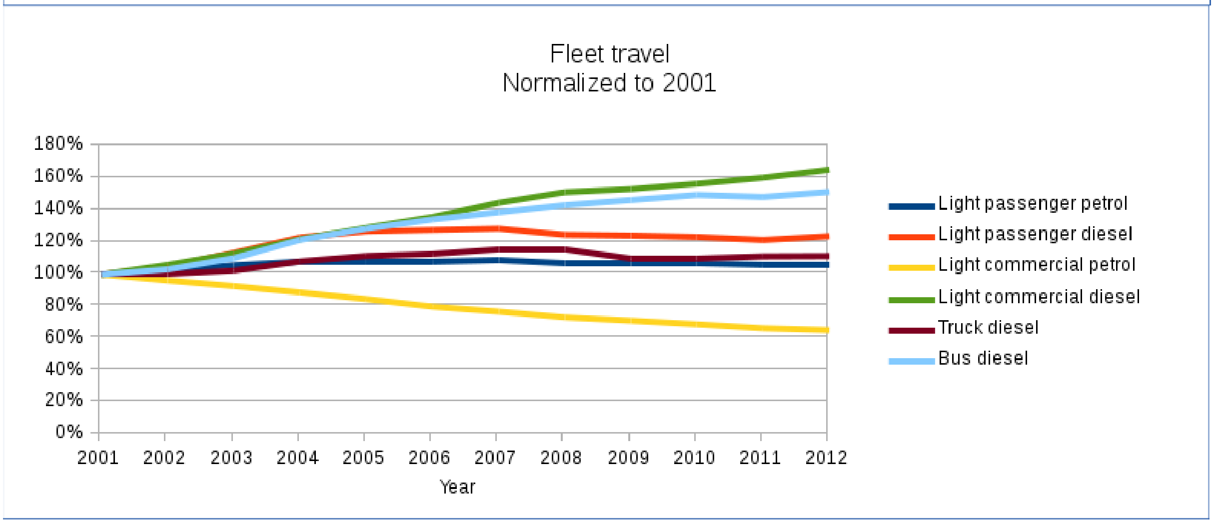


Figure 2-2: Vehicle kilometres travelled time series as function of vehicle type.

VEPM provides separate estimates for exhaust PM (as $PM_{2.5}$) and brake/tyre wear PM (size selectable and reported here as PM_{10}). VEPM's documentation includes the size distribution of tyre and brake wear particles and therefore $PM_{2.5}$ emissions are calculated adding the exhaust contribution to 70% of the tyre/brake wear. The total PM_{10} emissions are calculated as the $PM_{2.5}$ emissions plus the remaining 30% of the tyre/brake wear emissions.

Both PM_{10} and $PM_{2.5}$ total emissions have decreased markedly over the past decade, particularly since 2005 but the relative contribution of the different vehicle classes has changed (Figure 2-3). Heavy duty diesel vehicles continue to dominate the PM_{10} emissions but their contribution has decreased from 35% of PM_{10} in 2001 (36% for $PM_{2.5}$) to 29% in 2012 (30% for $PM_{2.5}$). The contribution of light petrol vehicles has increased from around 16% (13% for $PM_{2.5}$) in 2001 to 21% (18% for $PM_{2.5}$) in 2012. This may be related to the increased age of the light fleet as reported by the MoT (indicator TV006) which drives the emission factor calculation within VEPM.

The second largest change in the fleet contribution is that of light duty diesel vehicles (private and commercial) to $PM_{2.5}$. Even though their combined contribution remains ~50% for both

PM_{10} and $PM_{2.5}$, since 2001, there has been a shift towards light duty diesel **commercial** vehicles that has offset the decrease in the contribution of light duty diesel **private** vehicles.

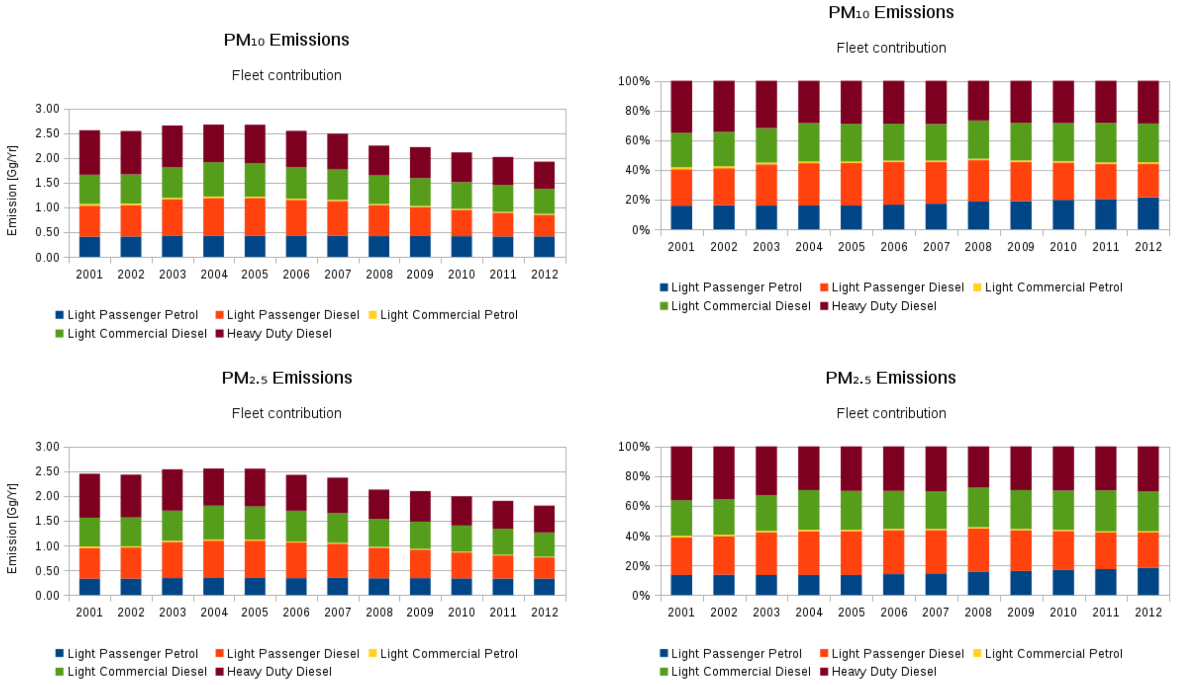


Figure 2-3: Time series of total PM emissions as function of vehicle type. Left - estimated emissions (Gg/yr), Right - as % of total emissions.

For NO_X, Figure 2-4 shows that the reduction in total emissions has been due primarily to the change in the relative contribution of the vehicle classes. The light petrol fleet (private plus commercial) has decreased its emissions by 54% since 2001 and hence its contribution to the total emissions from around 60% in 2001 to 43% in 2012. On the other hand, the light diesel fleet (private plus commercial) has only reduced its emissions by 3% which means that it increased its contribution from 12% in 2001 to 19% in 2012.

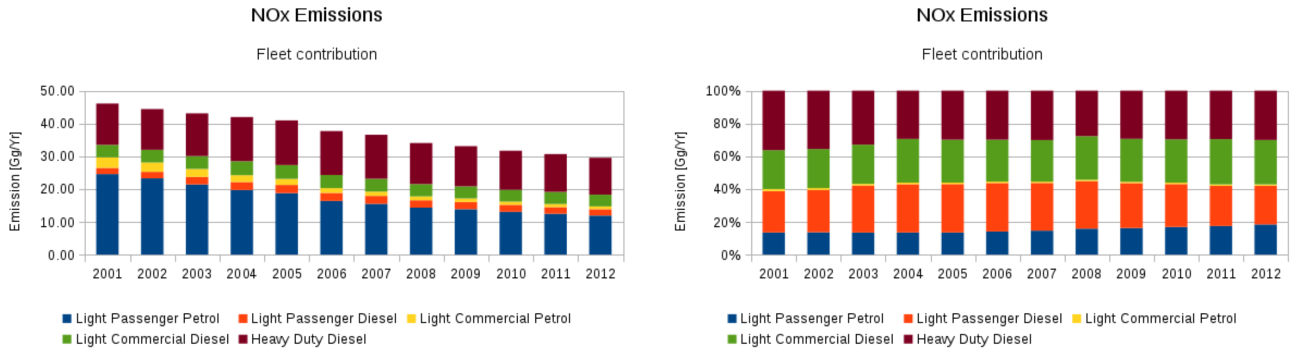


Figure 2-4: Time series of total NOx emissions as function of vehicle type. Left - estimated emissions (Gg/yr), Right - as % of total emissions.

The analysis of the regional contributions is difficult because of the issues in the underlying VKT information. For some regions, particularly Northland, Gisborne, Tasman-Marlborough and West Coast, there was a significant increase in the reported VKT between 2002 and 2003 (up to 60% increase) that is due to changes in the operation of the RAMM data (Stuart Badger - MoT, pers. comm. 20-Dec-2013). These issues do not affect the national estimates as they come from a different data source (WOF) that is more robust and reliable.

After 2004, all the regions have followed the same trends in terms of their emissions with Wellington region leading the decrease in emissions primarily due to a drop in the VKT for the region.

The accompanying workbooks ("inputs vehicle emissions" and "outputs vehicle emissions") contain all the information to generate these plots for all the pollutants and all the regional detail.

2.6 Limitations and Assumptions

The main assumptions in the emission inventory are:

The vehicle fleet is the same in all the regions. From an emissions perspective it is vehicle travel that determines the impact of a vehicle and therefore the indicator VT001 was used as a national estimate of the vehicle fleet weighted by travel, i.e. the sum of the vehicle-kilometres travelled by different vehicle classes. In absence of equivalent regional information, this was used to describe the vehicle fleet everywhere. In the future, if efforts are made to make the use of the RAMM data more uniform and robust, these estimates can be revised.

The open road speed from the speed survey is only descriptive of highway traffic but urban traffic speed needs to take account of congestion. The most consistent information about congestion comes from the NR002 indicator for urban areas. The spatial coverage of this congestion indicator is small but it does cover more than 60% of the VKT and it focuses on the areas where congestion is most significant. If more information about congestion delays is obtained in future surveys, it can be incorporated into the calculations.

This work assumes that the VEPM accurately describes the emissions of the New Zealand vehicle fleet. Some work has been undertaken comparing VEPM with on-road emissions measurements (see Bluett *et al.*, 2013, Auckland Council (2012) and an unpublished report from the NZTA – Metcalfe & Bluett, 2012). These show **reasonably good agreement** between the overall emissions of the fleet measured and the VEPM predictions, however Bluett *et al.* conclude that "despite the encouraging results, the comparison suggests a need to improve our understanding of the relationship between modelled and real-world vehicle fleet emissions."

VEPM is currently the best available source for New Zealand vehicle emission factors and is regularly updated incorporating latest international research where appropriate. . Appendix F summarises how this indicator meets MfE and Stats NZ's criteria for indicators.

2.7 Future updates of the indicator

The raw data on which this indicator depends is routinely generated on a regular basis. Future updates should consider automation of the update process, so that that the indicator can be automatically recalculated each time new data becomes available.

3 Indicator of Pressure: Contribution of natural processes to PM_{10}

3.1 The indicator

A substantial proportion of PM_{10} concentrations is derived from entirely natural processes and sources, independently of any human activity. MfE has expressed the desire to have an indicator informing the topic of the pressure that emissions unrelated to human activity place on PM_{10} concentrations in New Zealand. Natural sources of particles are sea-salt, windblown dust, bushfires, volcanoes, pollens and other biogenic material. Although the potential health effects of such particles cannot be separated from the total effects of PM_{10} they are sources beyond the control of management or abatement strategies. Estimating the health costs of pollutants from anthropogenic sources (see chapter 6), which can be managed, requires that they are separated from natural sources.

The recommended indicator component is **the average contribution of natural processes to PM_{10} ($\mu g\ m^{-3}$)**.

3.2 Data sources

The current indicator has been derived entirely from data provided by GNS Science (*Pers. comm*. Dr Perry Davy, December 2013). The data is derived from chemical source apportionment analyses of particles collected on filter samples at 18 locations in 12 towns or cities since 2000. With the exception of Auckland these data are non-continuous and limited to campaigns of varying duration (ranging from single winters to several years) and sampling frequency (ranging from hourly to every sixth day). In Auckland data has been derived continuously (every third day) from 6 sites since 2006 (5 since 2007). The data is described in further detail in Appendix B.

3.3 Method

For this assessment we have chosen to define the natural component of PM_{10} as coming from marine, crustal (sometimes also referred to as soil) and secondary sulphate sources.

The source apportionment method used by GNS attributes a proportion of the total PM_{10} sampled to various sources, including marine, crustal and sulphate. Marine refers to particles derived from sea spray, the generation of which is an entirely natural process. Crustal particles, although natural materials, are emitted into the air by both natural weathering and by anthropogenic processes such as quarrying, demolition, construction and agriculture. The anthropogenic contribution of crustal material can be highly localised. This means that extrapolation of crustal material to unmonitored locations should be undertaken with caution. Similarly sulphate material can have both a natural and anthropogenic source. For example, shipping sulphate contributions have been identified for urban areas next to ports (pers.comm, Dr. Perry). Other sources have not yet been analytically separated in New Zealand. Due to the chemical processes involved in the formation of secondary sulphate particles, they are usually formed some distance upwind from where they are measured and therefore less localised than crustal sources.

Where source contributions are measured, the crustal and sulphate components will come from both natural and anthropogenic sources but it is not possible to separate the two.

After a review of available data (summarised in Appendix B) and discussion with Dr Davy, we have concluded that although the anthropogenic contribution can be highly localised, they are often short lived and hence tend to average out over time and space. Dr Davy's advice is that the annual mean contribution of **natural processes only** to airborne crustal material and sulphate may be assumed to be up to 1 $\mu g\ m^{-3}$ each, everywhere (see e.g. Davy *et al*., 2011, Allen *et al*., 1996, Davison *et al*., 1996, Wylie & De Mora, 1996).

Consequently, the estimated contribution of natural processes to PM_{10} at a location where measurements have been made is the campaign-mean concentration attributed to marine sources + 1 $\mu g\ m^{-3}$ crustal + 1 $\mu g\ m^{-3}$ sulphate.

A way of estimating concentrations in locations without measurements is given in Appendix B. This is the method used for calculating health effects in section 6. The fraction of total PM_{10} attributable to natural sources can then also be easily calculated.

3.4 Does the indicator meet MfE criteria?

We consider that it is **not** currently possible to provide a fully robust and representative estimate of the average contribution of natural sources to PM_{10} that is applicable across the country. This is largely due to the very limited number of observation sites available for this indicator, which are mostly clustered in Auckland (7) and Greater Wellington (4), and the significant variability within these data. Therefore values are provided here for these monitoring sites only. Furthermore, the underlying data required for the present method is not regularly collected so that it is not possible to track trends in time. However, these limitations could be addressed by future changes to the method. Consequently, **this indicator component is recommended for interim or case-study use only at this time.**

3.5 Results

The results are presented in Table 3-1 and Figure 3-1.

Table 3-1: Average contribution of natural processes to PM_{10} concentrations.

Location	Estimated mean contribution of natural processes to PM_{10} ($\mu g\ m^{-3}$)	Estimated mean proportion of PM_{10} attributable to natural processes
Alexandra[4]	0.9	3%
Nelson	5.8	30%
Masterton	6.3	38%
Tahunanui	5.8	28%
Blenheim	4.3	40%
Hastings	5.9	30%
Napier	6.0	39%
Upper Hutt	5.9	54%
Lower Hutt	8.4	50%
Dunedin	7.1	26%
Patumahoe	7.3	68%
Wainuiomata	7.4	55%
Kingsland (Auckland)	8.6	54%
Henderson (Auckland)	8.2	59%
Penrose (Auckland)	9.0	51%
Takapuna (Auckland)	8.5	52%
Khyber Pass (Auckland)	9.5	51%
Queen Street (Auckland)	8.9	49%

[4] Data from Alexandra is for winter only and therefore should not be considered representative of annual means.

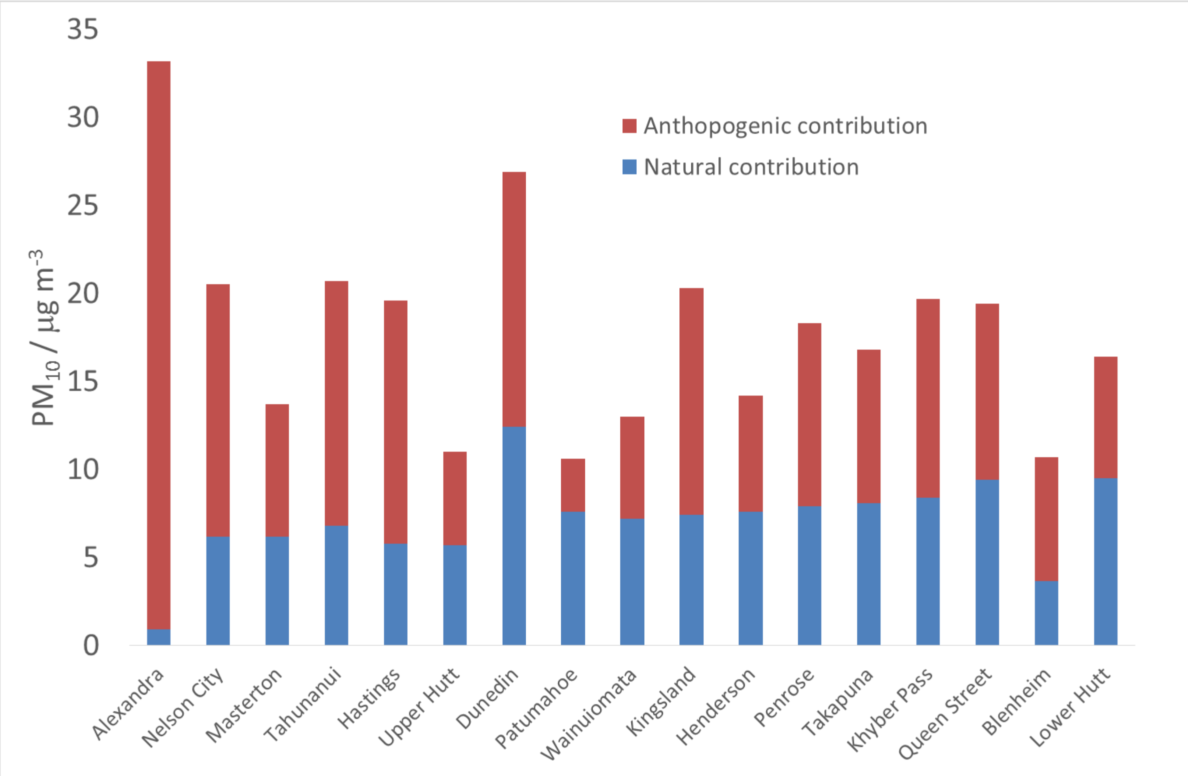


Figure 3-1: Average contribution of natural sources to PM_{10} concentrations.

