NIWA
Taihoro Nukurangi

# $PM_{2.5}$ in New Zealand

## Modelling the current (2018) levels of fine particulate air pollution

*Prepared for the Ministry for the Environment*

*December 2019*

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NIWA CLIENT REPORT No: 2019319AK
Report date: December 2019
NIWA Project: MFE20101

| Quality Assurance Statement | | |
|---|---|---|
| | Reviewed by: | |
| | Formatting checked by: | Emma Hope-Ede |
| | Approved for release by: | Jonathan Moores<br>Regional Manager - Auckland |

Version history
First draft released July 2016 as NIWA CLIENT REPORT No: AKL2016-015
Circulated to central and local government agencies
Feedback and new data incorporated October 2019
This updated version released December 2019

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# Executive summary

As part of an update of the NESAQ (National Environmental Standards for Air Quality), the Ministry for the Environment (MfE) wished to investigate the introduction of new standards to control concentrations of $PM_{2.5}$ in ambient air. A baseline of current concentrations and associated health impacts was required as an input to a cost-benefit analysis of various policy options, which will include future projections of $PM_{2.5}$ levels.

No pre-existing national model of $PM_{2.5}$ exposure was available for this work. Thus, one had to be created from scratch. Consequently, the model currently stands unvalidated and we anticipate that further improvements may be made. However, we believe that this work best represents the data available now and is fit for purpose.

Once $PM_{2.5}$ exposures were estimated, health effects were calculated using the same well-established method used in the 2012 Updated HAPINZ study and in subsequent MfE environmental reporting. A required modification was the adoption of an internationally-approved dose-response function for $PM_{2.5}$ in the absence of one based on New Zealand data.

For 2018 we estimated the following:

- The national population-weighted average concentration of $PM_{2.5}$ is **5.6 μg m$^{-3}$**.
- The national population-weighted average concentration of $PM_{2.5}$ from anthropogenic sources is **3.3 μg m$^{-3}$**.
- **11 airsheds** have an annual mean $PM_{2.5}$ concentration of 10 μg m$^{-3}$ or higher covering an approximate population of 228,000.
- **19 airsheds** have an annual mean $PM_{2.5}$ concentration of 8 μg m$^{-3}$ or higher. These airsheds have an estimated population of around 666,000.
- **19 airsheds** are estimated to exceed a daily mean $PM_{2.5}$ standard of 25 μg m$^{-3}$.
- Anthropogenic $PM_{2.5}$ exposure is associated with
  - 646 premature deaths in adults per year
  - 215 extra cardiac hospital admissions
  - 422 extra respiratory hospital admissions
  - 1.6 million restricted activity days.

# 1 Introduction

## 1.1 Background

As part of an update of the NESAQ (National Environmental Standards for Air Quality), the Ministry for the Environment (MfE) wished to investigate the introduction of new standards to control concentrations of $PM_{2.5}$ in ambient air. A baseline of current concentrations and associated health impacts was required as an input to a cost-benefit analysis of various policy options, which will include future projections of $PM_{2.5}$ levels.

## 1.2 Purpose and scope of this report

This report covers the methods used and results for:

- Production of estimates of the current concentrations of $PM_{2.5}$ in unmonitored gazetted airsheds across the country.
- Estimation of the contributions of natural and anthropogenic sources to current $PM_{2.5}$ concentrations for each gazetted airshed.
- Estimation of the likely number of exceedances of a daily $PM_{2.5}$ standard of 25 $\mu g\ m^{-3}$, and alternative values.
- The use of $PM_{2.5}$ concentration estimates (monitored where available, otherwise modelled: see section 2.2) to produce estimates of the current health impacts of anthropogenic $PM_{2.5}$.
- An assessment of the current health impacts of anthropogenic $PM_{10}$.

All assessments are based on the year 2018, or the nearest alternative year for which credible data or estimates can be generated.

This report is accompanied by three spreadsheets providing full results.

This report does not cover the cost-benefit analysis which was conducted by other parties.

## 1.3 Limitations of this work

No pre-existing national model of $PM_{2.5}$ was available for this work. Thus, one had to be created from scratch. The model stands unvalidated at present and we anticipate that further improvements could be made. The timeframe also meant that a comprehensive health effects literature search could not be conducted.

# 2 Methods

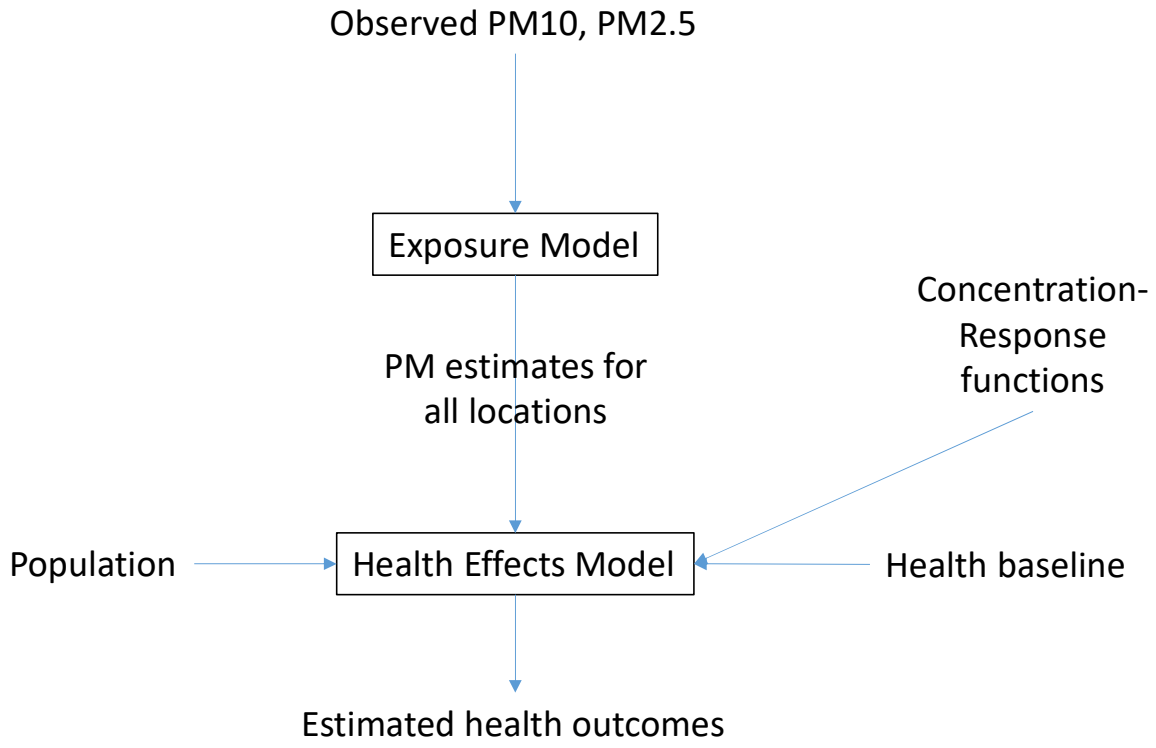
## 2.1 Overview

This assessment, like other similar assessments before it, consists of two parts:

- Exposure modelling
- Health effects modelling

The relationship between them is illustrated in Figure 2-1. $PM_{10}$ is only observed at a limited number of locations and $PM_{2.5}$ in fewer locations. The purpose of the Exposure Model is to allocate estimates of PM to all locations across the country. The Health Effects Model then estimates the fraction of relevant observed health outcomes that can plausibly be attributed to PM exposure.

**Figure 2-1: Flow diagram of the risk assessment process.**




The approach used for the Health Effects Model, popularised by Künzli et al (2000), is highly consistent with international practice, and is identical to that used in the 2012 Updated HAPINZ assessment (Kuschel et al., 2012).

Exposure models, however, vary in approach across the world in response to the nature and coverage of data available. The 2007 HAPINZ assessment (Fisher et al., 2007) and the Updated 2012 HAPINZ assessment (Kuschel et al., 2012) used different exposure modelling approaches to reflect the different amounts of $PM_{10}$ data available at the time. For this work, a growing amount of $PM_{10}$ data was available, but $PM_{2.5}$ data was sparse. For this reason, we have adopted some parts of the 2012 Updated HAPINZ Exposure Model but also introduced a new modelling approach to generate plausible estimates of $PM_{2.5}$.

## 2.2 Origin, coverage and use of monitoring data

The observed PM data used in this assessment was all collected by regional councils and unitary authorities (with one exception – data from Huntly was collected for Genesis Energy). Other data collected by, or on behalf of, NIWA, NZTA or other industrial concerns have not been included. Data were provided to us by MfE. Additional $PM_{10}$ data were provided by Auckland Council, Bay of Plenty Regional Council, Environment Southland and Environment Canterbury.

For inclusion in this assessment we required that any measure of annual mean $PM_{10}$ had to meet a 75 % data coverage criterion, as required by the NESAQ and consistent with the 2014 Air Domain Report and Our Air 2018 (MfE & StatsNZ, 2014, 2018). 2018 data was used as a priority. Where it was not available data from the most recent year available was used, using either data directly provided by councils, the 2014 Air Domain Report, Our Air 2018 or the 2012 Updated HAPINZ exposure model.

For $PM_{2.5}$ data meeting this criterion for 2018 were available from 18 sites, each representing a separate airshed: four in Auckland, four in Greater Wellington, one in Marlborough, and nine in Canterbury. Due to the scarcity and lack of geographical coverage, we relaxed the 75 % criterion. Where an annual mean was not available for a full calendar year but > 6 months of data was available including at least 2 months of winter data, an annual mean was estimated (Tokoroa, Nelson A and Nelson B). Further historical data or data fragments were available from Auckland (four sites), Hamilton, New Plymouth, Hastings, Richmond and Dunedin.

$PM_{10}$ data was available from 52 locations in 2018, covering 37 gazetted airsheds and three locations outside gazetted airsheds. Historic data was available from 98 locations, (covering 53 gazetted airsheds and 21 locations outside gazetted airsheds).

Modelling is based on 2013 CAUs, which are then aggregated up to airshed level for policy development. Each of the 16 regions in New Zealand is considered as an airshed. Regional councils and unitary authorities may define specific areas for management within their region by notice in the NZ Gazette to be a separate airshed. There are currently 73 gazetted airsheds in New Zealand (https://data.mfe.govt.nz/layer/98617-nz-airsheds-gazetted/). The airsheds from which data are available to be used in this assessment are therefore only a subset of all airsheds in New Zealand.

## 2.3 Exposure Model – Conceptual approach

The Exposure Model has two components:

- Generation of $PM_{2.5}$ estimates for locations where PM monitoring is being conducted, or has in the recent past
- Allocation of $PM_{2.5}$ estimates to locations where no monitoring has ever been conducted (both within gazetted airsheds, and outside gazetted airsheds).

### 2.3.1 Generating $PM_{2.5}$ estimates

$PM_{2.5}$ is a subset of $PM_{10}$ such that $PM_{10} = PM_{2.5} + PM_{coarse}$. International research, and local studies by the Institute of Geological and Nuclear Science (GNS Science) (see for example Appendix A), show that coarse particulate matter ($PM_{coarse}$, also known as $PM_{2.5\text{-}10}$) is, in most locations, dominated by particles with natural sources (sea salt, soil and mineral dust) whose spatial variation is largely determined by physical geography. The most prevalent anthropogenic component of $PM_{coarse}$ is generally considered to be road dust.

To estimate $PM_{2.5}$ we considered two approaches:

- a 'direct' approach in which $PM_{2.5}$ is estimated as a function of local emissions and meteorology,
- an 'indirect' approach in which $PM_{coarse}$ is estimated as a function of geographical proxies and the result subtracted from observed $PM_{10}$.

With a very limited timeframe, we chose the **indirect** approach after a consideration of the data availability and likely errors involved in each approach. In future we recommend that both approaches are developed further, and their differences resolved so that their relative merits and limitations are better understood.

Thus, we took the following conceptual approach.

- Where $PM_{2.5}$ is measured, those data will be used
- $PM_{coarse}$ and the natural contribution to $PM_{2.5}$ will be modelled for every CAU in the country. This modelling will be based, in part, on compositional data generated by GNS (Appendix A) and is described in more detail in section 2.4.
- Where $PM_{10}$ is measured but $PM_{2.5}$ is not, $PM_{2.5}$ will be estimated by subtracting the modelled $PM_{coarse}$ estimate from observed $PM_{10}$

This process results in estimates of $PM_{coarse}$ and the natural contribution to $PM_{2.5}$ for every CAU in the country and estimates of total $PM_{2.5}$ for every CAU where $PM_{2.5}$ or $PM_{10}$ monitoring data are available. This approach allows us to estimate the anthropogenic and natural components of PM from a bottom-up summing of separately modelled components, rather than a top-down splitting up of a total PM estimate. We believe our approach generates more realistic estimates of this split in locations where it has not been observed (>99% of the country).

### 2.3.2 Allocating $PM_{2.5}$ estimates to unmonitored CAUs

For this task we largely followed the approach of the 2012 Updated HAPINZ Exposure Model, with some modifications.

- The natural component of $PM_{2.5}$ is already estimated for every CAU. Therefore, it is only the anthropogenic component which is allocated.
- In airsheds where a $PM_{2.5}$ estimate has been generated, the estimate for the anthropogenic component is applied to all CAUs in the airshed. This is then added to the estimated natural component for each CAU.
- In the multi-town airsheds of Otago, a single $PM_{2.5}$ value has been allocated to all CAUs in all towns constituting the airshed (a decision made in agreement with MfE). This introduces a known error but can easily be changed.
- There appears to be no official definition of which CAUs lie in which airsheds as most airshed boundaries cut across CAUs. We have taken a relatively conservative approach and allocated airshed $PM_{2.5}$ estimates to CAUs at the edge of the airshed which are substantially rural. This affects a population of approximately 200,000.