3.6 Limitations and assumptions

In this work we have concluded that there is insufficient raw data to consider whether the contribution of natural sources varies from year to year. A small amount of variability may be expected related to variability in meteorology. Future research should be conducted to address this issue and the implications for how this indicator is updated and tracked into the future. Where a source apportionment measurement campaign is less than a whole year, we have assumed that the campaign mean concentration is representative of the annual mean concentration: this should also be investigated.

At the specific locations where measurements exist, the indicator is highly accurate and robust. However, the data are time- and location-specific and cannot be considered to have either full geographical coverage or be timely. The data for Auckland is more robust being derived from several years of continuous analysis and covering a large population. It can be seen that the estimates of natural source contribution is quite consistent over Auckland sites. However, it may be noted that there is no data from Christchurch (although work by GNS is underway in the city and may inform future updates of this indicator). Importantly, there is only very limited data from the interior of both islands, which is a limitation that should be addressed as soon as possible in order to improve the representativeness of the indicator.

Emissions from events such as volcanoes and bushfires tend to be episodic and largely unpredictable. Source apportionment methods applied thus far in New Zealand tend to include bush fires in a *biomass* component and volcanic material as part of a *crustal* or *soil* component. It is not possible to separate out natural from anthropogenic contribution to b*iomass* and the proportion of each is not known but given the episodic nature of bush fires it seems reasonable to assume that the anthropogenic portion outweighs the natural, hence it is not considered here as part of the natural indicator.

3.7 Future updates of the indicator

New chemical source apportionment data is sparse and new data is generated only occasionally. We are aware that new data will be forthcoming from sampling in Whangarei and Christchurch. Long-term sampling from Auckland will soon be of sufficient duration to investigate inter-annual variability in natural contributions to PM_{10}.

In order to develop the indicator until it meets MfE's criteria, three main issues need to be addressed: geographical coverage, timeliness and coverage of sporadic high-emission episodes. These are discussed further in section 7.

4 Indicator of Pressure: Meteorological conditions

4.1 The Indicator

This chapter describes exploratory research on whether an indicator can be developed of the influence of inter-annual variations in meteorology on air quality. A skeleton indicator was provided of “the prevalence of conditions that can lead to poor air quality”. The results of this exploratory research are presented in a separate report (Somervell *et al*., 2014). In brief, an interim indicator has been recommended. This indicator has two components, which are:

- **The proportion of hourly wind speed records in the Seven Station Series that are below 0.5 m s^{-1} (i.e. “% of calms”) during a given year.**
- **The proportion of hourly wind speed records in the Seven Station Series that are above 8.0 m s^{-1} (i.e. “% of windy records”) during a given year.**

4.2 Data sources

The Seven Station Series is an established group of meteorological stations used to track long-term temperature across New Zealand. The stations are situated in Auckland, Masterton, Wellington, Christchurch, Nelson, Hokitika and Dunedin chosen because they “provide broad geographical coverage and long records” (NIWA, 2013).

4.3 Method

The wind speed threshold for Calm of 0.5 m s^{-1} was set using the WMO’s (World Meteorological Organisation) value. This is an internationally recognised standard for meteorology, however its relevance to air quality is untested and could be refined in response to further research. The wind speed threshold for Windy was set using the Beaufort scale descriptions of the effect of wind speeds on the sea surface. Beaufort Force 5 (8 - 11 m s^{-1} is classified as “moderate waves…many whitecaps, some spray”. Identifying the proportion of wind speeds above this threshold gives an indication of the effect of sea spray on air quality. This is particularly important considering the majority of air quality measurement sites are in cities and towns close to the coast and the relatively high contribution of sea spray to PM_{10} levels (see Appendix B).

For each of the Seven Station Series, for the years 2000 to 2012, the years’ hourly recorded wind speeds were tallied into three bands:

- Calm: below 0.5 m s^{-1} (i.e., calm < 0.5)
- Medium: between 0.5 m s^{-1} and 8 m s^{-1} (i.e., 0.5 ≤ medium < 8)
- Windy: over 8 m s^{-1} (i.e., windy ≥ 8)

The percentage of Calm and Windy hours for each year at each site was calculated and the average over all sites is reported in the results.

4.4 Does the indicator meet MfE criteria?

These indicators are proposed on an interim basis. We propose that they meet MfE’s criteria of relevance, timeliness, accessibility, coherence and interpretability. However their accuracy, and whether alternative forms of indicator provide more direct relevance, is not yet established. The relationship between these conditions and elevated concentrations of PM_{10} are well established at a local scale in the short term. However, the effect of calm conditions is strongly moderated by the strength of emissions. For example, calm conditions on winter evenings will reduce dispersion of domestic heating emissions leading to high PM_{10} levels. Consequently, on a national, annual scale, the relationship between meteorological conditions and air quality is less clear. Further research is recommended to demonstrate accuracy, which may involve refinement of the indicator.

4.5 Results

The mean proportion of Calm and Windy hours each year are recorded in Table 4-1 and Figure 4-1.

Table 4-1: Mean proportion of calm and windy conditions across the "Seven Station Series" meteorological sites. Calm = < 0.5m s^{-1}, Windy ≥ 8m s^{-1}.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
% Calms	1.7	1.7	1.4	2.3	1.7	1.8	2.6	1.9	1.6	0.9	1.4	1.8	1.9
% Windy	13.5	11.1	13.9	11.9	14.3	10.3	14.0	11.3	11.8	11.8	11.6	11.3	11.1

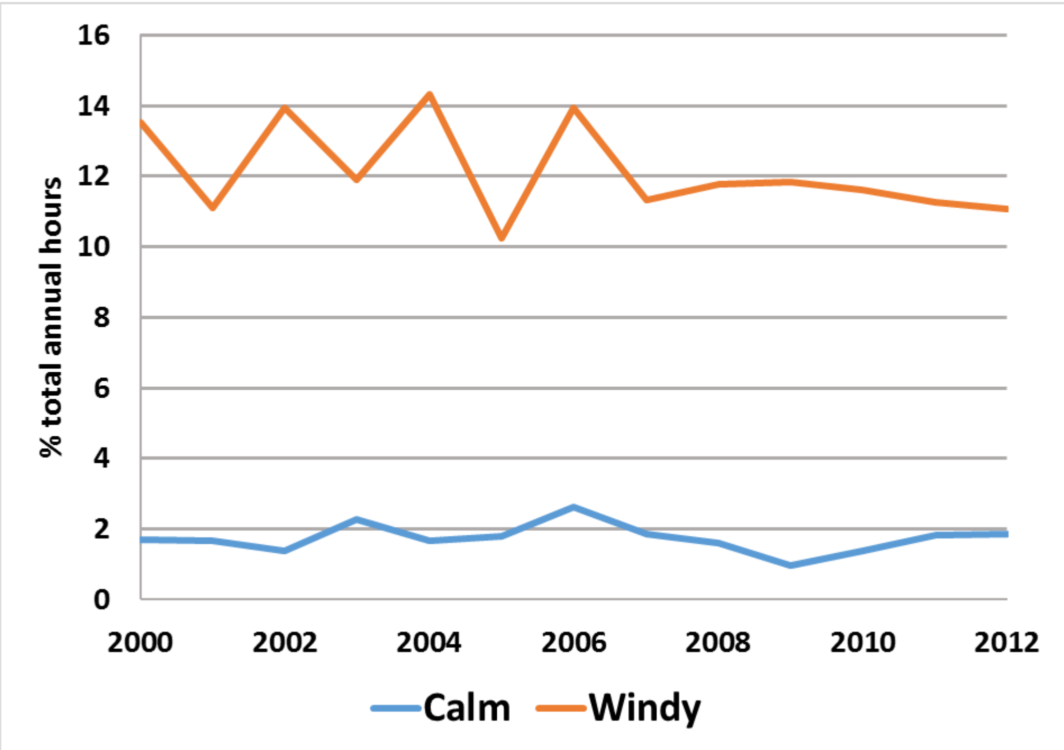


Figure 4-1: Mean proportion of calm and windy conditions across the "Seven Station Series" meteorological sites. Calm = <0.5 m s^{-1}, Windy = >8 m s^{-1}.

It can be seen that there was a higher incidence of calms in 2006 than all other years. The impact on annual mean PM_{10} concentrations was subtle and inconsistent, and difficult to establish due to the large number of PM_{10} stations which were not reporting before 2006. Nevertheless, a number of stations, particularly in Waikato and Canterbury, reported higher annual mean PM_{10} concentrations that year than might have been expected compared to other years. Further research is recommended to further explore these relationships.

4.6 Limitations and assumptions

A number of issues must be addressed when choosing the definitive dataset from which the meteorological indicator will be calculated in order to meet the MfE's criteria for indicators:

- Which meteorological parameters are most appropriate?
- What stations provide broad climatological coverage as well as being representative of most of the population?
- Consistency of measurement and data processing

Were the "Seven Station" Series to become the base data for the meteorological indicator or other stations chosen instead, a research study would be necessary to establish whether these stations were representative for the parameter used. Currently, there is no documentation on the representativeness of any meteorological measurement sites with regards to air quality.

4.7 Future updates of the indicator

The raw meteorological data upon which the proposed interim indicator is based is readily available at any time.

With the aim of upgrading this interim indicator to one which fully meets the MfE criteria, the brief exploratory work investigating meteorological indicators identified several ideas worth pursuing (Somervell *et al*., 2014).

5 Indicator of State: Mean PM_{10} concentrations

5.1 The indicator

The indicator of state chosen and reported here is the **population-weighted annual mean PM_{10} concentration**. The reasons for choosing this measure are outlined below and in Appendix C.

The pollutant of most concern in New Zealand is PM_{10} (airborne Particulate Matter with a diameter of ten micrometres or smaller). PM_{10} is consequently the most widely monitored pollutant across the country. PM_{10} is monitored using methods equivalent to many other countries, facilitating international comparison. Long-term average concentrations are probably the best indication of the long-term chronic risk to health posed by air pollution and are generally expressed using annual mean values. The World Health Organisation (WHO) recommend a maximum annual concentration of PM_{10} of 20 µg m^{-3}. The annual mean concentration also best represents the typical exposure of most New Zealanders whilst also responding to significant atypical periods of air quality.

Although PM_{10} is the most widely monitored pollutant, it is not possible to measure everywhere, so judgements have to be made about how to compile a national average from limited coverage. Some available options are discussed in Appendix C. In New Zealand the key issue (compared to other countries) is the huge variation in populations of monitored towns and the relatively high number of small towns with relatively high concentrations, which could bias a national indicator. Hence, for the purposes of this work, (and following some sensitivity tests reported in Appendix C) a population-weighting of available current observational data has been chosen.

5.2 Data sources

Two types of data are required to calculate the indicator: population estimates and PM_{10} concentrations. Population estimates are supplied by Stats NZ as estimated population by CAU, at 30 June for each of the years 2006-2013, using 2006 CAU boundaries. PM_{10} concentrations are supplied by Regional Councils as annual mean concentrations.

PM_{10} concentrations are reported on an hourly, daily or less regular basis at monitoring sites operated around the country by Regional and District Councils. Councils have a responsibility under the National Environmental Standards for Air Quality (NES) to monitor pollutants at locations that breach (or might breach) the regulations. Although established for a different purpose (demonstrating compliance with regulation rather than informing indicators) the monitoring methods are prescribed by law and so the data are consistent and of high quality across the country and likely to continue in the foreseeable future.

Most sites are operated continuously, some during the winter only. Some sites have been operating for many years, whilst others are installed for a fixed period only (a few months to a few years). **To qualify for inclusion in this indicator a site has to provide valid data for more than 75 % of the days in a given year** so that it can be considered relevant and accurate, whilst allowing for inevitable gaps in monitoring records. This is consistent with MfE's Good Practice Guide Air Quality Monitoring and Data Management (2009). This results in the exclusion of data from a number of locations in which either 1 day in 3 (or 6) is monitored, or where only winter monitoring is conducted. The number of sites qualifying rose sharply from 2004 (11 sites) reaching a peak in 2009 (69 sites) in response to the NES coming into force. Since then the number of sites has slowly fallen to 55 in 2012. The reduction has largely been related to removal or discontinuation of sites with concentrations below the NES concentration limits (i.e. the airshed is deemed to be compliant with the NES by the Council and further monitoring is not required), as well as reallocation or reduction of resources available for monitoring.

A database was created of annual mean concentrations of PM_{10} (where the 75 % valid data criterion was met) from every Regional and District Council from 2006 to 2012 inclusive. This is Workbook D_Indicator of State NIWA. A small amount of additional data is held by other organisations, such as NZTA, NIWA or industrial companies which is not included in this database at present (except data for Huntly from Genesis Energy).

5.3 Method

'Workbook D_Indicator of State NIWA' has a number of worksheets to aggregate PM_{10} and population data into the indicator, and some supplementary analysis, presented in section 5.5 or Appendix C.

The sheet 'Annual Mean' houses all the PM_{10} concentration data by monitoring site. Information is given about each site: what city and region the site is in, what instrument was used to take the measurement and the corresponding site name used in the HAPINZ model.

The sheet 'Represented Populations' houses the inter-census population estimates for all urban areas in New Zealand. Towns currently greyed out do not have any monitoring data for the years 2006-2012 that meet the 75 % valid data criterion. Hence their populations are not used to calculate the indicator. They are kept in place for future use if/when monitoring data becomes available.

The sheet 'Indicator of State' calculates the indicator. Data for each PM_{10} site for each year is matched with its urban area's population estimate for that year. Where there are multiple PM_{10} sites for an urban area, the population estimate is divided evenly among them, giving equal weight to each measurement in that town or city. It should also be noted that monitoring sites in areas categorised as 'rural' are not assigned any represented population, and so data from these sites are not included in the indicator.

To calculate population weighted annual mean PM_{10}, each PM_{10} data point is multiplied by its corresponding population estimate. These are added together and the total is divided by the total population used:

$$Population\ Weighted\ Annual\ Mean\ PM_{10} = \frac{\sum PM_{10}\ concentration\ \times Population\ estimate}{\sum Population\ estimates}$$

5.4 Does the indicator meet MfE criteria?

We consider that this indicator meets all of the criteria set by MfE and Stats NZ (see Appendix F for details on each criterion). The scale and consistency of the monitoring of the major towns and cities provides good coverage, the measurements are made with methods meeting national standards and the data has robust quality control procedures. The method of aggregation is reliable, however it should be noted that future changes to downsize the monitoring effort would affect the indicator in terms of its representativeness. Otherwise, the indicator is highly relevant, robust, transparent, accurate and timely.

5.5 Results: national indicator of state (PM_{10}), 2006-2012

All of the data presented in this section are available in the accompanying workbook "D_Indicator of State PM10_NIWA"'.

Table 5-1 shows the values of the indicator from 2006 to 2012 inclusive. There is a general downward trend, the reasons for which are complex. However, it is likely that a major factor is reduced domestic heating emissions resulting from a reducing proportion of homes using solid fuel on a regular basis. This is due to voluntary switching to other fuels (particularly electricity), which may have been accelerated by financial incentive schemes, and a general preference for electric heating in newly built properties. It is also likely due to the impact of emissions control policies covering solid fuel burning and outdoor burning. Other contributing factors could be the increased penetration of new technology vehicles into the fleet which may have been accelerated by emission standards for new and particularly imported used vehicles.

Table 5-1: Population weighted annual mean PM_{10} - Indicator of State, 2006-2012.

Year	Population weighted annual mean PM_{10} ($\mu g\ m^{-3}$)
2006	17.0
2007	17.0
2008	16.9
2009	16.4
2010	15.7
2011	16.0
2012	15.6

Figure 5-1 shows the range of annual mean PM_{10} concentrations measured across the country for each year the indicator has been calculated. The central 50% of measurements (interquartile range) for each year fall within the box, with the central bar indicating where the median value lies. The whiskers indicate the range of the bottom and top 25% of the data points. The red diamonds show the value of the Indicator of State and the blue line shows the World Health Organisation's (WHO) guideline value for PM_{10}, which is 20 $\mu g\ m^{-3}$.

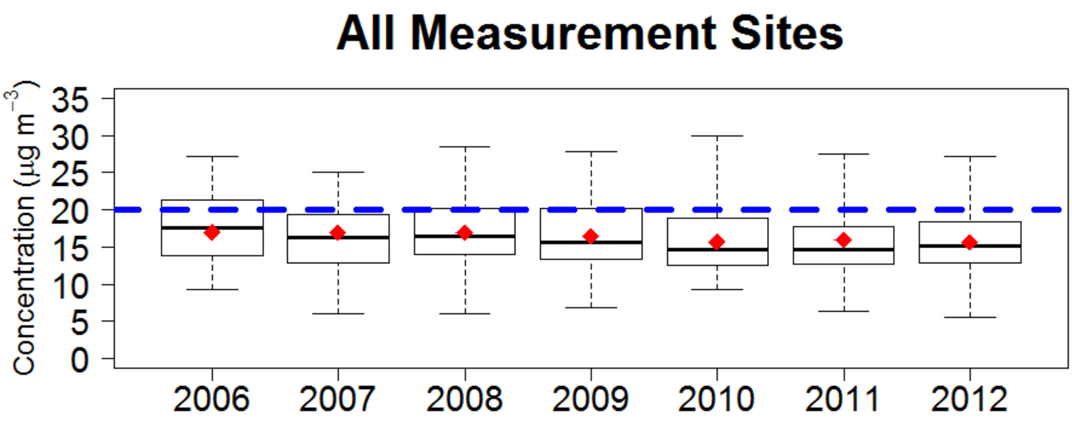


Figure 5-1 Box and whisker plot of all PM_{10} data, with population weighted annual mean (red diamonds) and WHO PM_{10} guideline (blue dashed line).

Appendix D provides detailed analysis of geographical variation within this indicator. Brief results are presented here. Every monitoring site sits within a Census Urban Centre Descriptor (UCD) and data can be pooled based upon that UCD's population and location. The groups we have opted to use in this comparison are:

- Auckland (metro area)
- Christchurch
- Greater Wellington (excluding Wairarapa)
- "Smaller Cities" (Hamilton + Tauranga + Dunedin + Palmerston North)
- "Medium Towns" (population between 25,000 and 60,000)
- "Small Towns" (population less than 25,000)
- Rural areas

For each group, the population weighted annual mean PM_{10} can be calculated and compared with the national Indicator of State. It can be seen from Figure 5-2 that the downward trend is broadly consistent across all groups with the possible exception of Christchurch. The 2011 data for Christchurch is significantly affected by the seismic activity in the city (mainly liquefaction silt resuspended in high winds). Due to the large represented population, the impact is noticeable in the national indicator where the value for 2011 is slightly above that for 2010 and 2012 (Figure 5-1). The 2012 data recovers somewhat from this but it is unclear at this time, whether the slight downward trend seen in the Christchurch before 2011 is resuming. For every year, concentrations in Christchurch are clearly elevated above the **average** of all other groups and are roughly double the lowest average values (from Greater Wellington). Mean concentrations for Greater Wellington are substantially below the national average, due in part to its windy situation.