- To exploit the higher density of monitoring data and attempt to capture spatial variation in the Auckland Region, we have adapted the method of the 2012 Updated HAPINZ model, i.e. a simple linear regression between emission density per CAU and concentrations observed within that CAU (adapted to use estimated anthropogenic contribution to $PM_{2.5}$).
- Towns where no qualifying PM monitoring has ever been conducted are allocated an anthropogenic $PM_{2.5}$ estimate in the same manner as the 2012 Updated HAPINZ model, i.e. by allocating data from other towns in the same region, or by allocating estimated rural or small-town values.

## 2.4 Modelling coarse and natural particles

### 2.4.1 The GNS Science dataset

For over a decade GNS Science has been collecting air particulate filter samples from monitoring stations around the country on behalf of some regional councils, and as part of a research programme. Ion beam analysis is used to determine elemental composition. Principal Component Analysis (PCA) was used to provide an initial indication of the number of sources that may be contributing to the sample. Positive Matrix Factorisation (PMF) was used to apportion mass contributions and determine relative uncertainties and closeness of fit of the model to the data. This approach is used successfully for source apportionment studies by researchers in New Zealand and overseas.

For the purposes of this work, monthly summary data were provided to NIWA by GNS Science. This dataset covers 23 monitoring sites, including two in Alexandra, seven in Auckland and five in Greater Wellington. It consists of $PM_{10}$ data at 20 sites and $PM_{2.5}$ at 16 sites. NIWA has subsequently used these data to calculate annual mean contributions for several key recurring sources (Appendix A). In doing so we acknowledge that this method introduces some error. The attribution of certain elemental combinations to a given source is location-specific related to local source activity, thus generalisations must be made carefully. Some sources can be distinguished in some places and not in others (the power to disaggregate sources generally improves with the number of filters analysed).

For this work we mainly make use of the contribution estimates for coarse particles of natural source. Data for $PM_{coarse}$ is available from 14 sites – seven of which are direct measurements, and seven of which are calculated from $PM_{10} – PM_{2.5}$. The most important natural coarse particle sources are marine aerosol, and "soil" particles. These two classes of particles are generally quite compositionally distinct which allows them to be separately resolved at all but one of the 14 sites[1]. Source definition is aided, in some cases, by meteorological analysis (especially analysis by wind direction) where a site is influenced by different sources in different wind directions. However, the "soil" class is likely to include a range of different types of particles from different sources, including wind-blown natural dusts (particularly gravel and top-soil), soils disturbed by agricultural practices and quarrying. Industrial processes may also emit 'soil'-like particles as may construction, although these may be mixed with combustion products. At four sites a "road dust" contribution – which may incorporate dusts from unsealed roads and yards and vehicle wear products) is separately resolved, largely because of the association with combustion-related chemicals, whereas at others it is

[1] The exception is Kingsland in Auckland. Marine aerosol and soil are resolved in PM10 samples here, but not in PM2.5 samples, preventing a calculation of separate contribution in the coarse fraction.

assumed to be included in the "soil" source, but the contribution cannot be quantified. Furthermore, a "fertiliser" source is also resolved at Dunedin and Patumahoe which is tentatively related to specific local sources such as handling and use of fertiliser. In practice this means that the particles included in an estimate of "soil" varies from site to site and it is very difficult to specify how much of that soil contribution is generally representative of the region, and how much is highly local. Nevertheless, we believe that this source apportionment approach is of enough power to be valuable.

### 2.4.2 Marine aerosol

Filter analysis work by GNS Science has indicated that marine aerosol presents the largest contribution of any identified source to $PM_{coarse}$ at 12 out of 13 locations assessed[2] contributing 3 – 7 $\mu g\ m^{-3}$ as an annual average (Appendix A), or 23 - 75 % of $PM_{coarse}$ and 14 – 40 % of $PM_{10}$. GNS data also shows marine aerosol contributes 0 – 3 $\mu g\ m^{-3}$ to $PM_{2.5}$ where it has been identified. The impact of the transport of airborne sea salt inland in New Zealand has previously been characterised in terms of the potential for corrosion, which has been mapped at high resolution across the country (HERA, 2011). We extracted estimates of corrosivity for the air monitoring locations from where the GNS data originate. We found a good correlation between annual mean marine aerosol concentrations and airborne corrosivity for all west-facing coasts and inland sites. A linear parameterisation was generated (Figure 2-2) and subsequently applied to all CAUs in the exposure model. A cap of 11 $\mu g\ m^{-3}$ was introduced to prevent predicted $PM_{coarse}$ exceeding observed $PM_{10}$ in the most-affected monitoring site of Westport.

For sites within ~10 km of east-facing coasts the marine aerosol was lower than that predicted using the west-facing coast model. We hypothesise that this is related to either the lower prevalence of easterly winds, or the typically lower wind speeds on the east coast. We recommend that this is explored further in future. However, for this work we generated an empirical adjustment to the west-facing coast model as a function of distance to an east-facing coast (Figure 2-3). This was based on marine contribution to $PM_{10}$ rather than $PM_{coarse}$, due to more data being available and a better empirical fit. We therefore reduced the adjustment by a further 25 % as 75 % of $PM_{10}$ marine aerosol is typically in the coarse fraction.

[2] The 13th location was Dunedin where contributions from fertiliser soil were found to be greater than marine aerosol.