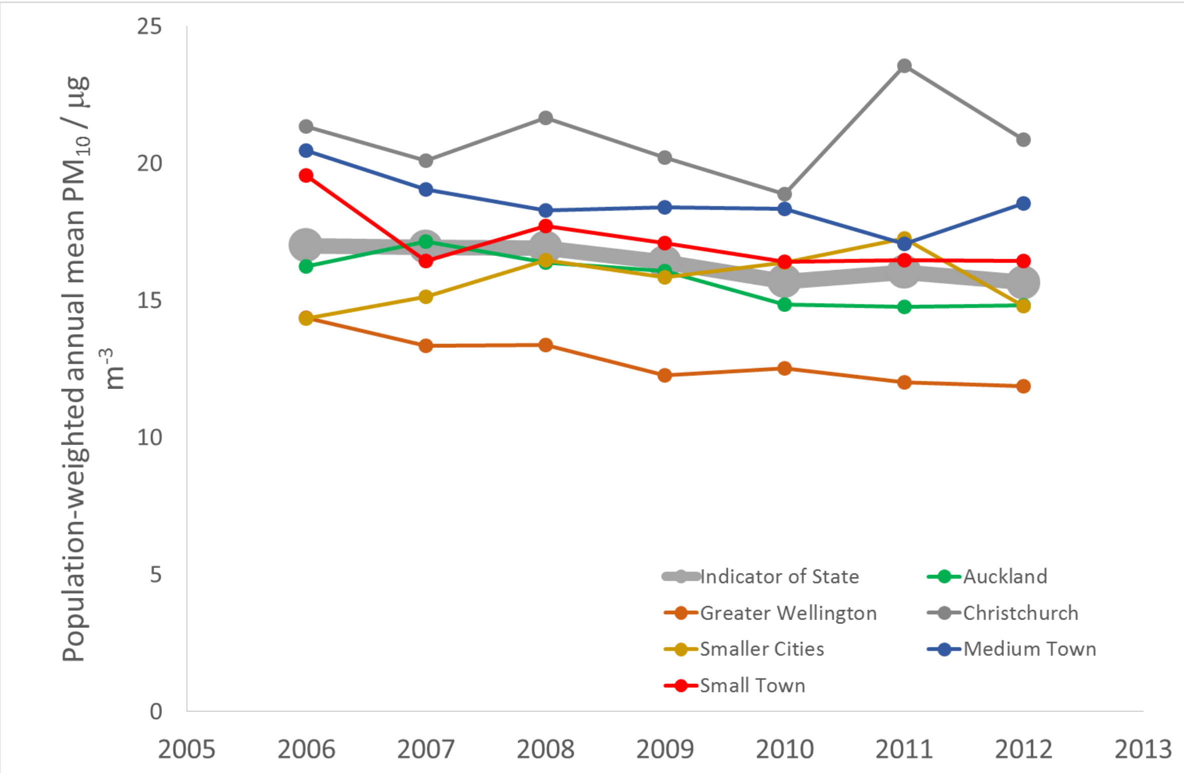


Figure 5-2 The national Indicator of State compared to the population weighted mean PM_{10} for each urban group.

5.5.1 Comparison of North and South Island

In order to further illustrate the representativeness of the current monitoring data around the country, two groups were further divided into North and South Islands. Medium and small sized towns were plotted as individual points (with the WHO guideline value as a blue dashed line and the Indicator of State as red diamonds). Figure 5-3 shows the medium sized towns and Figure 5-4 the small sized towns.

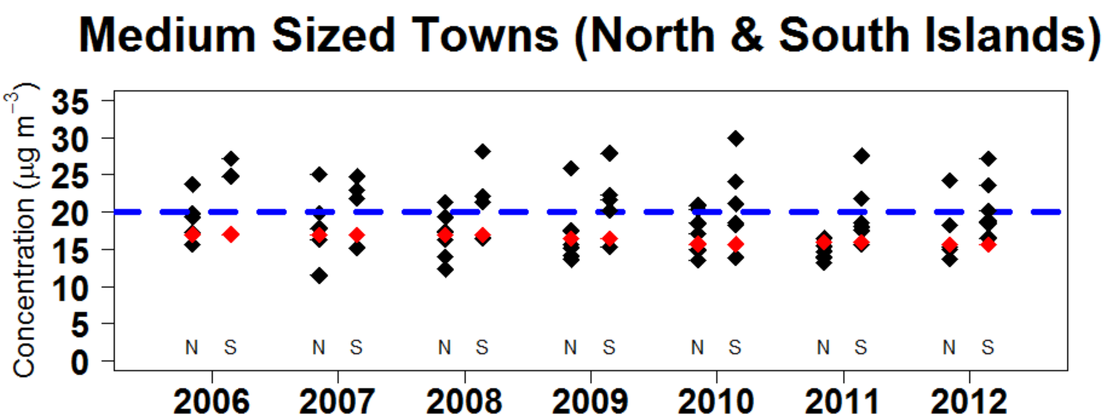


Figure 5-3 Annual mean PM_{10} measured in Medium sized towns (including WHO PM_{10} guideline value (blue dashed line) and Indicator of State (red diamonds).

Both figures show that in general, sites in the South Island measure higher concentrations than the North Island. This is explained by the South Island's greater requirement for residential heating and thus, greater wood-burning emissions in the south.

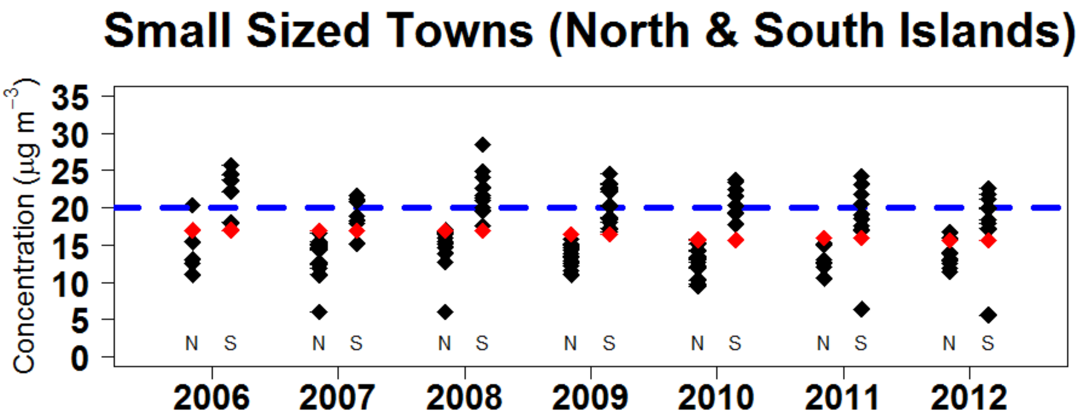


Figure 5-4 Annual mean PM_{10} measured in Small sized towns (including WHO PM_{10} guideline value (blue dashed line) and Indicator of State (red diamonds).

5.6 Limitations and assumptions

The current configuration of monitoring sites was not designed to provide full population coverage, neither was it designed for the purposes of this indicator. Like any country, New Zealand is made up of a small number of larger cities and large number of smaller towns and it is not practical to monitor all parts of all towns. In brief, the assumptions made in this work are:

- Data from any given urban monitoring site(s) is representative of the whole urban area in which it is situated,
- The representativeness of data from rural monitoring sites cannot be established at this time and so is not used.

Table 5-2 shows how qualifying PM_{10} data available in 2012 is distributed geographically. There are more sites in the Small Towns group (providing the highest number of PM_{10} data points per capita), yet these monitoring sites cover a smaller proportion of the population than any other group, simply because there are so many small towns.

Table 5-2: Number of PM_{10} sites grouped by urban type.

Group	Number of PM_{10} sites (2012)	Represented population (2012)
Auckland	10	1 397 300
Greater Wellington	5	366 050
Christchurch	2	321 600
Dunedin, Tauranga and Hamilton	3	293 180
Medium Towns (25,000 to 100,000)	11	345 640
Small Towns (below 25,000)	21	155 970
Rural	3	indeterminate
TOTAL	55	2 879 740

Christchurch is represented by only two PM_{10} data points and the Smaller Cities (Tauranga, Hamilton and Dunedin) by one site each. This makes the indicator very sensitive to these sites, their spatial representativeness and continuation.

The largest towns not represented by monitoring data are Palmerston North, Gisborne and New Plymouth. In some cases the represented population is smaller than the town's population because some of the town is deemed to be too geographically distinct from the area where the monitoring site lies. For instance, Mt Maunganui is not included in the population represented by Tauranga.

Table 5-2 also highlights that the rural population is under-represented by PM_{10} data. This is understandable given that rural concentrations are expected to be low (and so not a high priority area for monitoring) and the population highly diffuse. In urban areas it is assumed (when creating this indicator) that the entire population of an urban area is represented by PM_{10} monitoring in that area. With rural areas it is more difficult to define the boundaries of the area and hence the number of people, represented by the monitoring.

PM_{10} sites qualifying as rural (interpreted as not located within identifiable urban areas) are all clustered in the upper North Island, meaning concentrations in other rural areas of New Zealand (especially the South Island) are largely unknown. According to the 2013 Census, the total population in rural areas (including small towns classed as "Rural Centres" in the Census) is over half a million people, spread throughout the country.

5.7 Future updates of the indicator

New PM_{10} data is generated annually. Updates of this indicator should be relatively routine. However, a process should be included for reviewing the consequences of any changes in the locations from where data is available, and revising the method if necessary.

We understand that MfE wish to update the indicators at least every 3 years. There are no major challenges to achieving this, but it would be made substantially easier if as much as the process as possible were automated.

6 Indicator of Impact: PM_{10} intake, health outcomes and costs

6.1 The indicator

The indicator of impact is the **estimated number of health incidents attributed to exposure to anthropogenic PM_{10}**. Health incidents included for this indicator are premature mortality, hospitalisations and restricted activity days.

The indicator considers PM_{10} arising from anthropogenic sources only. This means that the impact of the contribution to PM_{10} levels arising from natural sources are discounted. The rationale is that the health impacts related to anthropogenic sources are the sources that can be managed. This indicator has a small sensitivity to the definition of 'natural sources' used (see Appendix B).

Currently, the indicator is limited to the impacts related to exposure to particulate matter (PM_{10}). Indicators of the impact of other pollutants (e.g. NO_2) or other sources (e.g. natural PM_{10}, domestic heating emissions, etc.) could be constructed in the future using a similar method. However, the data available does not currently meet MfE's criteria and such indicators were outside the scope of this work.

6.2 Data sources

- Population from census at census area unit level,
- PM_{10} as used by the Indicator of State (see chapter 5 of this report),
- Health incidence from MoH (see HAPINZ Update – Kuschel *et al*., 2012),
- Natural contribution from indicator of pressure (see HAPINZ Update – Kuschel *et al*., 2012),
- Exposure-response functions and costings (see HAPINZ Update – Kuschel *et al*., 2012).

6.3 Method

Conceptually, the health incidents associated with PM_{10} exposure are estimated following the approach:

Health incidents = **total intake** (i.e. $\sum$ (PM_{10} x population))

x **population vulnerability** (base health incidence rates)

x **dose-response ratio**

The dose-response ratio is derived from national and international research. Base incidence health rates are provided by the Ministry of Health. In this work we calculate the mean (per capita) intake, the total intake and the number of health incidents.

In order to provide full geographical coverage, it is necessary to estimate PM_{10} exposures at every location across the country, including locations with no PM_{10} monitoring. This was done using an exposure allocation model first developed for the 2012 Update of the Health and Air Pollution in New Zealand (HAPINZ) study (Kuschel *et al.*, 2012). On instruction from MfE and Stats NZ we put greater weight on the criterion of accuracy than the original method allowed, whilst also seeking to improve consistency, timeliness and interpretability. Consequently two methodological modifications were made:

- The PM_{10} exposure allocation model was slightly modified to compensate for changes in available PM_{10} data (described in detail in Appendix E).
- A 75% annual PM_{10} data coverage criterion was implemented to exclude data with low accuracy or timeliness, thus improving consistency.

The changes had negligible effect on the estimated total anthropogenic PM_{10} intake, and hence health incidents and costs.

The method for disaggregating PM_{10} concentrations into an anthropogenic portion (used to calculate impact) and natural portion was identical to that used in the 2012 HAPINZ Update. In brief, estimates were based solely on source apportionment data provided by GNS Science based on filter-based measurements from a limited number of sites around the country. Concentrations associated with 'marine' and 'crustal' sources were considered to be natural and all other sources (domestic heating, motor vehicles and sulphate) to be anthropogenic. Where filter measurements had been made, local data was applied to the whole airshed. For all other locations a national average concentration was applied.

Once estimates of anthropogenic PM_{10} are allocated to every census area unit in the country, the health incidents and costs are calculated using an identical method to the 2012 HAPINZ study.

6.4 Does the indicator meet MfE criteria?

We consider that the indicator meets the criteria set by MfE. The criterion of accuracy is met as the underlying model is based upon best international understanding and data. The criteria for accessibility is only partly met because whilst the HAPINZ-based modelling method is relatively simple in concept, it is complex in implementation. The criterion of timeliness is met, although minor parts of the data used are more than three years old. This is acceptable. The criteria of relevance, interpretability and international consistency are met: the underlying data and methods are consistent with international practice, although the separation of impact into natural and anthropogenic contributions is not widely done internationally, mainly through lack of appropriate data.

6.5 Results

6.5.1 Health incidents and costs

Table 6-1 summarises the estimated annual number of health outcomes for the whole country associated with anthropogenic $PM_{10.}$ The values are compared for the original 2012 HAPINZ Update using 2006 census data and the same data but with the 75% valid data criterion implemented. 2006 census and 2013 census, both with 75% valid data are then compared. Table 6-2 summarises the estimated annual health costs for the country associated with anthropogenic PM_{10} with the same comparisons. For all indicator components, values have fallen by 9 – 15 %.

Table 6-1 Estimated health outcome cases per year associated with exposure to anthropogenic PM_{10}.

	2012 HAPINZ Update	2012 HAPINZ Update with 75% valid data criterion	% decrease between HAPINZ 2012 and 75% valid data	This study (75% valid data)	% decrease between 2012 HAPINZ and this study (both with 75% valid data)
Census year	2006	2006		2013	
Census Population	4,027,902	4,027,902		4,242,030	
PM_{10} data	2006-2008	2006-2008		2012	
Mortality adults age 30+	1,170	1,168	0.0 %	1003	14 %
Mortality Adults Maori age 30+	195	194	0.5 %	160	17 %
Mortality Babies age 0 – 1	3.9	3.9	0 %	3.4	13 %
Cardiac Hospital Admissions: All ages	232	232	0 %	197	15 %
Respiratory Hospital Admissions: All ages	375	375	0 %	319	15 %
Respiratory Hospital Admissions: Children 1-4 yrs	126	126	0 %	108	14 %
Respiratory Hospital Admissions: Children 5-14 yrs	77	77	0 %	66	14 %
Restricted Activity Days	1,486,491	1,486,491	0 %	1,348,479	9 %

Table 6-2 Estimated costs (NZ$ million) per year associated with exposure to anthropogenic PM_{10}.

	2012 HAPINZ update	2012 HAPINZ Update with 75% valid data criterion	% decrease between HAPINZ 2012 and 75% valid data	This study (75% valid data)	% decrease between 2012 HAPINZ and this study (both with 75% valid data)
Cardiac Hospital Admissions: All ages	1.5	1.5	0 %	1.3	13 %
Respiratory Hospital Admissions: All ages	1.7	1.7	0 %	1.4	18 %
Respiratory Hospital Admissions: Children 1-4 yrs	0.6	0.6	0 %	0.5	17 %
Respiratory Hospital Admissions: Children 5-14 yrs	0.3	0.3	0 %	0.3	0.0%

6.5.2 Mean and total intake

The change in PM_{10} intake due to introducing the 75% valid data criterion was also evaluated for intake and the results are presented in Table 6-3, with further detail in Appendix E.

Table 6-3 Summary of PM_{10} intake.

	2012 HAPINZ update	2012 data using 2013 method	This study
Census year	2006	2006	2013
PM_{10} data	2006-2008	2006-2008	2012
Mean intake (total PM_{10}) ($\mu g\ m^{-3}$)	14.2	14.6	13.4
Mean intake (anthropogenic PM_{10}) ($\mu g\ m^{-3}$)	7.1	7.1	5.9
Total population intake (anthropogenic PM_{10}) (g/day)	573	573	504

The use of mean and total intake as indicator components separates the differing impact of changes in pollution and changes in population on health incidents. Our analysis shows that the mean intake of anthropogenic PM_{10} (i.e. the average exposure to PM_{10}) fell by 17 %. However, the **total** intake fell by only 12 %, indicating that the reduction in average exposure was slightly offset by the increase in the exposed population. As the number of health incidents and health costs are derived from the total intake the same principle applies.

30% of the total intake is attributed to the Auckland Region, roughly in proportion to its population. 16% is attributed to Christchurch City, despite it representing only 8% of the national population, due to above-average PM_{10} concentrations in the city. 9% is attributed to Greater Wellington, 42% to other urban areas and 2% to rural areas.

6.6 Limitations and assumptions

The estimations of mean and total intake are based on calculations at the CAU level, but are subject to the same assumptions as the data and indicators upon which it is based, i.e.

- That it is appropriate to take PM_{10} data from monitored towns to represent unmonitored towns
- That PM_{10} data (including source apportionment results) accurately represents an entire town
- That it is appropriate to use a national average value for natural source contribution in unsampled airsheds across the whole country.

Furthermore, as our method was largely unchanged since the 2012 HAPINZ Update, this work incorporates the same assumptions and limitations as that work (Kuschel *et al*., 2012), in particular that the dose-response ratios used are appropriate. The calculation of restricted activity days in the 2012 HAPINZ model is based on $PM_{2.5}$ values determined as a fixed fraction of PM_{10} (0.6 in urban areas and 0.4 in rural areas), rather than on observations. This method has not been altered in this work. However, we recommend that this $PM_{2.5}$ estimate be replaced with one more closely based on physical principles when available.

A detailed sensitivity assessment has not been conducted. However, the opinion of the authors is that the results are most sensitive to:

- The representativeness of monitoring data for Christchurch (given the high concentrations and population, but low number of existing monitors)
- The validity and accuracy of the emission-regression technique used to estimate PM_{10} levels across Auckland.

The health impacts estimated here are associated with exposure to anthropogenic PM_{10} only, not to urban air pollutants in general. The trend in PM_{10} health effects may not reflect the trend of health effects for other pollutants. However, PM_{10} is considered the air pollutant of most concern in New Zealand and is the pollutant that most often exceeds health-related guidelines in NZ.

The definition of natural and anthropogenic sources used in this work, and method used to evaluate their contributions, class all sulphate particles as anthropogenic, even though some are derived naturally from ocean biota, and class all crustal particles as natural. Many crustal particles, however, are resuspended in the air by human activities, such as quarrying, demolition, construction, road wear and agricultural practices.

Base incidence rates for health outcomes were not updated in this work. Base rates represent the vulnerability of the population. Health incidents and costs are linearly proportional to these base rates, such that a 1% reduction in vulnerability across the population would translate into a 1% reduction in estimated health incidents and costs. Base mortality rates have fallen an average of 1.5 % over the period covered by this analysis, which is a minor change relative to the 17% fall in mean PM10 intake and ~5 % rise in population.

6.7 Future updates of the indicator

The impact indicator components are reliant on four main sources of raw data: population (census), health incidence rates, PM_{10} data and natural contribution estimates. Furthermore, the health incidence and costs are dependent upon dose-response functions and cost rates.

New PM_{10} data is made available annually. This indicator is sensitive to changes in the locations providing PM_{10} data, with changes currently requiring expert intervention and ad hoc decisions.

Natural contribution estimates are not routinely generated. An update would need to be specifically commissioned. We recommend that if this happens, the method is reviewed to better address gaps in spatial coverage.

7 Recommendations for further research

This chapter summarises the recommendations for future research that would support and further the robustness of the proposed indicators for the Air Domain report, and would aid the proposed indicators that do not currently meet the criteria to meet them in the future.

The five indicators considered in this report have been:

- three Indicators of Pressure:
  - a national road vehicles emission inventory,
  - contribution of natural sources of PM_{10},
  - meteorological conditions relevant to air quality
- one Indicator of State:
  - the national average PM_{10} concentration
- one Indicator of Impact:
  - health outcomes and costs from anthropogenic PM_{10}.

Three indicators have been put forward for inclusion in the domain report, while two (meteorological conditions and contribution of natural sources) require more work to sufficiently match the required criteria. Appendix F: Evaluation of indicators presented in this work against MfE criteria, gives an assessment of how each indicator currently meets the criteria.

7.1 Representativeness of PM_{10} data

There are two areas for improvement regarding aggregating PM_{10} that should be addressed. These are the representativeness of monitoring sites of their urban area, and the relationships between monitoring sites and PM_{10} levels in other towns.

Specifically this work shows spatial variation within towns and cities exists. **We recommend that research into establishing spatial variation in PM_{10} within towns and cities so as to make the best use of available data and improve representativeness.**

As time moves on, it is increasingly likely that some monitoring sites will be discontinued or relocated**. It is important to improve our understanding of how any given site relates to the distribution of concentrations across any given town or city. We recommend quantitative investigation of the relationships between PM_{10} levels in different towns and cities.**

We recommend that at least one rural/regional background South Island monitoring site is established. We also recommend that existing data from rural, semi-rural sites and small town sites, especially in South Island, are carefully mined to extract information regarding background and natural source contributions.

One of the criteria set out by MfE for the environmental indicators is international comparability. Increasingly international jurisdictions are basing air quality and health risk assessments on $PM_{2.5}$ rather than PM_{10} data, in part due to the availability of more robust and comprehensive dose-response relationships. There is currently insufficient $PM_{2.5}$ data available in New Zealand (except in Auckland, Christchurch and Masterton) to expand the indicators to include $PM_{2.5}$. **We recommend that credible estimates of $PM_{2.5}$ be modelled across the country** using either airshed modelling, statistical analysis or machine learning methods.

7.2 Contributions of natural and anthropogenic sources of PM

To improve the disaggregation of the anthropogenic and natural sources **we recommend that filter-based apportionment studies are conducted in South Island, and the interior of both islands. We also recommend that other methods are developed other than filter sampling and analysis campaigns**.

We recommend that a natural sources inventory is developed.

We consider the method of the HAPINZ model is an appropriate and preferred basis upon which to build the contributions indicator. However, we find that is does not fully meet all of MfE's criteria (see Appendix F). In order to meet the remaining criteria, we recommend two particularly important modifications. Firstly, **we recommend that the HAPINZ model is simplified**. Secondly, **we recommend the introduction and consistent application of evidence-based rules governing how data from one location is used (or not used) to represent another.** By taking the second approach as outlined in Section 1.3 of this report, NIWA has already made improvements on this front.

More generally, we recommend that a process is developed to incorporate new research findings well in advance of any update.

7.3 Evaluation of health incidents

The indicator of impact, health incidents, exceeds the minimum standards for indicators as set out in Section 1.2 of this report. The criterion of accuracy is met as the model is based upon best international understanding and data. However, there is currently no available method to validate the results**. Comparison with health incidence data** may corroborate the results and this should be considered for future research.

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Appendix A Indicator of Pressure: National road vehicle emissions inventory

Goal

The objective of this indicator was to develop a **national** road traffic emission inventory based on the best available information about New Zealand's vehicle fleet, its composition and movements. This inventory is to be able to show changes in emissions and the parameters feeding into the emissions over time.

On a more practical level, the emission inventory was to be developed as a set of spreadsheets where input information can be provided and outputs easily obtained.

Method

The first step in the development of this inventory was to identify the relevant data sources for this task. In order to maintain a **national** perspective and be compatible with other annual statistics, the identified data sources are:

- MoT indicators:
  - Indicator TV034 (http://www.transport.govt.nz/ourwork/TMIF/Pages/TV034.aspx).
  - Indicator SS008 - Speed survey (http://www.transport.govt.nz/research/roadsafetysurveys/).
  - Indicator NR002 (http://www.transport.govt.nz/ourwork/tmif/networkreliability/nr002/).
  - Indicator TV001 (http://www.transport.govt.nz/ourwork/TMIF/Pages/TV001.aspx).
- Vehicle emission prediction model v5.1 (VEPM).

Once this information was identified, we developed an INPUTS workbook where each sheet represents one year and the relevant data can be copied directly from the defined data sources.

This spreadsheet is able to automatically generate a **VEPM Bulk Input** sheet that can be then directly used in VEPM to generate the emission factors for the different fleet components.

This sheet is generated by taking the speed information from the speed survey and the congestion information from the network reliability indicator to generate different speeds for the light and heavy duty fleet in urban areas and on open roads.

The contents of the **VEPM Bulk Output** sheet can be then copied to the OUTPUTS workbook. Also, it is required that the vehicle fleet composition information be copied to the OUTPUTS workbook in order to generate the total emission estimates for the fleet.

The VEPM output information is then scaled by regional VKT and the national fleet composition is estimated from the national VKT data.

Finally, a set of SUMMARY sheets in the OUTPUTS workbook provide direct access to the long term trend in the fleet emissions as well as descriptions of the fleet travel.

Assumptions

The main assumptions in the emission inventory are:

- **The vehicle fleet is the same in all the regions**. From an emissions perspective, it is vehicle travel that determines the impact of a vehicle and therefore the indicator TV001 was used as a national estimate of the vehicle fleet weighted by travel. In the absence of equivalent regional information, this was used to describe the vehicle fleet everywhere. The impact of this assumption has not been quantified but it is expected to be minor, given the national aggregation required for the indicator.
- **NR002 describes the congestion in urban areas**. The open road speed from the speed survey is only descriptive of highway traffic but urban traffic speed needs to take account of congestion. The most consistent information about congestion comes from the NR002 indicator for urban areas. The impact of this assumption is expected to be minor because NR002 focuses on the areas that are affected by congestion and as that indicator evolves and is updated, so will the estimates from this inventory.

Operation of the emission inventory

INPUTS workbook

The structure of the workbook is one sheet per year where the input information (sourced from the links indicated on the worksheet) needs to be pasted on the grey cells of the same sheet for the corresponding year (Figure A-1: Sample INPUTS screenshot.).

A	B	C	D	E	F	G	H	I
Total VKT	39971					Indicator TV034	http://www.transport.govt.nz/o	
Fleet composition (VKT)	VKT (millions)	%						
Light passenger petrol travel	27779	69.50%				Indicator TV034	http://www.transport.govt.nz/o	
Light passenger diesel travel	3075	7.69%				Indicator TV034	http://www.transport.govt.nz/o	
Light commercial petrol travel	1425	3.57%				Indicator TV034	http://www.transport.govt.nz/o	
Light commercial diesel travel	4573	11.44%				Indicator TV034	http://www.transport.govt.nz/o	
Motorcycle travel	356	0.89%				Indicator TV034	http://www.transport.govt.nz/o	
Truck petrol travel	8	0.02%				Indicator TV034	http://www.transport.govt.nz/o	
Truck diesel travel	2514	6.29%				Indicator TV034	http://www.transport.govt.nz/o	
Bus petrol travel	2	0.01%				Indicator TV034	http://www.transport.govt.nz/o	
Bus diesel travel	238	0.60%				Indicator TV034	http://www.transport.govt.nz/o	
Electric bus travel	1	0.00%				Indicator TV034	http://www.transport.govt.nz/o	
Speed profile	Speed km/hr	Congested Speed (Km/Hr)						
Car open speed	96	96				Speed survey	http://www.transport.govt.nz/re	
Car urban speed	51	38				Speed survey	http://www.transport.govt.nz/re	
Heavy vehicles open speed	89	89				Speed survey	http://www.transport.govt.nz/re	
Heavy vehicles urban speed	49	37				Speed survey	http://www.transport.govt.nz/re	
Congested speed decrease	March (min/Km	Urban VKT in region	November (min/Km)	Urban VKT in region	Average delay (Hr/Km)	Indicator NR002	http://www.transport.govt.nz/o	
Auckland All Day	0.5	7939	0.33	7939	0.0069	Indicator NR002	http://www.transport.govt.nz/o	
Tauranga All Day	0.35	1167	0.32	1167	0.0056	Indicator NR002	http://www.transport.govt.nz/o	
Wellington All Day	0.37	1849	0.37	1849	0.0062	Indicator NR002	http://www.transport.govt.nz/o	
Christchurch All Day		0		0	N/A	Indicator NR002	http://www.transport.govt.nz/o	
Hamilton All Day	0.44	2060	0.47	2060	0.0076	Indicator NR002	http://www.transport.govt.nz/o	
Urban Areas Average	0.45858471	13015	0.356945063	13015	0.0068			
Regional VKT	Raw VKT	Local Road VKT	VKT (millions)					
Northland Region	1715	789	1661			Indicator TV001	http://www.transport.govt.nz/o	
Auckland Region	12282	7939	11897			Indicator TV001	http://www.transport.govt.nz/o	
Waikato Region	5249	2060	5085			Indicator TV001	http://www.transport.govt.nz/o	
Bay of Plenty Region	2716	1167	2631			Indicator TV001	http://www.transport.govt.nz/o	
Gisborne Region	387	204	375			Indicator TV001	http://www.transport.govt.nz/o	
Hawkes Bay Region	1464	814	1418			Indicator TV001	http://www.transport.govt.nz/o	
Taranaki Region	1040	372	1007			Indicator TV001	http://www.transport.govt.nz/o	
Manawatu-Wanganui Region	2405	1071	2330			Indicator TV001	http://www.transport.govt.nz/o	
Wellington Region	3438	1849	3330			Indicator TV001	http://www.transport.govt.nz/o	
Tasman-Marlborough Region	1322	595	1281			Indicator TV001	http://www.transport.govt.nz/o	
Canterbury Region	5382	3085	5213			Indicator TV001	http://www.transport.govt.nz/o	
West Coast Region	523	121	507			Indicator TV001	http://www.transport.govt.nz/o	
Otago Region	2194	910	2125			Indicator TV001	http://www.transport.govt.nz/o	
Southland Region	1147	530	1111			Indicator TV001	http://www.transport.govt.nz/o	
	41264							
Local Road	52.12%		20832			Indicator TV001	http://www.transport.govt.nz/o	

Figure A-1: Sample INPUTS screenshot. Gray cells correspond to input fields and the source of the data is listed to the right of the sheet.

Once all the input data cells for individual years have been populated, then the VEPM input needs to be populated with the years for which there is information in the workbook. Each year requires 4 rows:

- Open road light duty vehicle speed.
- Urban congested light duty vehicle speed.
- Open road heavy duty vehicle speed.
- Urban congested heavy duty vehicle speed.

Figure A-2 shows a screenshot of the **VEPM input** sheet with the grey cells that need to be populated with the years available in the workbook.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
Required Inputs						Optional Inputs		Optional Inputs		Optional Inputs		Optional Inputs		Optional Inputs		Optional Inputs		Optional Inputs		
						Light Duty Vehicles <3.5t						Diesel HCV >3.5t								avg tri
Run number	year	Speed Car	speed LCV	Speed HCV	B&T PM size	% car petro	% car diese	% car hybrid	% LCV petro	%LCV diese	%LCV hybrid	% buses	% HCV 3.5-7.5 t	% HCV 7.5-12t	% HCV 12-15t	% HCV 15-20t	% HCV 20-25t	% HCV 25-30t	% HCV >30t	
1	2001	100.2	100.2	100.2	PM10	72.08%	6.86%	0.70%	6.04%	7.64%	0.00001	0.43%	0.00001	6.24%	0.00001	0.00001	0.00001	0.00001	0.00001	
2	2001	55.2	55.2	55.2	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
3	2001	91	91	91	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
4	2001	53	53	53	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
5	2002	99	99	99	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
6	2002	54	54	54	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
7	2002	90	90	90	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
8	2002	53	53	53	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
9	2003	98	98	98	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
10	2003	36	36	36	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
11	2003	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
12	2003	36	36	36	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
13	2004	98	98	98	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
14	2004	39	39	39	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
15	2004	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
16	2004	38	38	38	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
17	2005	97	97	97	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
18	2005	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
19	2005	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
20	2005	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
21	2006	96	96	96	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
22	2006	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
23	2006	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
24	2006	36	36	36	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
25	2007	96	96	96	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
26	2007	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
27	2007	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
28	2007	36	36	36	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
29	2008	97	97	97	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
30	2008	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
31	2008	89	89	89	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
32	2008	36	36	36	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
33	2009	96	96	96	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	
34	2009	37	37	37	PM10	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07142857	0.07143	0.071428571	0.071428571	0.07142857	0.07142857	0.07142857	0.07142857	0.0714286	

Figure A-2: VEPM input screenshot. The grey cells correspond to where the user needs to populate the years that have information in the workbook.

VEPM run

A full description of the use of VEPM is outside the scope of this report but below are the instructions to execute a **Bulk Run** with the data provided by the INPUTS workbook.

After opening VEPM, go to the **Bulk Run** sheet and click on the “Go to Input” button. You will be taken to a different sheet where the full contents of the INPUTS **VEPM input** sheet should be copied (tip: press CTRL+A to select the full sheet, then CTRL+C to copy to the clipboard and then paste the result on the VEPM sheet.

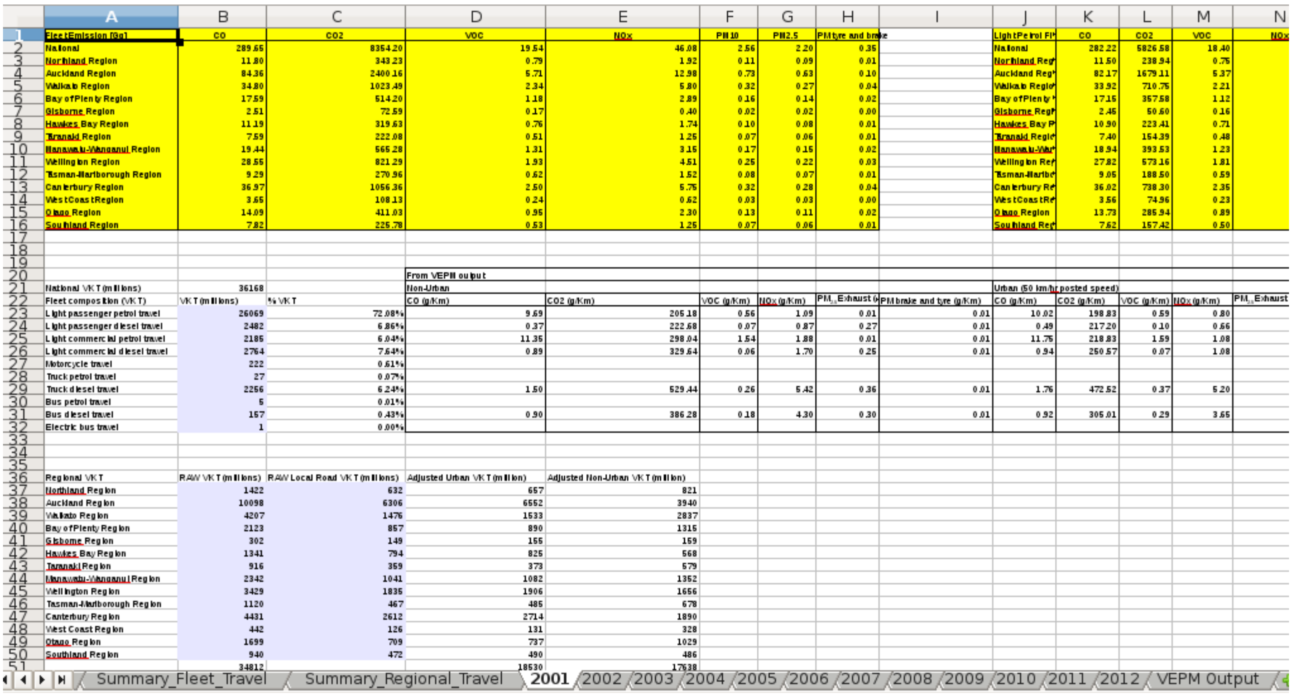
Once the input sheet is populated, go back to the **Bulk Run** sheet and click on the **Run** button that will execute VEPM and populate the output sheet.

OUTPUTS workbook

Once the VEPM run has finished, copy only the columns A to DY from the VEPM workbook to the OUTPUTS workbook **VEPM outputs** sheet.

Now, for each year (2001 to 2012) it is necessary to copy the VKT information from the INPUTS sheet for the corresponding year. It was decided that including a link to a different workbook could cause problems if the INPUTS and OUTPUTS workbooks are not stored together in the same folder.

Once all the sheets have the VKT information in them, the yellow highlighted cells will contain the fleet emission information (Figure A-3) and the **Summary** sheets will contain the estimates of long term trends on emissions and fleet composition information (Figure A-4).