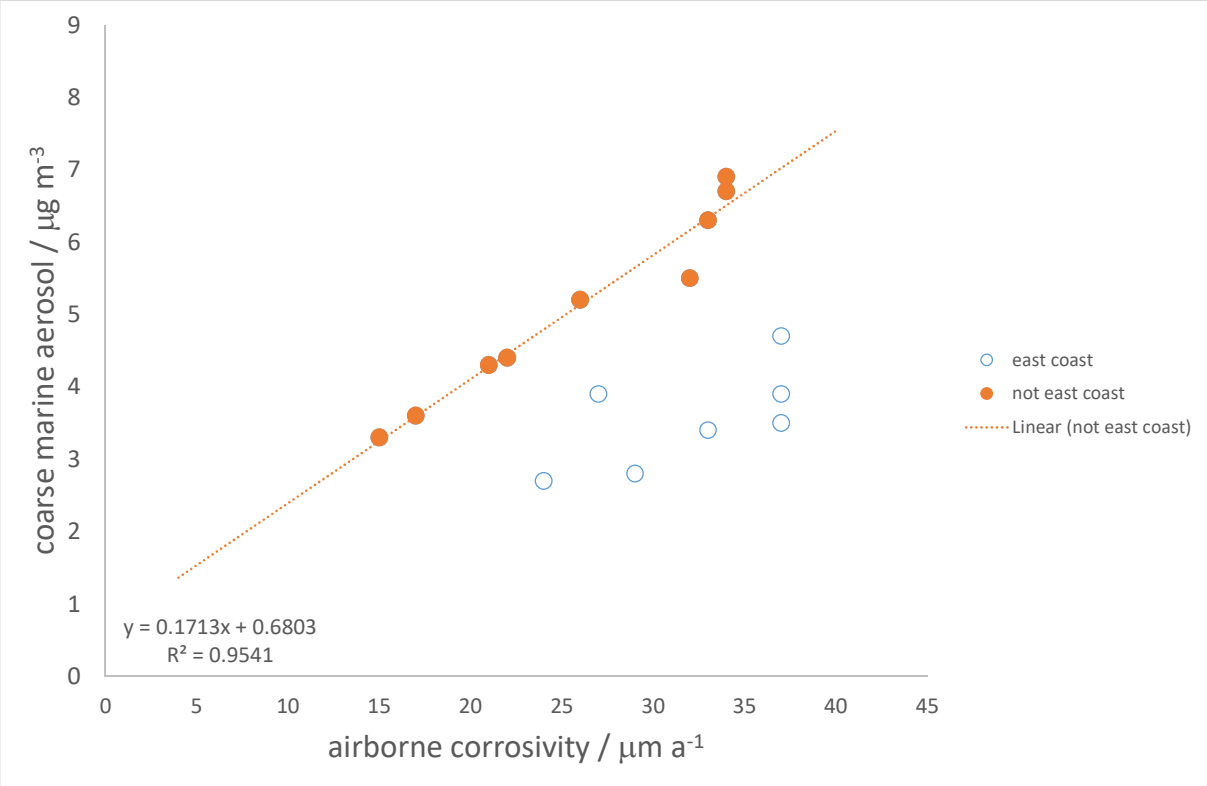



**Figure 2-2: Annual mean marine aerosol contribution to $PM_{coarse}$ (GNS), and airborne corrosivity (HERA, 2011).**

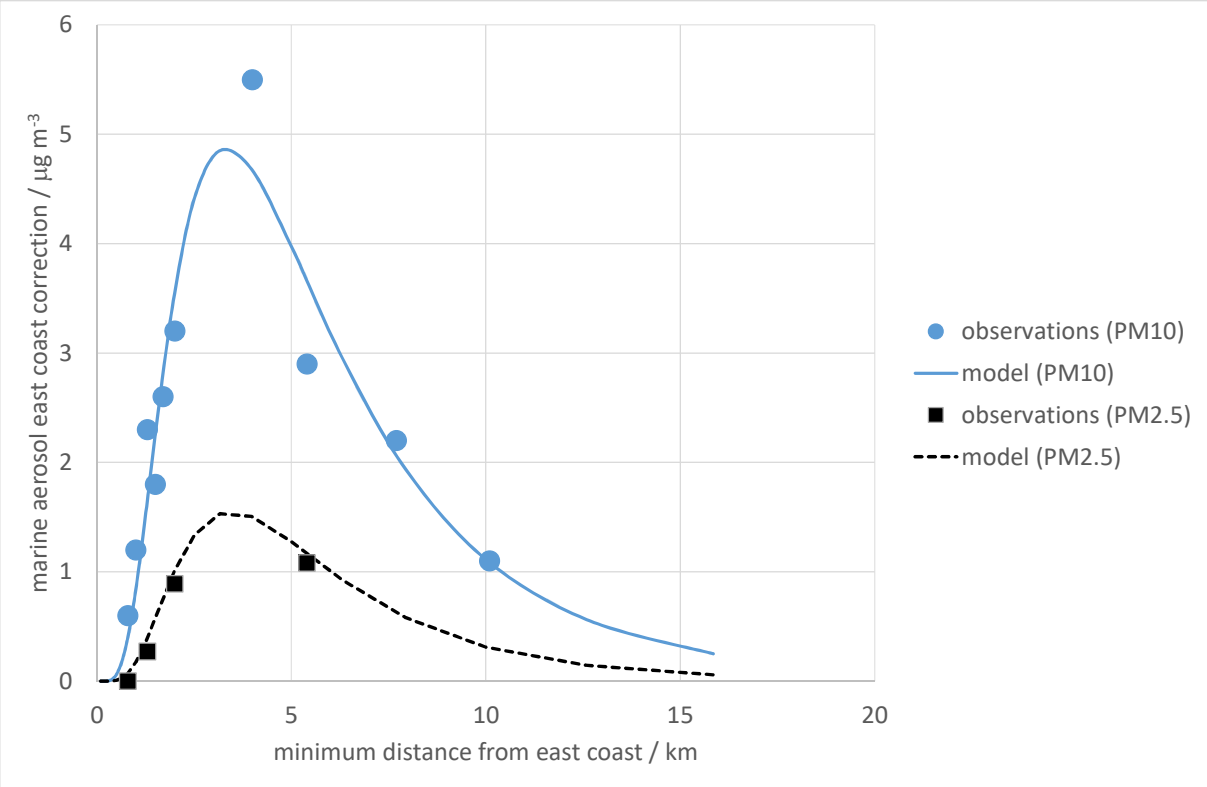



**Figure 2-3: Empirical correction function for marine aerosol for east coast sites.**

The marine aerosol contribution to $PM_{2.5}$, which is required so that $PM_{2.5}$ can be apportioned between natural and anthropogenic fractions, was also estimated through correlation with corrosivity followed by a correction for east coast sites.

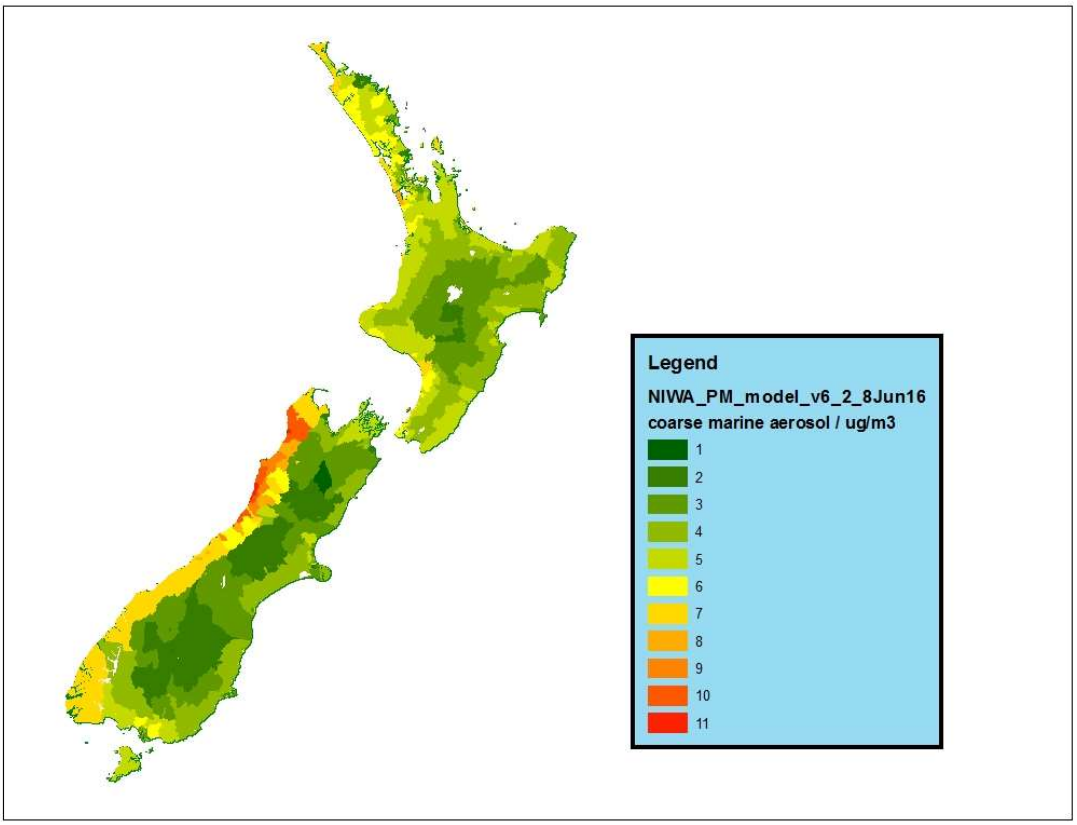



**Figure 2-4: Final model of coarse marine aerosol at CAU level.**

### 2.4.3 Non-marine contributions to coarse particles

Data from GNS Science indicate that, after marine aerosol, the next most prevalent source contribution to $PM_{coarse}$ that has been identified is 'soil' (see Appendix A). There is some ambiguity as to what this source profile precisely represents but is likely to include agricultural soils resuspended into the air by the wind, but also by mechanical action (machinery and road transport). It may also include soils or mineral dusts resuspended by quarrying, construction, demolition, from dust-emitting industries, etc. An additional anticipated, but poorly quantified source is dust resuspended by the wind from braided river valleys. In some analyses GNS Science have resolved an independent source profile relating to road dust or a local industry.

In general, coarse particles have a reduced atmospheric residence time relative to finer particles. This gives their airborne concentrations strong spatial gradients, and which are responsive to highly local sources, i.e. concentrations vary significantly over hundreds, even tens of metres. Consequently, there is a large degree of variability in source contributions, and how likely they are to be resolved by source apportionment techniques, relative to the small number of observations available. This makes generalisation across the country very challenging.

In view of this we took a relatively subjective approach. We estimated the non-marine contribution to $PM_{coarse}$ at a range of locations (by subtracting estimated or observed coarse marine aerosol from observed $PM_{coarse}$) and found moderately higher concentrations in Canterbury and Otago.

We hypothesised that part of the soil contribution would be related to surface dryness. We trialled correlating the non-marine contribution to $PM_{coarse}$ with the number of wet days per year at the monitoring location. The correlation was insufficiently strong to justify modelling any relationship across the country. Alternatively, we applied the following simple estimates for 'soil' contribution:

- 3 μg $m^{-3}$ in Canterbury and Otago Regions
- 1 μg $m^{-3}$ in all other regions

To account for the observably higher non-marine contribution to $PM_{coarse}$ at urban sites, which we hypothesise is primarily due to road dust, we assumed a relationship with motor vehicle emissions. A linear relationship was empirically derived which contributed 0 – 1.6 μg $m^{-3}$ of $PM_{coarse}$ across the country.

Other contributions to $PM_{coarse}$ were not modelled. Contributions identified in GNS Science source apportionment include biomass burning (at Masterton and Raumati South only), sulphate (at Lower Hutt only) and fertiliser soil (at Dunedin and Patumahoe only). It is not possible currently to further specify the origin of the 'biomass burning' component. It may, or may not include woodsmoke from domestic heating, open or agricultural burning, or industrial sources. We hold that there is insufficient data currently available to include these contributions, which may be highly localised, in a national model.

Data on the non-marine contribution to $PM_{2.5}$ is even scarcer. Based on a review of GNS Science data we opted to apply an estimate of 1.4 μg $m^{-3}$ (made up of 1 μg $m^{-3}$ sulphate and 0.4 μg $m^{-3}$ soil) across the whole country.

### 2.4.4 Estimation of anthropogenic and natural contributions to PM

The natural and anthropogenic PM concentrations were calculated as below (bold = modelled unless observed, italic = observed or allocated):

Natural $PM_{2.5}$ = **marine $PM_{2.5}$** + **soil & sulphate $PM_{2.5}$**

Natural $PM_{coarse}$ = **marine $PM_{coarse}$** + **soil $PM_{coarse}$**

Anthropogenic $PM_{10}$ = *$PM_{10}$* – (**Natural $PM_{2.5}$** + **Natural $PM_{coarse}$**)

$PM_{coarse}$ = **Natural $PM_{coarse}$** + **Urban $PM_{coarse}$**

$PM_{2.5}$ = *$PM_{10}$* - **$PM_{coarse}$**

Anthropogenic $PM_{2.5}$ = $PM_{2.5}$ – **Natural $PM_{2.5}$**

### 2.4.5 Worked example 1: Gore (example of small airshed with $PM_{10}$ monitoring)

The Gore airshed consists of seven census area units. Environment Southland runs a $PM_{10}$ monitoring site in the town. In 2018 the annual mean $PM_{10}$ concentration was 18.5 μg $m^{-3}$. The contribution of

natural coarse particles to this concentration is estimated for the CAU in which the monitoring site is situated, and all other CAUs in the airshed.

**Table 2-1: Estimated contribution to natural coarse particles in Gore (μg $m^{-3}$).**

| | Monitoring site | All airshed |
|---|---|---|
| **Coarse marine aerosol** | 2.7 | 2.6 – 3.0 |
| **Dust** | 1.0 | 1.0 |
| **Urban dust (Urban $PM_{coarse}$)** | 0.4 | 0.1 – 0.4 |
| **Total $PM_{coarse}$** | 4.1 | 3.8 – 4.1 |

We therefore estimate $PM_{2.5}$ as $PM_{10} - PM_{coarse}$ = 18.5 – 4.1 = 14.4 μg $m^{-3}$ at the Gore monitoring site.

The natural contribution to $PM_{2.5}$ is estimated as in Table 2-2.