Fleet Emission [Gg]	CO	CO2	VOC	NOx	PM10	PM2.5	PM tyre and brake
National	289.65	8354.20	19.54	46.08	2.56	2.20	0.35
Northland Region	11.80	343.23	0.79	1.92	0.11	0.09	0.01
Auckland Region	84.36	2400.16	5.71	12.98	0.73	0.63	0.10
Waikato Region	34.80	1023.49	2.34	5.80	0.32	0.27	0.04
Bay of Plenty Region	17.59	514.20	1.18	2.89	0.16	0.14	0.02
Gisborne Region	2.51	72.59	0.17	0.40	0.02	0.02	0.00
Hawkes Bay Region	11.19	319.63	0.76	1.74	0.10	0.08	0.01
Taranaki Region	7.59	222.08	0.51	1.25	0.07	0.06	0.01
Manawatu-Wanganui Region	19.44	565.28	1.31	3.15	0.17	0.15	0.02
Wellington Region	28.55	821.29	1.93	4.51	0.25	0.22	0.03
Tasman-Marlborough Region	9.29	270.96	0.62	1.52	0.08	0.07	0.01
Canterbury Region	36.97	1056.36	2.50	5.75	0.32	0.28	0.04
West Coast Region	3.65	108.13	0.24	0.62	0.03	0.03	0.00
Otago Region	14.09	411.03	0.95	2.30	0.13	0.11	0.02
Southland Region	7.82	225.78	0.53	1.25	0.07	0.06	0.01

Light Petrol Fl	CO	CO2	VOC	NOx
National	282.22	5826.58	18.40	
Northland Reg	11.50	238.94	0.75	
Auckland Reg	82.17	1679.11	5.37	
Waikato Regio	33.92	710.75	2.21	
Bay of Plenty	17.15	357.58	1.12	
Gisborne Regi	2.45	50.60	0.16	
Hawkes Bay P	10.90	223.41	0.71	
Taranaki Regio	7.40	154.39	0.48	
Manawatu-Wa	18.94	393.53	1.23	
Wellington Re	27.82	573.16	1.81	
Tasman-Marlbo	9.05	188.50	0.59	
Canterbury Re	36.02	738.30	2.35	
West Coast Re	3.56	74.96	0.23	
Otago Region	13.73	285.94	0.89	
Southland Reg	7.62	157.42	0.50	

			From VEPM output											
National VKT (millions)	36168		Non-Urban						Urban (50 km/hr posted speed)					
Fleet composition (VKT)	VKT (millions)	% VKT	CO (g/Km)	CO2 (g/Km)	VOC (g/Km)	NOx (g/Km)	PM_{10} Exhaust (	PM brake and tyre (g/Km)	CO (g/Km)	CO2 (g/Km)	VOC (g/Km)	NOx (g/Km)	PM_{10} Exhaust
Light passenger petrol travel	26069	72.08%	9.69	205.18	0.56	1.09	0.01	0.01	10.02	198.83	0.59	0.80	
Light passenger diesel travel	2482	6.86%	0.37	222.68	0.07	0.87	0.27	0.01	0.49	217.20	0.10	0.66	
Light commercial petrol travel	2185	6.04%	11.35	298.04	1.54	1.88	0.01	0.01	11.75	218.83	1.59	1.08	
Light commercial diesel travel	2764	7.64%	0.89	329.64	0.06	1.70	0.25	0.01	0.94	250.57	0.07	1.08	
Motorcycle travel	222	0.61%											
Truck petrol travel	27	0.07%											
Truck diesel travel	2256	6.24%	1.50	529.44	0.26	5.42	0.36	0.01	1.76	472.52	0.37	5.20	
Bus petrol travel	5	0.01%											
Bus diesel travel	157	0.43%	0.90	386.28	0.18	4.30	0.30	0.01	0.92	305.01	0.29	3.65	
Electric bus travel	1	0.00%											

Regional VKT	RAW VKT (millions)	RAW Local Road VKT (millions)	Adjusted Urban VKT (million)	Adjusted Non-Urban VKT (million)
Northland Region	1422	632	657	821
Auckland Region	10098	6306	6552	3940
Waikato Region	4207	1476	1533	2837
Bay of Plenty Region	2123	857	890	1315
Gisborne Region	302	149	155	159
Hawkes Bay Region	1341	794	825	568
Taranaki Region	916	359	373	579
Manawatu-Wanganui Region	2342	1041	1082	1352
Wellington Region	3429	1835	1906	1656
Tasman-Marlborough Region	1120	467	485	678
Canterbury Region	4431	2612	2714	1890
West Coast Region	442	126	131	328
Otago Region	1699	709	737	1029
Southland Region	940	472	490	486
	34812		18530	17638

Summary_Fleet_Travel | Summary_Regional_Travel | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | VEPM Output

Figure A-3: OUTPUTS year sheet screenshot. The grey cells indicate data that needs to be populated manually from the INPUTS sheet for the corresponding year. The yellow cells correspond to the emissions calculated for that year.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		Road Transport Emissions [Gg]													
2															
3	2	National Emissions													
4			2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
5	2	Carbon Monoxide (CO)	290	283	305	303	289	267	257	235	227	213	187	177	
6	3	Carbon Dioxide (CO2)	8354	8610	9314	9602	9750	9757	9926	9734	9705	9651	9476	9467	
7	4	VOlatile Organic Compounds (V	20	18	18	17	16	15	14	13	13	12	11	10	
8	5	Nitrogen Oxides (Nox)	46	44	43	42	41	38	37	34	33	32	31	30	
9	6	Particulate Matter (PM10)	2.6	2.5	2.6	2.7	2.7	2.5	2.5	2.2	2.2	2.1	2.0	1.9	
10	7	Particulate Matter (PM2.5)	2.2	2.2	2.5	2.5	2.5	2.4	2.4	2.1	2.1	2.0	1.9	1.8	
11															
12		Normalized to 2001													
13			2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
14		Carbon Monoxide (CO)	100%	98%	105%	105%	100%	92%	89%	81%	78%	74%	65%	61%	
15		Carbon Dioxide (CO2)	100%	103%	111%	115%	117%	117%	119%	117%	116%	116%	113%	113%	
16		VOlatile Organic Compounds (V	100%	91%	94%	89%	83%	77%	73%	65%	64%	60%	54%	51%	
17		Nitrogen Oxides (Nox)	100%	96%	93%	91%	89%	82%	79%	74%	72%	69%	67%	64%	
18		Particulate Matter (PM10)	100%	99%	103%	104%	104%	99%	97%	87%	86%	82%	78%	75%	
19		Particulate Matter (PM2.5)	100%	99%	115%	115%	115%	110%	107%	96%	95%	90%	86%	81%	
20															
21															
22	2	Carbon Monoxide (CO)													
23			2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
24	2	National	289.65	282.50	304.85	302.81	288.73	266.79	256.75	234.86	226.64	213.38	187.03	176.89	
25	3	Northland Region	11.80	11.41	11.61	11.72	11.10	10.96	10.36	9.78	9.52	8.87	7.70	7.25	
26	4	Auckland Region	84.36	82.55	92.24	93.49	87.16	82.91	79.25	72.74	69.98	65.50	57.13	54.11	
27	5	Waikato Region	34.80	35.11	35.31	35.88	33.97	31.34	29.73	27.66	26.27	25.23	23.09	21.86	
28	6	Bay of Plenty Region	17.59	17.11	17.96	18.38	18.54	17.10	16.17	15.15	14.28	13.76	11.91	11.41	
29	7	Gisborne Region	2.51	2.29	2.57	2.63	3.01	2.74	2.51	2.34	2.51	2.02	1.76	1.66	
30	8	Hawkes Bay Region	11.19	11.01	12.08	11.81	10.95	9.87	9.76	8.88	8.32	7.83	6.70	6.32	
31	9	Taranaki Region	7.59	7.45	7.35	7.41	6.87	6.36	6.05	5.69	5.41	5.15	4.52	4.30	
32	10	Manawatu-Wanganui Region	19.44	19.04	19.26	19.05	18.23	16.39	15.47	14.13	13.49	12.90	10.76	10.14	
33	11	Wellington Region	28.55	27.55	28.54	28.52	26.56	24.39	22.57	20.78	19.76	19.19	15.91	14.79	
34	12	Tasman-Marlborough Region	9.29	8.88	9.82	9.20	9.05	7.76	8.31	7.38	7.24	6.72	6.04	5.58	
35	13	Canterbury Region	36.97	34.82	40.46	38.34	37.45	33.89	33.65	29.88	29.37	27.06	24.38	23.34	
36	14	West Coast Region	3.65	3.35	3.54	3.50	3.53	2.99	3.12	2.60	2.71	2.39	2.26	2.10	
37	15	Otago Region	14.09	14.42	15.94	15.14	14.89	13.46	13.26	11.98	11.78	11.12	9.76	9.18	
38	16	Southland Region	7.82	7.50	8.18	7.74	7.42	6.62	6.57	5.89	6.00	5.64	5.12	4.85	
39															
40															
41	3	Carbon Dioxide (CO2)													

Summary_Emissions_Light_Petrol | Summary_Emissions_Fleet | **Summary_Emissions_Regions** | Summary_Fl

Figure A-4: OUTPUTS emission summary screenshot. All the cells in the summary sheets contain links to other parts of the workbook and therefore shouldn't be modified.

Sensitivity of the results to the vehicle fleet composition

As indicated above, one of the main assumptions in this inventory is that the vehicle fleet is the same throughout the country but in reality there are regional variations, both in terms of types of vehicles and in terms of age of vehicles. This is particularly relevant for Auckland that concentrates around 30% of the national VKT.

On-road emission studies (Bluett *et al*., 2013, Auckland Council, 2012) have found that Auckland's fleet is 1.5 years younger than the national average and therefore it is expected to have a different emissions profile than the rest of the country.

To test the impact of Auckland's fleet age, we estimated the national emissions for 2012 using two emission factor years. This was done by using 2011 fleet-year with 2012 VKT data for Auckland and comparing the total emissions with estimates for the 2012 fleet year. Table A-1 shows that the difference is less than 2% for the national emissions estimate and it is well within the uncertainty levels expected for this estimate.

Table A-1: National emission estimates for 2012 using the current fleet (2012 fleet-year) and an older fleet (2011 fleet-year).

Species	2011 fleet-year [Gg]	2012 fleet-year [Gg]	Difference
Carbon Monoxide (CO)	180	177	1.9%
Carbon Dioxide (CO_2)	9,492	9,467	0.3%
Volatile Organic Compounds (VOC)	10	10	1.5%
Nitrogen Oxides (NO_x)	30	30	1.3%
Particulate Matter (PM_{10})	1.9	1.9	1.8%
Particulate Matter ($PM_{2.5}$)	1.8	1.8	1.9%

Appendix B Indicator of Pressure: Contribution of natural sources/processes to PM_{10}

Introduction

MfE and Statistics New Zealand wishes to report on the contribution natural factors make to the state of New Zealand's air quality. Natural sources of particles are sea-salt, windblown dust, bushfires, volcanoes, pollens and other biogenic material. By accurately accounting for these natural sources their contribution to the impacts of PM_{10} pollution on health may be discounted. (Although the potential health effects of such particles cannot be separated from the total effects of PM_{10} they are sources beyond the control of management or abatement strategies.)

Both marine and crustal (and to a lesser extent, sulphate) particles have background and local sources. Background, or long-range sources (i.e. from outside New Zealand) are oceanic whitecaps (marine), dust, particularly from deserts (crustal) and volcanic and oceanic phytoplankton (sulphate) sources (Longley *et al*., 2008). Each of these sources are derived from natural processes, i.e. exist in the absence of any human activity. Local sources derived from natural processes include sea spray from coastal surf (marine) and wind-driven resuspension of dust from dry soils (crustal) and local volcanism (sulphate).

The implication is that the indicator represents particles derived from natural processes only. In practice, this means that it also represents background or long-range particles only. We believe that this is also consistent with the purpose of the indicator, i.e. to report on the contribution of processes and sources that are independent of human activity in New Zealand. The rest of this Appendix explains how this definition of "natural" particles has been implemented.

Previous estimates of natural source concentrations

Previously estimates of the contribution of natural sources to PM_{10} have been made in the HAPINZ study, and are described in more detail below. In that case, estimates were derived from chemical source apportionment studies by GNS Science conducted on particles collected on filter samples. The method used by GNS attributes a proportion of the total PM_{10} sampled to various sources, including marine, crustal and sulphate, based on statistical associations between their chemical composition and the anticipated composition of the source.

In the HAPINZ study it was assumed that marine and crustal particles were "natural" sources, and all other particles were "anthropogenic". However, this is not the only way that these particles can be classified, and it poses some challenges for deriving estimates for unmonitored locations.

Not all crustal or sulphate particles are created by natural process: anthropogenic processes can locally generate particles that in the HAPINZ study would have been classed as natural. This includes crustal particles from quarrying, construction, demolition, agriculture and vehicle-induced resuspension of dust. It also includes sulphate derived from the atmospheric transformation of anthropogenic emissions of sulphur dioxide – mainly from combustion of sulphur-containing fuels.

The original (2007) HAPINZ study used a “Background” value for different types of location derived from analysis of PM_{10} data as shown in table B-1. These values were then applied to all the towns used in the study (Fisher *et al*., 2007).

Table B-1: Background values used in HAPINZ 2007.

Category	Background PM_{10} Value ($\mu g\ m^{-3}$)
Inland (low population density)	2
Urban flat	4
Urban valley	6
Coast – not exposed	2
Coast – exposed	8
Coast – highly exposed	16

The 2012 update of HAPiNZ had access to some source apportionment data derived from filter measurements made in several New Zealand Towns and summarised in Table B-2. From these results an average value of 6.8 $\mu g\ m^{-3}$ was applied in all locations except when measured values were available (i.e. those from which the average value had been derived) (Kuschel *et al*., 2012).

Table B-2: Natural contribution to PM_{10} used in HAPINZ 2012. (in $\mu g\ m^{-3}$)

	Auckland	Blenheim	Hastings	Lower Hutt	Napier	Nelson	Wainuiomata
Marine	6.3	2.3	3.9	6.4	4.0	3.8	6.2
Crustal	1.6	1.3	1.7	3.1	1.9	3.1	1.3
Total	7.9	3.6	5.6	9.5	5.9	6.9	7.5

Updated estimates

To separate natural sources of PM from anthropogenic ones we have reviewed available source apportionment data. A summary of the known source apportionment studies and the available measured contributions of marine and crustal material to PM_{10} from those studies was provided by Dr Perry Davy of GNS (pers com Dec 2013) and is shown in Tables B-3 and B-4.

Table B-3: New Zealand Source Apportionment studies.

NZ APM Speciation Sites						
Location	**Sites**	**Dates**	**Sampling Frequency**	**Size fraction**	**Data owner**	**Report**
Northland	Whangarei	2004-2012	1 day-in-6	PM_{10}	NRC, GNS	In progress
Wellington Region	Masterton	2002-2004	1 day-in-3,	$PM_{2.5}$, $PM_{10-2.5}$	GNS, GWRC	PK Davy, PhD Thesis. Victoria University Wellington.
	Masterton	Winter 2010	Hourly	$PM_{2.5}$, $PM_{10-2.5}$	GNS	MSI APM Prog C05X903
	Upper Hutt	2000-2002	Variable	$PM_{2.5}$, $PM_{10-2.5}$	GNS, GWRC	PK Davy, PhD Thesis. Victoria University Wellington.
	Wainuiomata	2006-2008, 2011-	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	GWRC	GNS Client report 2009/188
	Seaview	2002-2004, 2005-2007	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	GWRC	PK Davy, PhD Thesis. Victoria University Wellington. 2008/160
	Wairarapa	Winter 2009	Daily (screening)	$PM_{2.5}$, $PM_{10-2.5}$	GWRC	GNS Client report 2009/365
	Mt Victoria Tunnel	Summer 2009		$PM_{2.5}$, $PM_{10-2.5}$	GNS	Ancelet *et al.*, 2011 (Atm Env)
	Baring Head	1996-1998		$PM_{2.5}$, $PM_{10-2.5}$	GNS	PK Davy, PhD Thesis. Victoria University Wellington.
	Raumati	Winter 2010	12-hourly	$PM_{2.5}$, $PM_{10-2.5}$	GWRC	GNS Client report 2011/83
Auckland Region	Kingsland	2004-2007	1 day-in-3	$PM_{2.5}$, PM_{10}	AC	GNS Client report 2009/165
	Takapuna	2006-	1 day-in-3	$PM_{2.5}$, PM_{10}	AC	GNS Client report 2010/262
	Takapuna	Winter 2012	Hourly	$PM_{2.5}$, $PM_{10-2.5}$	GNS	MSI APM Prog C05X903
	Queen Street	2006-	1 day-in-3	$PM_{2.5}$	AC	GNS Client report 2010/262
	Queen Street	2006-	Daily	PM_{10}	AC	GNS Client report 2010/262
	Penrose	2006-	1 day-in-3	$PM_{2.5}$, PM_{10}	AC	GNS Client report 2010/262

	Khyber Pass	2006-	1 day-in-3	$PM_{2.5}$, PM_{10}	AC	GNS Client report 2010/262
	Henderson	2006-	1 day-in-3	PM_{10}	AC	GNS Client report 2010/262
	Patumahoe	2010	Daily	$PM_{2.5}$, $PM_{10-2.5}$	AC	GNS Client report 2011/258
Nelson	Tahunanui	2008-2009	1 day-in-3	PM+	NCC	GNS Client report 2010/198
	Nelson City	2006-2012	1 day-in-6	$PM_{2.5}$, PM_{10}	NCC	In progress
	Nelson City	Winter 2011	Hourly	$PM_{2.5}$, $PM_{10-2.5}$	GNS	MSI APM Prog C05X903
Marlborough	Blenheim	2007	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	MDC	GNS Client Report, 2007
Otago	Dunedin	2010	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	ORC	GNS Client report 2011/131
	Alexandra	Winter 2011	Hourly	$PM_{2.5}$, $PM_{10-2.5}$	GNS	MSI APM Prog C05X903
Canterbury	Christchurch	2001-2002	Daily	$PM_{2.5}$	ECAN	A Scott PhD Thesis. University of Canterbury
	Timaru	2006-2007	1 day-in-3	$PM_{2.5}$	ECAN	ECAN report
	Woolston	2013-2014	2-hourly	$PM_{2.5}$, $PM_{10-2.5}$	ECAN/GNS	In progress
	Christchurch (Coles Place)	2013-2015	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	ECAN/GNS	In progress
Hawkes Bay	Hastings	2006-2007	1 day-in-3	$PM_{2.5}$, PM_{10}	HBRC, NIWA, GNS	NIWA Client Report CHC2007-137
	Meanee Rd	2006 +2008	1 day-in-2 (screening survey)		HBRC	GNS Client report 2009/175
	Napier	2008-2009?	1 day-in-3	$PM_{2.5}$, $PM_{10-2.5}$	HBRC	Hawkes Bay Regional Council report - Envirolink 869-HBRC130

Table B-4: A summary of the measured contributions of marine and crustal material to PM_{10} at locations around New Zealand.

Location	Sites	Total PM_{10} ($\mu g\ m^{-3}$)	Marine aerosol component ($\mu g\ m^{-3}$)	Crustal matter component ($\mu g\ m^{-3}$)	Comments
Wellington Region	Masterton	16.4	4.3	3.1	
	Upper Hutt	10.9	3.9	2.1	
	Wainuiomata	13.4	5.4	1.3	
	Raumati	23.9	6.6	1.2	Winter only
Auckland Region	Kingsland	15.9	6.6	1.1	
	Takapuna	16.2	6.5	1.0	
	Queen Street	18.1	6.9	1.4	
	Penrose	17.6	7.0	1.4	
	Khyber Pass	18.5	7.5	1.5	
	Henderson	13.8	6.2	0.9	
	Patumahoe	10.8	5.3	2.4	
Nelson	Tahunanui	20.6	3.8	3.1	The crustal component at Tahunanui is enhanced by local industrial area; 1:1 relationship between marine aerosol at Tahunanui and Nelson South
	Nelson City	19.6	3.8	2.7	
Otago	Dunedin	27.2	5.1	7.4	Crustal matter concentrations affected by local anthropogenic activities (construction of stadium)
	Alexandra	33.2	0.3	0.6	2 months data only so not representative of annual average
Hawkes Bay	Hastings	19.6	3.9	1.7	
Marlborough	Blenheim	10.7	2.3	1.3	

Note: Precision of results is approximately ±10%.

A source apportionment study is underway in Christchurch but results are not expected for another year.

Comparison with 2012 and synthesis of new values

Auckland

Auckland source apportionment data used in the 2012 HAPINZ update came from Takapuna, Queen St, Kowhai, Khyber Pass Rd and Penrose and were taken from earlier analyses. Auckland data were reanalysed in 2010 and published in November 2011, too late for the 2012 HAPINZ update. The latest supplied data also includes Kingsland, Henderson and Patumahoe (although not Kowhai due to the closure of the site). Values for both sets of data are shown in Table B-5.

Table B-5: Measured contributions of marine and crustal material to PM_{10} in Auckland before and after 2011.

Location	HAPINZ 2012 Marine ($\mu g\ m^{-3}$)	HAPINZ 2012 Crustal ($\mu g\ m^{-3}$)	HAPINZ 2012 Total ($\mu g\ m^{-3}$)	This study Marine ($\mu g\ m^{-3}$)	This study Crustal ($\mu g\ m^{-3}$)	This study Total ($\mu g\ m^{-3}$)
Takapuna	6.9	1.5	8.4	6.5	1.0	7.5
Queen Street	5	1.8	6.8	6.9	1.4	8.2
Kowhai	6.1	1.2	7.3	6.6	1.1	7.7
Khyber Pass	6.9	1.6	8.5	7.5	1.5	9.0
Penrose	6.6	1.7	8.3	7.0	1.4	8.4
Kingsland				6.6	1.1	7.6
Henderson				6.2	0.9	7.0
Patumahoe				5.3	2.4	7.7
Average (without Patumahoe)*	6.3	1.6	7.9	6.8	1.2	8.0

* Note: Patumahoe is excluded from the average because it is outside urban Auckland. Precision of results is approximately ±10%.

Wellington

Since the 2012 HAPiNZ Update new data has become available for Masterton and Wainuiomata. This data has been merged with the old data to produce the new annual mean values shown in Table B-6.

Table B-6: Marine and crustal contribution to PM_{10} in Wellington.

Wellington	Marine ($\mu g\ m^{-3}$)	Crustal ($\mu g\ m^{-3}$)	Total ($\mu g\ m^{-3}$)
Wainuiomata	5.4	1.3	6.7
Masterton	4.3	3.1	7.4
Lower Hutt	6.4	3.1	9.5

National

Since the 2012 HAPiNZ Update new data has become available for Nelson and Dunedin. This data has been merged with the old data to produce the new annual mean values shown in Table B-7.

Table B-7: Marine and crustal contribution to PM_{10} in 10 towns or cities in New Zealand.

	Marine ($\mu g\ m^{-3}$)	Crustal ($\mu g\ m^{-3}$)	Total ($\mu g\ m^{-3}$)
Auckland	6.5	1.4	7.9
Blenheim	2.3	1.3	3.6
Hastings	3.9	1.7	5.6
Napier	4.0	1.9	5.9
Lower Hutt	6.4	3.1	9.5
Wainuiomata	5.4	1.3	6.7
Nelson A	3.8	2.7	6.5
Tahunanui	3.8	3.1	6.9
Dunedin	5.1	7.4	12.5
Masterton	4.3	3.1	7.4

Indicator of pressure

For the Indicator of Pressure: **the average contribution of natural processes to PM_{10}** a modification to the natural source contributions calculated above is implemented in an attempt to remove all contributions from human activities. Crustal material can be from a variety of sources including both natural and anthropogenic but it is not possible to separate them using the measurement techniques available. Discussion with Dr Davy (GNS) leads us to conclude that in the absence of better data a value of 1 $\mu g\ m^{-3}$ for the long term average **natural component** of crustal material (i.e. excluding crustal material resuspended into the air by human activities) is a reasonable assumption at most locations in NZ. In addition, Dr Davy estimates that there is a long-term average background secondary sulphate contribution from natural sources (mainly oceanic) of approximately 1 $\mu g\ m^{-3}$ (*Pers. comm*. Dr Perry Davy, December 2013, informed by (Davy *et al*., 2011, Allen *et al*., 1996, Davison *et al*., 1996, Wylie & De Mora, 1996). Therefore, for the purposes of the indicator of pressure, the natural component is the marine contribution plus 2 $\mu g\ m^{-3}$ (one each for crustal and sulphate).

Figure B-1 presents this data in terms of splitting total PM_{10} into that derived from natural processes and anthropogenic processes. This represents our best understanding at present of the relative contribution of these two sources to PM_{10} and its variability between sites. Most data comes from Auckland and Greater Wellington where natural processes contribute 41 to 62% of total PM_{10}[5].

[5] Excluding the rural Patumahoe site near Pukekohe.

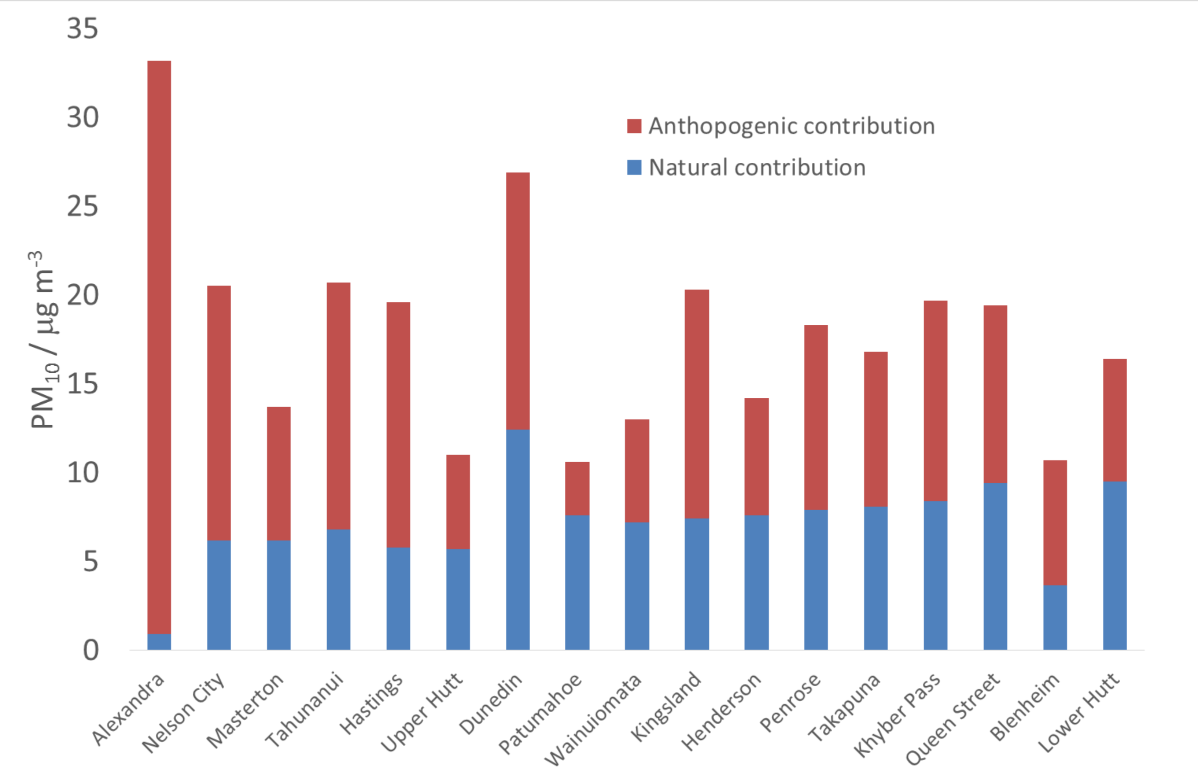


Figure B-1: Average contribution of anthropogenic and natural processes to PM_{10} at sites across the country. Derived from source apportionment studies conducted by GNS. Data from Alexandra is winter only and is not representative of annual mean concentrations.

Geographical extrapolation and the Indicator of Impact

Given the sparseness of measurements care must be taken when trying to use these data to generate values that are nationally representative. For the calculation of anthropogenic health impacts across the country an estimate of the natural component of PM_{10} at every location across the country is necessary. In this case we were instructed by MfE to implement the established approach used in HAPINZ, i.e. using a definition based on source profiles rather than natural processes, in order to maintain consistency with previous health effects estimates.

Filter-based source apportionment data of sufficient duration is currently available from only 16 locations in only 10 towns or cities around the country[6]. Any given site can be strongly influenced by highly localised sources making them unrepresentative. This makes extrapolation to a national indicator problematic.

For example, high levels of crustal particles have been attributed to local industry in Dunedin and Tahunanui. Meanwhile, high levels of marine particles at Lower Hutt have been attributed to the site's close proximity to the coast.

The method used in HAPINZ (and in the Indicator of Impact in this work) does not account for these biases due to the limited data available and calculates a national unweighted average natural source contribution. This value is then applied to all towns, cities and rural

[6] Data from Alexandra and Upper Hutt is considered unsuitable for this purpose.

areas with no measurements. The value calculated for this work is 7.3 μg m^{-3}. The calculation is provided in spreadsheet B, sheet SD3.

This carries the risk of leading to some potential errors. For instance, it is physically plausible that Northland Region has concentrations from natural sources closer to Auckland than the rest of the country, especially in the urban centres which are mostly near the coast. However, there are no data to verify this and so we apply the national default on the understanding that this may be an under-estimate.

Estimates are most uncertain for inland South Island. It is likely that sea salt concentrations are much lower in this region due to distance from the coast and deposition as air masses pass over the Alps. This is apparent at Te Anau in Southland where observed PM_{10} concentrations are 6.9 μg m^{-3}, i.e. lower than the national default value for natural sources. Again in this instance we over-ride the default value in the calculations of impact so that the natural sources make up 100 % of PM_{10}.

More generally, the contribution of naturally-resuspended crustal particle (soil) concentrations in South Island may be under-estimated due to the relative dryness and föhn winds in the eastern lee of the Alps. However, population exposures in this region are very low and it is unlikely that these uncertainties will contribute significantly to the estimated health costs of anthropogenic PM_{10}.

Table B-8: Summary of how particles are considered natural or anthropogenic in this work.

particles	Indicator of pressure	Indicator of impact/HAPINZ
Marine	Natural	Natural
Wind-suspended soil	Natural	Natural
Anthropogenically resuspended soil (agriculture, demolition, construction, quarrying, vehicle motion)	Anthropogenic	Natural
Volcanic events	Excluded (too small on annual basis)	Excluded (too small on annual basis)
Trans-Tasman dust transport	Excluded (too small on annual basis)	Excluded (too small on annual basis)
Oceanic biogenic sulphate	Natural	Anthropogenic
Volcanic sulphate	Natural	Anthropogenic
Other sulphate	Anthropogenic	Anthropogenic
Canterbury earthquakes[7]	Anthropogenic	Anthropogenic

[7] It is not yet analytical possible to separate the effects of the wind-driven resuspension of drying liquefaction silt, from traffic-related silt resuspension, demolition, construction and vehicle-related particles.

Appendix C Indicator of State: Mean PM_{10}

Introduction

Data and calculations for the Indicator of State can be found in spreadsheet D_Indicator of State PM10_NIWA.

The criteria for an indicator set out by MfE and Stats NZ (Table 1-1) require that the indicator is relevant in coverage, content and detail, accurate, timely, accessible and interpretable, with relevance and accuracy being the primary considerations. In the case of PM_{10} data however, relevance and accuracy are in conflict. This is primarily because of gaps and bias in the monitoring data. Gaps can be filled or biases compensated for by introducing proxy estimates for PM_{10} data. This increases relevance (particularly coverage and representativeness) but at the expense of accuracy, as estimated values of PM_{10} can have substantial uncertainties. In this section this conflict, and its implications for the method adopted to provide the desired indicators, is considered in detail.

Choice of method for constructing a national indicator of state from PM_{10} monitoring data

Although PM_{10} is the most widely monitored pollutant, it is not possible to measure everywhere, so judgements have to be made about how to compile a national average from limited coverage. There are several choices, including;

- Average of **all** or **selected** measurements from across the country
- **Simple** or **weighted** average of measurements from across the country
- **Modelled estimates** from across the country (often combined with above to fill monitoring gaps

Different countries approach reporting at the national level in different ways, according to their own needs, resources and available data. Producing a national value is problematic for large countries with huge geographical variation, such as Russia, China and Australia, although it is done for Canada. Modelling approaches are more common in assessments covering such areas. Many countries of similar size to New Zealand do not report nationally aggregated values, but opt instead to report data from individual cities or measurement sites (e.g. Bangladesh – 2 sites, Tunisia – 5 sites, Malaysia – 51 sites). In doing so, the issues of how to represent areas that are not monitored are avoided and the question of how representative the measurements are of their immediate locale takes precedence.

Where data from multiple sites are aggregated, a selection of sites can be chosen to represent (for example) a location or a population. This approach is used across the European Union – for example the UK's national Average Exposure Index combines data from 47 'urban background' measurement sites, excluding measurement sites with other designations. Weightings can also be applied to allow for differences in geographic or population coverage. For example, population-weighting has been used in pan-European assessments.

An alternative approach for aggregating PM_{10} is to apply a population-weighting to both measured data and estimate PM_{10} levels for the remainder of the population which is not represented by current monitoring. This method was used in the New Zealand HAPINZ study of 2012 and is used in this work to develop the Indicator of Impact, which is based upon HAPINZ. A review and evaluation of this method and the population weighting used to calculate the indicator is included below.

Also included below are example analyses of the data used to calculate the indicator, including differences between different urban types and between the North and South islands.

Bias within the current monitoring sites

Peak sites

The key issue to be considered in generating such an indicator is that the underlying raw data – observed PM_{10} concentrations – are derived from monitoring stations which have not been established to meet MfE's Indicator criteria. Rather, monitoring sites have been chosen by individual Regional and District Councils to meet the requirements of the Resource Management Act for the purposes of monitoring compliance with the NES. Such compliance monitoring requires that peak sites, rather than more generally-representative sites are monitored, and does not require monitoring of locations with lower, compliant concentrations. There are some monitoring sites in the national network that do measure in non-peak locations. Consequently, the raw data do not provide full geographical coverage, but one potentially biased towards peak sites.

Full quantification of this effect will require a one to two year research programme and the establishment of new monitoring sites (possibly only short-term). However, exploratory research has indicated the potential scale of the effect. For example, Figure C-1 shows the estimated enhancement of observed PM_{10} levels due to proximity to state highways at the 15 sites estimated to be most affected by emissions. These estimates were made using the Roadside Corridor Model developed by NIWA (Longley et al., 2011). Only 4 sites show a significant elevation in PM_{10} levels, all of which are adjacent to State Highway 1 (3 in Auckland and 1 in Wellington). For all other sites the impact is $\leq 1\ \mu g\ m^{-3}$. At the time of writing research is ongoing to estimate similar highly local impacts due to street canyons, coastal emissions and local topography.

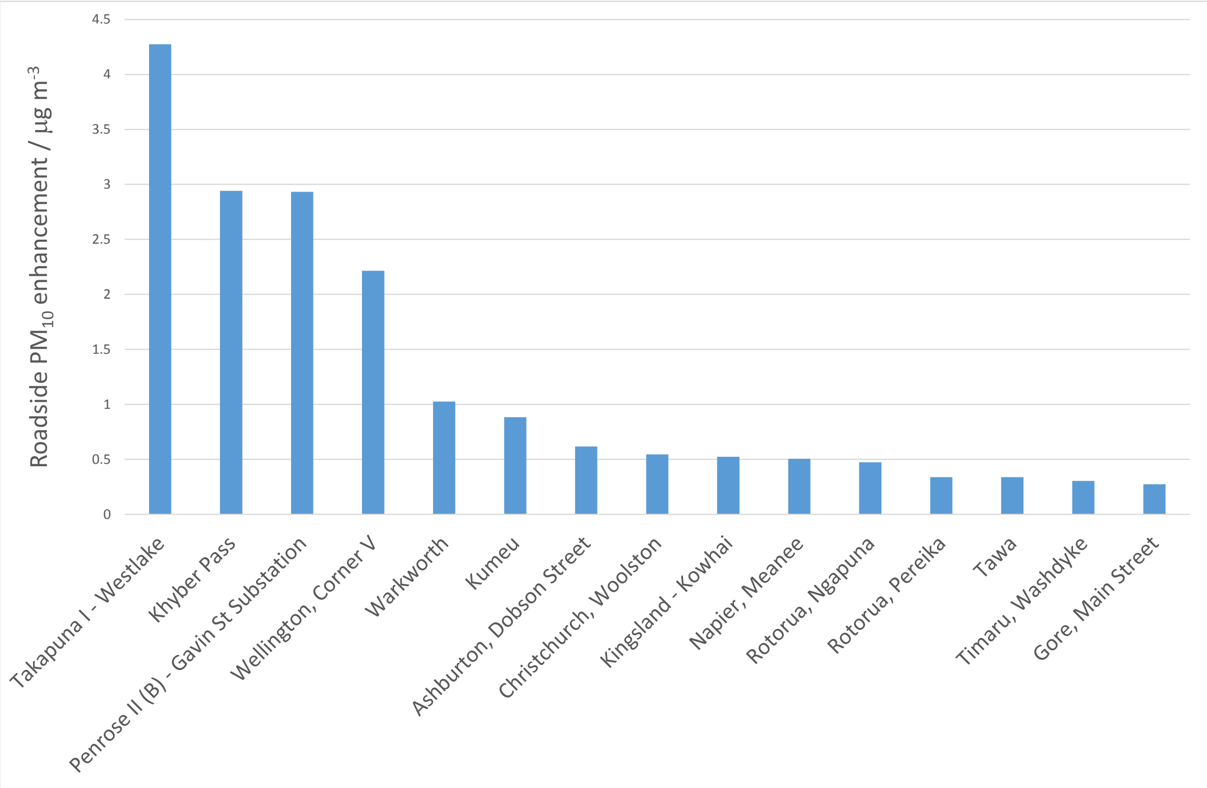


Figure C-1: Estimated enhancement of observed annual mean PM_{10} due to immediately adjacent state highways at top 15 affected sites.