**Table 2-2: Estimated contribution to natural fine particles in Gore (μg $m^{-3}$).**

| | Monitoring site | All airshed |
|---|---|---|
| **Fine marine aerosol** | 0.5 | 0.5 – 0.6 |
| **Soil & sulphate** | 1.4 | 1.4 |
| **Total natural $PM_{2.5}$** | 1.9 | 1.9 – 2.0 |

Thus, the anthropogenic contribution to $PM_{2.5}$ is calculated as $PM_{2.5}$ – natural $PM_{2.5}$ = 14.4 – 1.9 = 12.5 μg $m^{-3}$.

This estimate is then assumed to be constant for every CAU in the Gore airshed and summed to the individually modelled natural $PM_{2.5}$ (1.9 – 2.0 μg $m^{-3}$) for each CAU to provide an estimate of total $PM_{2.5}$ for every CAU.

Finally, the $PM_{2.5}/PM_{10}$ ratio for Gore is taken from the values for the CAU containing the monitoring site, i.e. 14.4 / 18.5 = 0.78.

### 2.4.6 Worked example 2: Thames (example of small airshed with no $PM_{10}$ monitoring)

The method is the same as example 1, except that no $PM_{10}$ observation exists. In this case a $PM_{10}$ value is allocated using a method adapted from the 2012 Updated HAPINZ Exposure Model.

In the example of Thames, this is classed as a 'Type 3' urban rural classification (according to Stats NZ). The HAPINZ method allocates an anthropogenic $PM_{2.5}$ estimate to all Type 3 CAUs in the Waikato Region which is the lowest anthropogenic $PM_{2.5}$ concentration modelled in Type 1, 2 or 3 CAUs across the region. This happens to be 2.9 μg $m^{-3}$ at Pukekapia Rd, Huntly, which is then summed with the modelled estimate for natural $PM_{2.5}$ at Thames (2.7 μg $m^{-3}$) to give 5.6 μg $m^{-3}$.

## 2.5 $PM_{2.5}/PM_{10}$ ratios

MfE requested that we provide estimated values of the $PM_{2.5}/PM_{10}$ ratio for each airshed. This was done simply by dividing the estimated annual mean $PM_{10}$ concentration by the estimated annual mean $PM_{2.5}$ concentration, as both concentrations were outputs of the exposure modelling.

## 2.6 Exposure model validation

There are limited options available for validation of the exposure model. All available observational $PM_{2.5}$ data has been used for model training.

However, the spatial model for $PM_{coarse}$ can be partially validated. We have collated observed annual mean $PM_{coarse}$ data ($PM_{10} – PM_{2.5}$) from regional council monitoring for 2018. Sites where there is a known, local and unmodelled contribution to $PM_{coarse}$ (mainly industrial) should not be included in the validation. This includes Dunedin (where the monitoring site appeared to be locally impacted by ≈5 μg $m^{-3}$ of fertiliser-sourced $PM_{coarse}$ during sampling, according to GNS Science data), Woolston (local industry, impacted by an unusually high soil contribution according to GNS Science data), Nelson B (local industry) and Washdyke (local industry). The degree to which other locations may be similarly impacted by such localised sources is unknown and remains a limitation of our modelling approach.

The resulting data (16 sites, Figure 2-5) shows that our model predicts $PM_{coarse}$ to within 1.2 μg $m^{-3}$ at all sites except Auckland - Queen Street and Wellington Central - Willis Street, where the model over-estimates by 1.6 μg $m^{-3}$. The model under-estimates by 2 - 4 μg $m^{-3}$ at Woolston, Washdyke and Nelson B (not shown). These disagreements may also be due to shipping emissions (e.g. coarse sulphate), unsealed yards, earth-moving activities, etc., uncertainty in defining the distance to coast, the significance of elevation or differential deposition to urban surfaces within complex natural or built topography.

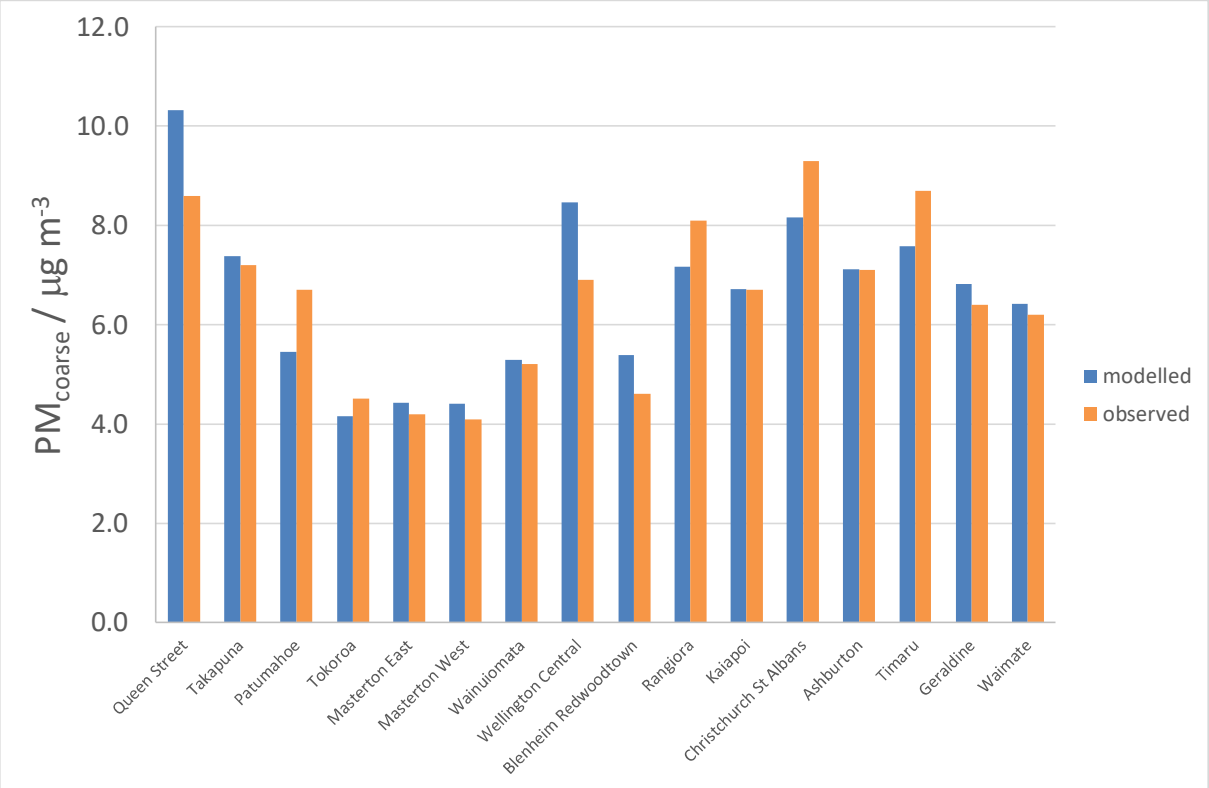



**Figure 2-5: Comparison of modelled and observed coarse PM at a selection of monitoring sites.**

## 2.7 Health effects modelling

The method used is identical to the 2014 Air Domain Report and with only minor changes from the 2012 Updated HAPINZ assessment. We used the same health baseline data, used 2013 population data[3], and assessed the impact of the anthropogenic fraction only.