The number of sites available providing sufficient continuous data to inform the indicator (i.e. >75% valid data per year to provide an acceptable estimate of annual mean concentration) rose sharply from 2004 (11 sites) reaching a peak in 2009 (69 sites) in response to the NES coming into force. Since then the number of sites has slowly fallen to 55 in 2012 (including 3 'rural' sites not used to calculate the indicator). The reduction has largely been related to removal or discontinuation of sites with concentrations below the NES (i.e. the airshed is deemed to be compliant by the Council and further monitoring is not required), as well as reallocation or reduction of resources available for monitoring.

Indicator options

A: Including estimates for unrepresented populations using the HAPINZ method

Using the HAPINZ method to evaluate national population-weighted PM_{10} involves the need to provide PM_{10} estimates for locations without current monitoring.

It was noted above how the approach adopted for dealing with urban areas with more than one monitoring site differed from the approach used in the 2012 HAPINZ assessment. In brief, the 2012 HAPINZ study only used data from one site to represent other parts of the urban area if that site was considered generally representative.

Being mindful of MfE's criteria for these indicators, we find that the HAPINZ approach to unrepresentative sites, while sensible, is only weakly supported by evidence.

In view of these issues, and in an attempt to maintain representativeness, timeliness, consistency and simplicity in developing the Indicator of State we made the much simpler assumption that data from all sites within UCDs are included and that the urban area is represented by the mean of data from all sites.

For completeness, the national population-weighted mean PM_{10} using the HAPINZ method (with minor adjustments necessitated by changes in data availability, described in Appendix E) are presented in Table C-1 for comparison with the Indicator of State. The HAPINZ values are 2.2 – 2.7 $\mu g\ m^{-3}$ lower than the Indicator of State. This is because the two principal differences between the methods both act to add more weight to areas with lower concentrations:

- HAPINZ introduces additional PM_{10} estimates for the unmonitored parts of the country which are based on the assumption that these will be largely low concentration areas,
- By including approaches to compensate for the bias of monitoring locations being biased towards peak sites the average concentrations of Christchurch, Auckland and possibly Wellington are slightly reduced but the reduction is weighted by large populations.

All approaches show a similar decreasing trend.

Table C-1: Nationally-aggregated Indicator of State (PM_{10}), 2006-2012.

Year	Population-weighted mean PM_{10} ($\mu g\ m^{-3}$) (Indicator of State)	Population-weighted national mean PM_{10} (HAPINZ method) / $\mu g\ m^{-3}$
2006	17.0	
2007	17.0	
2008	16.9	14.2
2009	16.4	
2010	15.7	
2011	16.0	
2012	15.6	13.4

B: Comparing the Indicator with simple averaging

Table C-2 compares the unweighted annual mean concentration[8] with the population weighted Indicator of State. For every year except 2007 the unweighted average concentration is higher than the population weighted average concentration. This is due to larger population centres such as Auckland, Greater Wellington and the smaller cities in the North Island having relatively low concentrations. The PM_{10} sites recording higher concentrations typically represent much smaller populations and so carry less weight. Overall the difference between an unweighted national average and a population weighted average concentration is between -2 % and +4 %.

[8] The unweighted annual mean excludes rural sites, so as to be consistent with the sites used to calculate the indicator.

Table C-2: The Indicator of State (population weighted PM_{10}) compared with nationally-aggregated annual mean, 2006-2012.

Year	Population-weighted annual mean PM_{10} ($\mu g\ m^{-3}$)	Unweighted annual mean PM_{10} ($\mu g\ m^{-3}$)
2006	17.0	17.5
2007	17.0	16.7
2008	16.9	17.2
2009	16.4	16.7
2010	15.7	16.2
2011	16.0	16.6
2012	15.6	16.1

C: Comparing the Indicator with a three year running mean

Although an annual mean concentration best represents the typical exposure of most New Zealanders while remaining sensitive to significant atypical periods of air quality, longer term averages can provide other insights, such as balancing out the effect of inter-annual variation in meteorological conditions and providing insight into long-term trends in air quality.

Using the same data as the Indicator, a 3-year running mean was calculated, by averaging the preceding three years of data from a site (e.g. the PM_{10} value for 2012 is the mean of the annual means of 2010, 2011 and 2012). This has the added value of increasing the number of data points by providing data for missing years, whereby if a site has data for the preceding two years but not the current year, an average can still be calculated. As three year's data is required for a running 3-year mean a comparison with the Indicator starts with the year 2008, as shown in table C-3. The difference between the approaches ranges from -1 % to 4 %.

Table C-3: The Indicator of State (population weighted PM_{10}) compared with a population weighted 3-year running mean, 2008-2012.

Year	Population-weighted annual mean PM_{10} ($\mu g\ m^{-3}$)	Population-weighted 3-year running mean PM_{10} ($\mu g\ m^{-3}$)
2008	16.9	17.0
2009	16.4	16.6
2010	15.7	16.3
2011	16.0	15.9
2012	15.6	15.6

Figure C-2 shows the Indicator of State (population weighted annual mean) compared with the unweighted annual mean of the same data and the population weighted running 3-year mean. Both the Indicator and the unweighted annual mean show higher values in 2011, while the 3-year running mean 'smooths over' this increase, showing a consistent downward trend in concentrations.

In short, the use of the annual mean illustrates year to year variation better, while the 3-year running mean better illustrates the longer term trend in air quality.

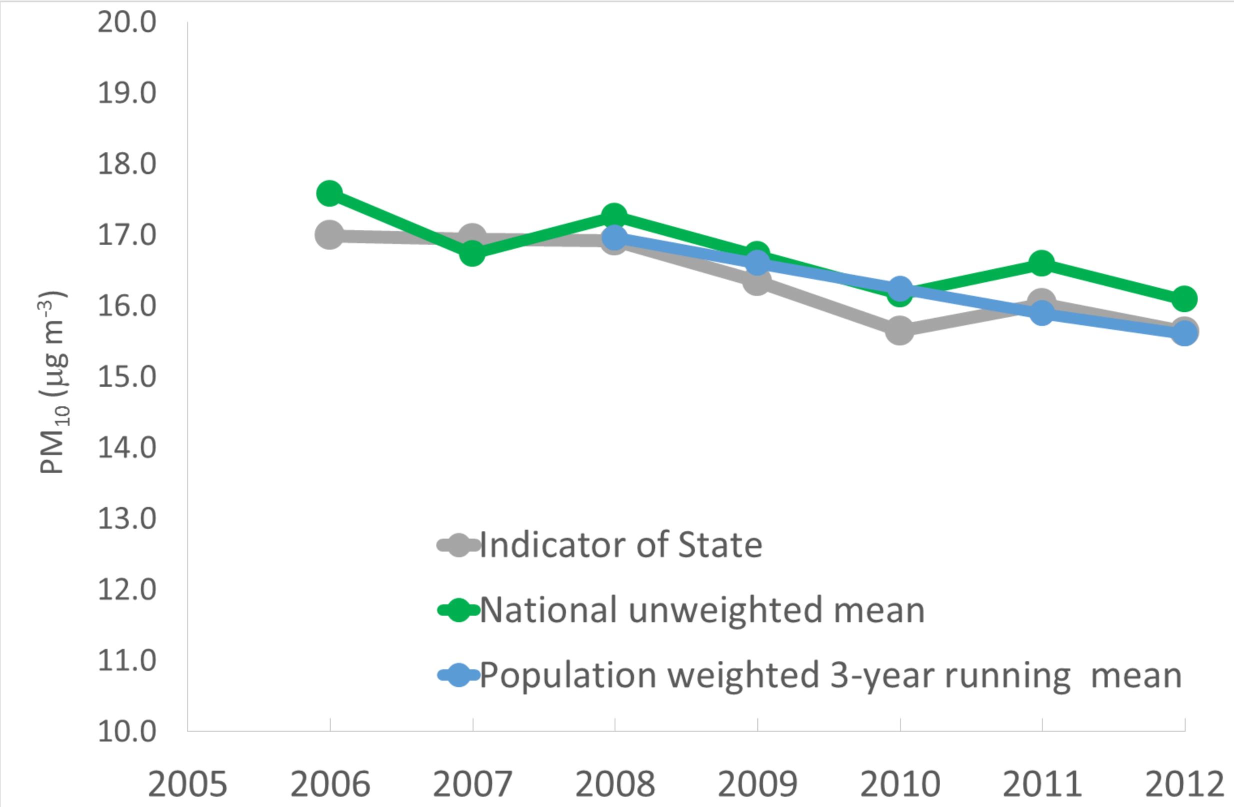


Figure C-2: The Indicator of State compared with simple averaging and population weighted 3-year running mean.

Conclusions and recommendation

The tests reported above show that the indicator has a low sensitivity to population weighting. Adopting a running 3-year mean makes long-term trends clearer but loses information on deviations from those trends. Considering the purposes of the indicator we recommend that, to maximise the information delivered and transparency, whilst minimising bias, thee indicator of state is based on a population-weighted annual mean PM_{10}.

Appendix D: Geographical variation in Indicator of State

Comparison of different urban types

In order to create a single national indicator, data from 52 sites (as of 2012) have been aggregated in a manner consistent with the criteria for indicators developed by MfE and Stats NZ. The essence of these criteria is to deliver primarily relevance (including representative geographical coverage) and accuracy, but also timeliness, accessibility, coherence and interpretability.

Every monitoring site sits within a Census Urban Centre Descriptor (UCD) and can be grouped based upon that UCD's population and location. The reasoning behind these groups is that each group has its own PM_{10} data (thus illustrating coverage and aiding accessibility/interpretability) and gaps in the representativeness of the available monitoring data in terms of urban form or population, can be clearly identified. The groups used in this comparison are:

- Auckland (metro area)
- Christchurch
- Greater Wellington (excluding Wairarapa)
- "Smaller Cities" (Hamilton + Tauranga + Dunedin + Palmerston North)
- "Medium Towns" (population between 25,000 and 60,000)
- "Small Towns" (population less than 25,000)
- Rural areas

For each group, the population weighted annual mean PM_{10} can be calculated and compared with the national Indicator of State. It can be seen from Figure D-1 that the downward trend is broadly consistent across all groups with the possible exception of Christchurch. The 2011 data for Christchurch is clearly effected by the seismic activity in the city. The 2012 data recovers somewhat from this but it is unclear at this time, whether the slight downward trend seen in the Christchurch before 2011 is resuming. For every year, concentrations in Christchurch are clearly elevated above the **average** of all other groups and are roughly double the lowest average values (from Greater Wellington). Mean concentrations for Greater Wellington are substantially below the national average, due in part to its windy situation.

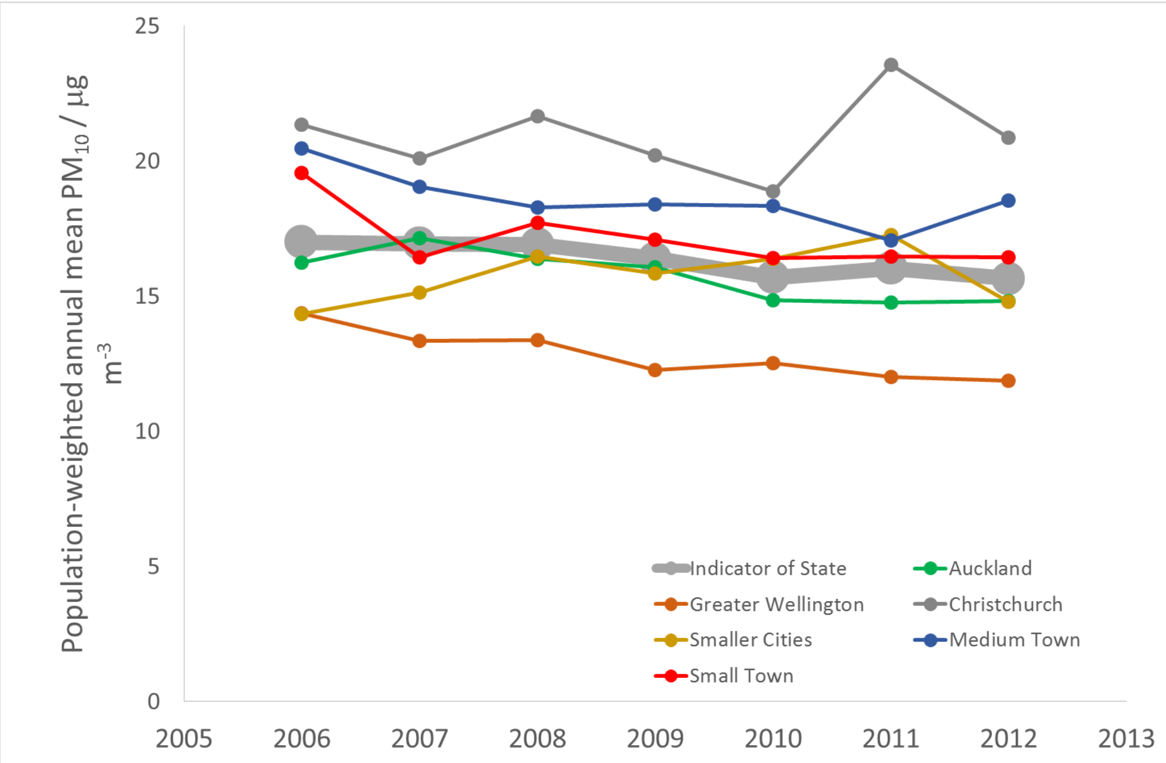


Figure D-1: The national Indicator of State compared to the population weighted mean PM_{10} for each urban group.

Figure D-2 shows the range of annual average PM_{10} concentrations measured at each site in each group and overall. (Individual site concentrations are **not** population weighted.) Where a group has enough data points boxplots are used to show the range of concentrations. Where a group has fewer measurement sites, individual data points are plotted. The WHO guideline value of 20 µg m^{-3} is shown as the blue dashed line across each plot and the value of the Indicator of State each year is shown as a red diamond.

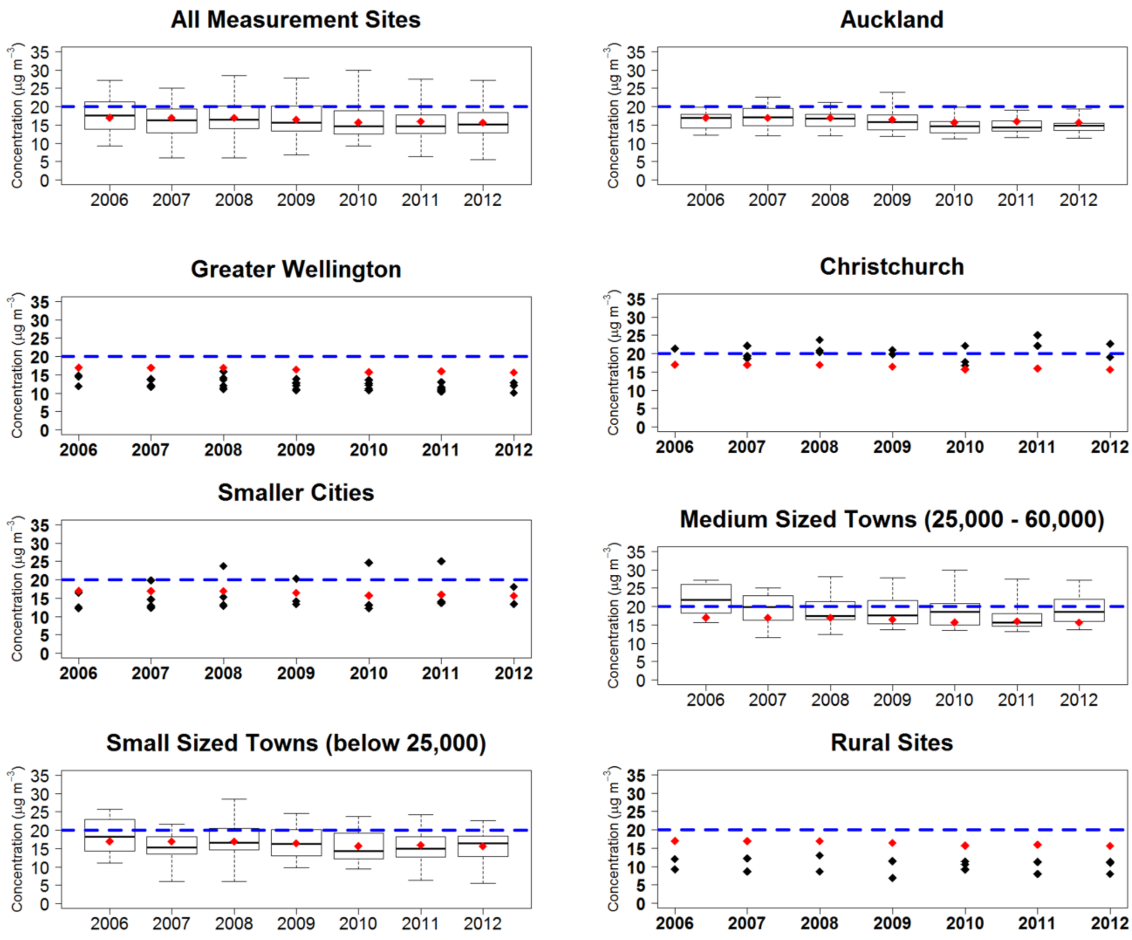


Figure D-2: Box and whisker plots of PM_{10} data for each group. (including WHO PM_{10} guideline value (blue dashed line) and Indicator of State (red diamonds).

From these charts the following features can be identified:

- Single urban areas (such as Auckland) can have as large a range of concentrations as all the Small or Medium towns together,
- All groups except Christchurch have some values below 15 $\mu g\ m^{-3}$,
- The highest values have generally been recorded in Medium sized towns.
- Rural sites generally measure the lowest concentrations, along with some small sized towns, as described in the next section.

Comparison of North and South Island

In order to further illustrate the representativeness of the current monitoring data around the country, two groups were further divided into North and South Islands. Medium and small sized towns were plotted as individual points (with the WHO guideline value as a blue dashed line and the Indicator of State as red diamonds). Figure D-3 shows the medium sized towns and Figure D-4 the small sized towns.