The major change that was required was to calculate health outcomes associated with $PM_{2.5}$ in addition to $PM_{10}$.

We conducted a limited review of available concentration-response functions. The 2012 HAPINZ assessment prioritised used of a local function for mortality (7% per 10 µg $m^{-3}$ of $PM_{10}$, Hales et al., 2010) over more commonly used international functions (such as 4.3 % per 10 µg $m^{-3}$ of $PM_{10}$, e.g. Künzli et al., 2000). For consistency with previous assessments in New Zealand, and in the absence of any new NZ-based function, we continued to use this function for this assessment.

There is, however, no equivalent New Zealand function for $PM_{2.5}$. Internationally, a function of 6.2% per 10 µg $m^{-3}$ of $PM_{2.5}$ is recommended by both the WHO (2013) and COMEAP (2009). We chose to adopt this function for our work as we consider it to be the most appropriate and robust approach.

[3] Although population data was collected in the 2018 census, it is not available at the required level of census area unit at the time of writing.

Alternative approaches considered but rejected were:

- Estimate an equivalent of the Hales et al. (2010) function for $PM_{2.5}$, based on observed $PM_{2.5}/PM_{10}$ ratios. However, our exposure modelling shows that this ratio is highly spatially variable in New Zealand (varying from approx. 20% - 90%), plus the 7% figure was based on a New Zealand's first PM exposure model which more recent monitoring and our modelling suggests contains significant errors.
- Use of a function of 17% for combustion-derived $PM_{2.5}$ particles based on a study of Los Angeles by Jerrett et al. (2005) and adopted in a Swedish national health risk assessment (Gustafsson et al., 2014). While we feel this approach has scientific merit, and could be applied in New Zealand, we also note that there is limited precedent (we found no other jurisdiction using this approach so far) and we recognise that the composition of combustion particles in most of New Zealand (dominated by woodsmoke) is substantially different to that in Los Angeles (traffic/industrial).
- Independent assessment of the health impacts associated with the coarse fraction $PM_{2.5-10}$. There is very limited and inconsistent international evidence of a robust association, especially representing the composition of coarse particles in New Zealand (dominated by marine aerosol). The WHO does not recommend any concentration-response function for coarse particles. In the Swedish assessment (Gustafsson et al., 2014) a function of 17 % was used for the road dust component of $PM_{10}$ based on a health effects study in Stockholm where the use of studded tyres in winter leads to far higher concentrations than observed in New Zealand. Other coarse particles were not assessed. A review of the health effects of coarse particulate matter conducted by Health Canada recently concluded
  - "In regard to the chronic effects of coarse PM, the health database is inadequate to infer a causal relationship with mortality, respiratory and cardiovascular health outcomes, as well as with the incidence of developmental outcomes." (Health Canada, 2016)

Other functions for $PM_{2.5}$ adopted followed the recommendations of the WHO (2013) were:

- 0.0091 cardiac hospital admission (all ages) per person per year per 10 $\mu g\ m^{-3}$ daily $PM_{2.5}$
- 0.019 respiratory hospital admission (all ages) per person per year per 10 $\mu g\ m^{-3}$ daily $PM_{2.5}$
- 0.9 restricted activity days (all ages) per person per year per 10 $\mu g\ m^{-3}$ daily $PM_{2.5}$

## 2.8 Likely number of exceedances of a daily $PM_{2.5}$ standard

An additional requirement for cost-benefit analysis was a prediction of the likelihood that there will be exceedances of a potential future daily $PM_{2.5}$ standard.

We considered that there was too little observational data to establish this through direct analysis alone. Most of the $PM_{2.5}$ data available is from Auckland where exceedances of likely daily standards (25 $\mu g\ m^{-3}$ and above) do not, or rarely occur.

To tackle this issue, we instead took two approaches. Firstly, we reviewed the factors influencing the number of daily exceedances of the $PM_{10}$ standard. Secondly, we created thousands of simulated daily $PM_{2.5}$ time series calibrated to broadly match the statistical characteristics of real $PM_{2.5}$ time series.

Through this work we were able to establish that the likely number of exceedances of any daily standard are related to

- The annual mean
- The duration of winter
- The mean summertime concentration

We found that the limited amount of $PM_{2.5}$ data available at this time meant that we could quantify only the first relationship. Specifically, we fitted a logarithmic relationship:

$$\text{Number of exceedances} = A \ln(\text{mean } PM_{2.5}) + B$$

Where *A* and *B* are functions of the daily standard limit value and the duration of winter.

This is illustrated in Figure 2-6. Deviations of observed data from the band created by the simulated results (grey) can be attributed by lower-than-simulated (points to the left) of higher-than-simulated (points to the right) summer average concentrations.