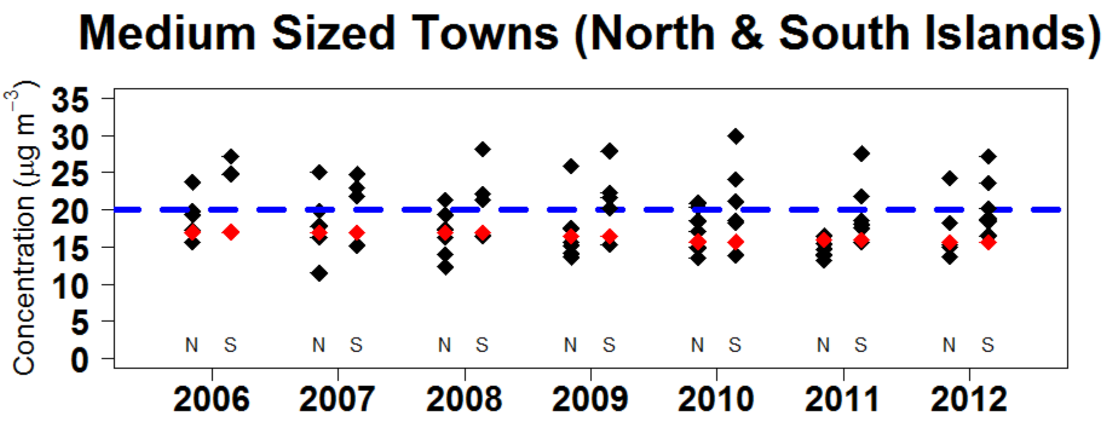


Figure D-3: Annual mean PM_{10} measured in Medium sized towns. (including WHO PM_{10} guideline value (blue dashed line) and Indicator of State (red diamonds).

Both figures show that in general, sites in the South Island measure higher concentrations than the North Island. This is explained by the South Island's greater requirement for residential heating and thus, greater wood-burning emissions in the south.

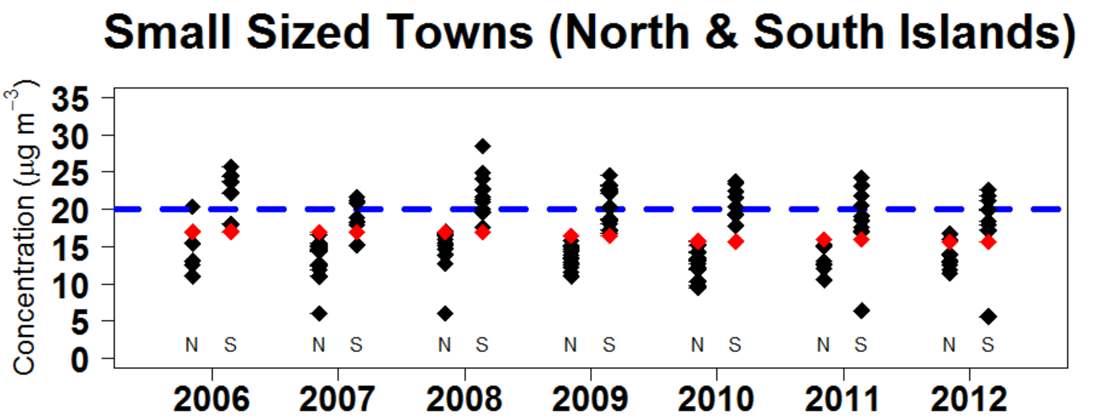


Figure D-4: Annual mean PM_{10} measured in Small sized towns. (including WHO PM_{10} guideline value (blue dashed line) and Indicator of State (red diamonds).

An example can be made of four very low data-points seen in Figure D-4. Two in the North Island for the years 2007 and 2008 come from a monitoring site in Kaitaia, while two in the South Island in the years 2011 and 2012 come from a monitoring site in Te Anau. These very low concentrations indicate that these two sites, although situated within a UCD may be more representative of a true pristine air background concentration than an urban area. Without the development of dedicated background sites within New Zealand, this cannot be confirmed and so the representativeness of these sites remains uncertain.

Table D-1 shows the number of data points, average PM_{10} concentrations and population weighted average concentration for the 2012 data for four groups. The number of sites are relatively even between the islands, apart from the rural group, which has no data from the South Island. The smaller cities and small towns groups in the North Island have lower average PM_{10} concentrations than their South Island counterparts, while the difference for medium sized towns is not as great. Once the concentrations data is population weighted the difference for medium sized towns increases.

Table D-1: Difference between North and South Island values for smaller cities, medium and small towns and rural groups for 2012.

Parameter	Group	Total	North Island	South Island
Number of data points for 2012	Smaller Cities	3	2	1
	Medium Towns	11	5	6
	Small Towns	21	12	9
	Rural	3	3	0
Average PM_{10} concentration for 2012 ($\mu g\ m^{-3}$)	Smaller Cities	15.0	13.4	18.1
	Medium Towns	19.2	17.3	20.8
	Small Towns	15.7	13.8	18.3
	Rural	10.1	10.1	n/a
Population weighted average concentration for 2012 ($\mu g\ m^{-3}$)	Smaller Cities	14.8	13.4	18.1
	Medium Towns	18.1	16.3	21.1
	Small Towns	16.4	13.9	19.5
	Rural	n/a	n/a	n/a

Appendix E: Indicator of Impact: PM_{10} health outcomes

Intake

Since the health effects of pollution, measured as PM_{10} in this case, are directly related to the amount ingested, i.e. the dose, we have calculated a measure of how much PM_{10} is breathed in by people. This measure, known as **intake**, is directly related to both the concentration of PM_{10} in the air and the dose received by people breathing in the pollutant.

Mean intake of PM_{10} is the average mass of particulate matter inhaled per capita, per unit time across the population. It may be more intuitively understood than exposure, as it is what the population breathes in. Total intake is the sum of intake across the population, i.e. the total mass of particles inhaled per unit time by everyone. It is a simple proxy for the total national burden of PM_{10}. For ease of interpretability it is expressed here as grammes per day. It is based on the assumption that inhalation rates are constant across the population and throughout the year at $20m^3$/day.

Review and update of 2012 HAPINZ Exposure Model

Introduction

As part of this work, the 2012 HAPINZ Model was reviewed and updated. The main features of this review and update focussed are summarised in Table E-1.

Table E-1: Data inputs to the 2012 HAPINZ model and 2013 update.

	2012 Model	This (2013) update
PM_{10} exposure data	Nominally mean of 2006 – 2008 inclusive. Data from other years was used to fill gaps	Nominally mean of 2010 – 2012 only where data meets criterion of 75 % valid data for each year
Population data	2006 census	2013 census
Health baseline data	2005 - 2007	2005 – 2007

Since 2006 the number of monitoring sites operating, and number of those providing >75% data coverage per year has varied, rising to a peak in 2009 and falling steadily since then (Figure E-1). These changes arise from a number of reasons including site relocation, sites reduced to winter-only, temporary closures, instrument redeployment, network consolidation, and expansion to previously unmonitored locations (often smaller towns). These changes are the main reason why the 2012 Model required review and some minor revisions.

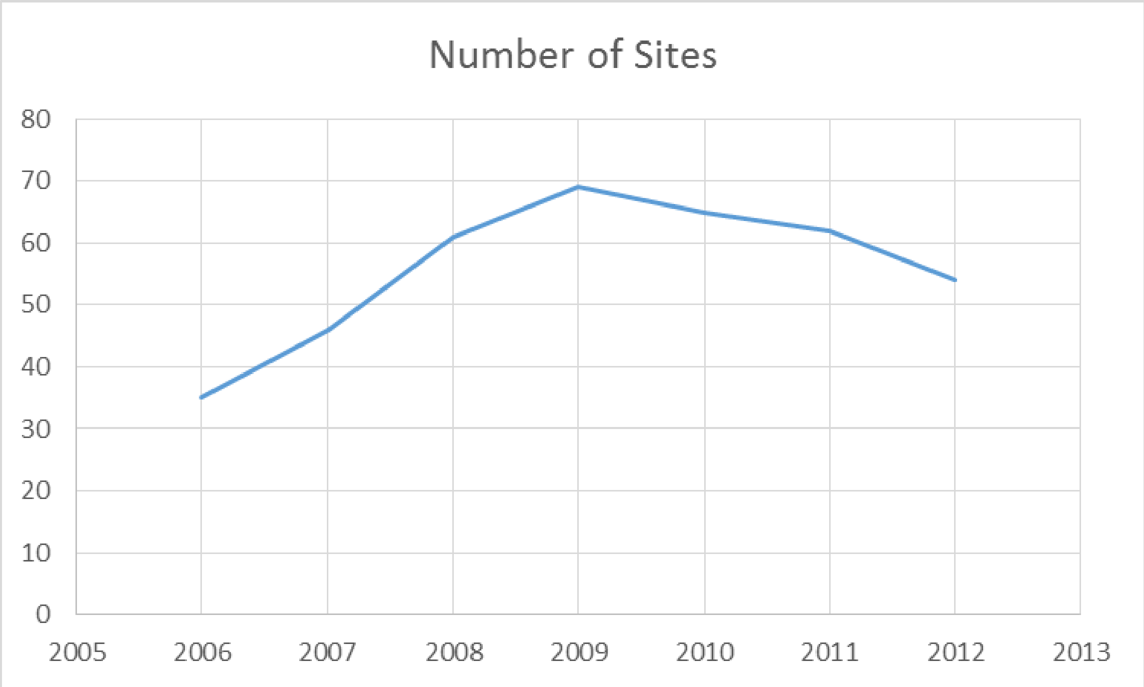


Figure E-1: Trend in number of monitoring sites with >75% annual PM_{10} valid data across the whole country.

Detailed review of the method

Changes to the method are summarised in Table E-2 and are described below.

Auckland

The 2012 Model assigned specific estimates to each individual CAU based on emission inventories. New emissions estimates are not consistently available, and many of the CAUs in Auckland have changed. In this work we have kept the relationship between emissions and concentrations constant and reassigned previous emissions values to the new CAUs, which were then used to perform a linear regression between the observational 2010-2012 PM_{10} data and the emission density estimates such that

$PM_{10\ (2010\text{-}2012)}$ = (0.00064 x emission density) + 11.4

This formula has been applied to all Auckland CAUs to generate new estimates.

Other monitored airsheds

The 2012 Model is inconsistent in regard to airsheds containing more than one operating monitoring site. In Rotorua and Invercargill, as with Auckland, a regression against emission density was applied. In Tauranga data from two sites were averaged. In Christchurch data from only one of three monitoring sites (Coles Place) was applied to most of the city.

To improve national consistency we have chosen to discard the emission-based approach for Rotorua and Invercargill. Furthermore, by 2012 Invercargill and Tauranga both only have one monitoring site. Rotorua has two, but one is in the industrial area of Ngapuna, outside the main urban area of the city. Hence for these three cities the general rule of extrapolating data from a single site is applied. In Christchurch, there have been three long-term monitoring sites maintained. Alongside the residential Coles Place site, the residential

Burnside site was closed at the end of 2010 and the Woolston site is considered unrepresentative of the majority of the city due to its industrial and roadside location. Therefore we apply the rule that Christchurch is represented by the average of Burnside (where data is available) and Coles Place, but exclude data from Woolston.

No further changes were implemented for monitored airsheds.

Unmonitored areas

No changes were implemented compared to the HAPINZ 2012 Update for any unmonitored areas with one exception. Category 1 Tauranga originally used the mean of two sites but only one site was still operating for this report, so it was used by itself.

Rural areas

The method of assignment was unchanged, with every rural CAU in the country effectively being assigned the value of PM_{10} from Pongawaka in Bay of Plenty.

Other changes required

Changes to Census Area Units

The 2013 census introduced a number of new census area units by splitting former units. This made it necessary to introduce the new units to the model spreadsheet, whilst removing the defunct ones. In the case of Auckland new emission density data was not available for the new CAUs. In this case the emission density of the predecessor unit areas was reproduced. Health incidence data from the defunct areas was split in proportion to populations of the new areas.

Update of emission estimates

Emission estimates were not updated.

$PM_{2.5}$ estimates

We consider the method used to generate $PM_{2.5}$ estimates in the 2012 HAPINZ model can be improved in the near future- see section 7 for more information.

Changes to the HAPINZ spreadsheet

The basic structure of the 2012 HAPINZ Exposure Model workbook ("A") was retained ("B"). However, as neither the emission density estimates, the industrial emissions, nor the breakdown of different anthropogenic sources were being updated several of the worksheets were deleted as they were deemed non-essential for the purposes of this work. Worksheet ED2 was re-formatted for clarity.

Similarly, the basic structure of the HAPINZ Health Effects spreadsheet ("C") was also retained. However, the scenario sheets were removed as they are not relevant to the purposes of this work.

Table E-2: Differences between 2012 HAPINZ update and this work.

	2012 HAPINZ update	2012 values, using 2013 rules	This study	Reason for change
Census year	2006	2006	2013	
PM_{10} data	2006-2008	2006-2008	2010-2012	
Areas represented by which PM_{10} sites				
Christchurch inner areas	St Albans	Mean of St Albans + Burnside	Mean of St Albans + Burnside	Reasons for Burnside's original exclusion not provided
Wellington	Govt House	Corner V	Corner V	Govt House no longer available
Rotorua	Emission-regression	Mean of Edmond Rd, Pererika Street and Ngapuna	Mean of Edmond Rd, Pererika Street and Ngapuna	Emission-regression method deemed unsuitable; consistency of approach
Invercargill	Emission-regression	Mean of Miller Street and Pomona Street	Pomona Street	Emission-regression method deemed unsuitable; only single site left in 2012; consistency of approach
Auckland	Emission-regression	Emission-regression	Emission-regression (re-calibrated with new PM10 data)	
Tauranga	Mean of Moreland Fox Park & Otumoetai	Mean of Moreland Fox Park & Otumoetai	Otumoetai	Moreland Fox Park not available in 2012
Gisborne, Taumaranui, New Plymouth	Monitoring data	Same values as 2012 HAPINZ Update	Same values as 2012 HAPINZ Update	Data does not meet 75 % criterion, but used as no alternative available
Nelson Airsheds B2 and C	Monitoring data	Same values as 2012 HAPINZ Update	Same values as 2012 HAPINZ Update	Data does not meet 75 % criterion, but used as no alternative available
Ngongontaha, Ngapuna, Turangi, Kawerau, Westport, Balclutha	Monitoring data	Same values as 2012 HAPINZ Update	Same values as 2012 HAPINZ Update	Data does not meet 75 % criterion, but used as no alternative available
Several small towns in Southland	Monitoring data	Same values as 2012 HAPINZ Update	Same values as 2012 HAPINZ Update	Data does not meet 75 % criterion, but used as no alternative available
Northland, Taranaki, Gisborne category 3 areas	Min value in cat 1, 2 or 3 areas in region	Min value in all cat 1, 2 or 3 areas in North Island	Same values as 2012 HAPINZ Update	No monitoring in these areas meeting 75% criterion

Appendix F: Evaluation of indicators presented in this work against MfE criteria

Indicator	Indicator component	Relevance		Accuracy		Timeli-ness	Accessi-bility	Coherence/Consistency		Inter-preta-bility	comments
		Content & detail	Geogra-phical coverage	Reflects topic	Informs indica-tors			Inter-nation al	Time series		
Indicator of Pressure: National Road Vehicle Emissions Inventory	total annual emissions of (O, CO_2, VOC, NO_x, PM_{10} and $PM_{2.5}$ from road transport	Highly relevant and detailed	Complete national coverage	See comments	Directly informs indicator	All data for current year	Highly accessible	Highly consist-ent	Consistent data every year	High trace-ability	Accuracy based upon VEPM model, which represents best available information on vehicle emission factors in NZ
Indicator of Pressure: Contribution of natural sources	Average contribution of natural processes to PM_{10}	Does not represent episodic sources Covers one pollutant only	Data available for limited sites only	Highly accurate for limited sites	Provides most pertinent information	Some data > 3 ys old	Highly accessible	Highly consist-ent	limited temporal information	High trace-ability	
Indicator of Pressure: meteorological conditions that exacerbate poor air quality (PM_{10})	proportion of calm winds per year		Degree of coverage required not determined	Not yet established	Not yet established	All data for current year	Highly accessible	Highly consist-ent	Consistent data every year	High trace-ability	
	proportion of high winds per year		Degree of coverage required not determined	Not yet established	Not yet established	All data for current year	Highly accessible	Highly consist-ent	Consistent data every year	High trace-ability	

<table>
<tr><th>Indicator</th><th>Indicator component</th><th colspan="2">Relevance</th><th colspan="2">Accuracy</th><th>Timeli-ness</th><th>Accessi-bility</th><th colspan="2">Coherence/Consistency</th><th>Inter-preta-bility</th><th>comments</th></tr>
<tr><th></th><th></th><th>Content & detail</th><th>Geogra-phical coverage</th><th>Reflects topic</th><th>Informs indica-tors</th><th></th><th></th><th>Inter-nation al</th><th>Time series</th><th></th><th></th></tr>
<tr><td>Indicator of State: Annual average concentration of PM_{10}</td><td>Nationally aggregated annual average concentration of PM_{10}</td><td>Highly relevant and detailed</td><td></td><td>Highly accurate</td><td></td><td>All data for current year</td><td>Highly accessible</td><td>Highly consist-ent</td><td>Some sensitivity (few %) to monitoring data availability</td><td>High trace-ability</td><td></td></tr>
<tr><td rowspan="4">Indicator of Impact: Health impacts of exposure to anthropogenic PM_{10}</td><td>Number of estimated population health incidents from exposure to anthropogenic PM_{10}</td><td rowspan="4">Highly relevant and detailed</td><td rowspan="4">Complete national coverage</td><td colspan="2">See comments</td><td rowspan="4">Some raw data is > 3 yrs old</td><td>Accessible</td><td rowspan="4">Highly consist-ent</td><td rowspan="2">Data is discontinuous due to availability of census data</td><td>High trace-ability</td><td>Dose-response relationships used are inherently uncertain, but are based on and consistent with international best practice</td></tr>
<tr><td>Costs of health effects from exposure to anthropogenic PM_{10}</td><td colspan="2">See comments</td><td>Accessible</td><td>High trace-ability</td><td>Validity of costings used are inherently uncertain, but are based on and consistent with international best practice</td></tr>
<tr><td>Mean intake of PM_{10}</td><td colspan="2" rowspan="2">See comments</td><td rowspan="2">HAPINZ-based method is simple in concept but complex in implemen-tation</td><td rowspan="2">Some raw data is > 3 yrs old, however, effect is small meaning trends still readily discernible</td><td rowspan="2">High trace-ability</td><td rowspan="2">Accuracy of HAPINZ-based method cannot be established, but represents best available information at present</td></tr>
<tr><td>Total intake of PM_{10}</td></tr>
</table>