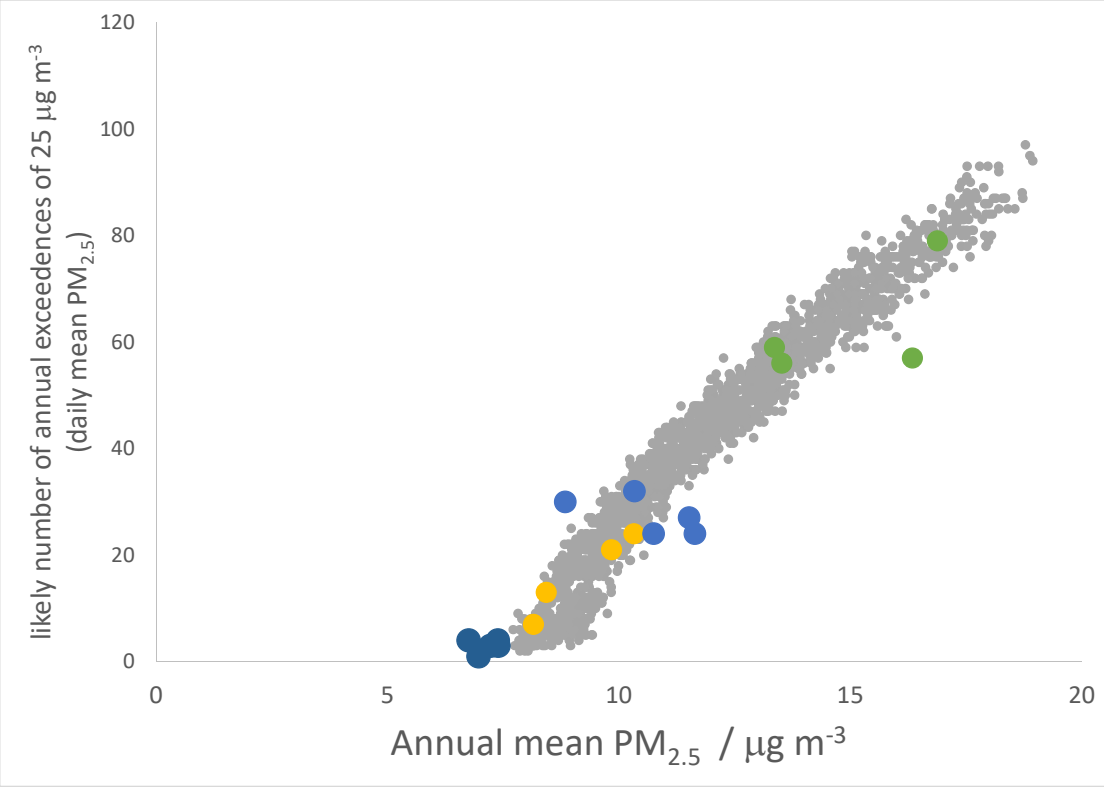



**Figure 2-6: Relationship between annual mean $PM_{2.5}$ and likely number of exceedances of a daily standard of 25.** Grey = simulation results, green = Timaru, light blue = St Albans, yellow = Woolston, dark blue = Takapuna.

In this work we have not implemented any influence of duration of winter. Exploratory work has indicated that the (currently not implemented) influence of summertime concentration could be significant. Summer concentrations are dominated by motor vehicle, marine and secondary sulphate sources. This omission remains an outstanding limitation of our method and estimates to date. Nevertheless, we believe our model represents the best understanding available currently.

# 3 Results

## 3.1 $PM_{2.5}$ exposure

We estimated that

- The national population-weighted average concentration of $PM_{2.5}$ in 2018 is **5.6 μg m$^{-3}$**.
- The national population-weighted average concentration of $PM_{2.5}$ from anthropogenic sources in 2018 is **3.3 μg m$^{-3}$**.
- **11 airsheds** have an annual mean $PM_{2.5}$ concentration of 10 μg m$^{-3}$ or higher covering an approximate population of 228,000.
- **19 airsheds** have an annual mean $PM_{2.5}$ concentration of 8 μg m$^{-3}$ or higher covering an approximate population of 666,000.

Estimates for gazetted airsheds are provided in Table 3-1.

**Table 3-1: Predicted annual mean $PM_{2.5}$ (2018) for all gazetted airsheds, plus natural and anthropogenic contributions.**

| Represented airshed | Representing monitoring site | $PM_{2.5}$ / μg m$^{-3}$ | | | $PM_{2.5}/PM_{10}$ ratio |
|---|---|---|---|---|---|
| | | Total | Natural | Anthropogenic | |
| Invercargill | Invercargill Pomona | 17.2 | 1.6 | 15.6 | 0.82 |
| Richmond | Richmond | 15.3 | 1.5 | 13.8 | 0.82 |
| Gore | Gore | 14.4 | 1.9 | 12.5 | 0.78 |
| Taihape | Taihape | 14.4 | 1.8 | 12.5 | 0.81 |
| Blenheim | Blenheim Redwoodtown | 13.2 | 2.2 | 11.0 | 0.74 |
| Otago 2 | Mosgiel | 13.1 | 1.9 | 11.2 | 0.68 |
| Awatoto | Awatoto | 11.5 | 3.3 | 8.2 | 0.58 |
| Nelson A | Nelson Airshed A | 11.3 | 1.5 | 9.8 | 0.67 |
| Timaru | Timaru | 10.8 | 2.3 | 8.5 | 0.55 |
| Tokoroa | Tokoroa | 10.2 | 2.0 | 8.2 | 0.69 |
| Masterton | Masterton East | 10.0 | 2.0 | 8.0 | 0.70 |
| Otago 1 | Alexandra | 9.9 | 1.7 | 8.2 | 0.70 |
| Kaiapoi | Kaiapoi | 9.9 | 1.9 | 8.0 | 0.60 |
| Geraldine | Geraldine | 9.6 | 2.1 | 7.5 | 0.60 |
| Rotorua | Rotorua Edmond Road | 9.1 | 2.0 | 7.1 | 0.67 |
| Ashburton | Ashburton | 8.9 | 2.1 | 6.8 | 0.56 |
| Te Kuiti | Te Kuiti | 8.5 | 2.1 | 6.4 | 0.64 |
| Warkworth | Warkworth | 8.2 | 1.5 | 6.7 | 0.47 |
| Christchurch | Christchurch St Albans | 8.1 | 2.3 | 5.8 | 0.47 |
| Napier | Napier | 7.9 | 2.1 | 5.8 | 0.61 |
| Waimate | Waimate | 7.8 | 2.0 | 5.8 | 0.56 |
| Nelson B | Nelson Airshed B | 7.6 | 2.5 | 5.1 | 0.42 |
| Ngaruawahia | Ngaruawahia | 7.5 | 2.3 | 5.2 | 0.57 |
| Taupo | Taupo | 7.5 | 1.9 | 5.6 | 0.67 |

| | | | | | |
|---|---|---|---|---|---|
| Otago 3 | Dunedin | 7.4 | 2.2 | 5.2 | 0.49 |
| Rangiora | Rangiora | 7.4 | 2.2 | 5.2 | 0.48 |
| Matamata | Matamata | 7.3 | 2.2 | 5.1 | 0.58 |
| Te Awamutu and Kihikihi | Te Awamutu | 7.0 | 2.1 | 4.9 | 0.59 |
| Turangi | Turangi | 6.8 | 1.8 | 5.0 | 0.68 |
| Cambridge | Cambridge | 6.7 | 2.0 | 4.7 | 0.61 |
| Whangarei | Whangarei | 6.6 | 2.9 | 3.7 | 0.47 |
| Putaruru | Putaruru | 6.6 | 2.0 | 4.5 | 0.59 |
| Hamilton City | Hamilton | 6.4 | 2.2 | 4.2 | 0.55 |
| Huntly | Huntly Croft Tce | 6.4 | 2.2 | 4.2 | 0.56 |
| Taumarunui | Taumarunui | 6.4 | 2.0 | 4.4 | 0.60 |
| Auckland Urban | Takapuna | 6.3 | 2.5 | 3.8 | 0.47 |
| Hastings | Hastings | 6.1 | 2.3 | 3.8 | 0.45 |
| Tuakau | Tuakau | 5.9 | 2.3 | 3.6 | 0.39 |
| Pukekohe | Pukekohe | 5.9 | 2.3 | 3.6 | 0.39 |
| Porirua | Porirua | 5.9 | 2.5 | 3.4 | 0.48 |
| Wainuiomata | Wainuiomata | 5.7 | 2.2 | 3.5 | 0.52 |
| Thames | Thames | 5.6 | 2.7 | 2.9 | 0.47 |
| Waihi | Waihi | 5.6 | 2.5 | 3.1 | 0.48 |
| Upper Hutt | Upper Hutt | 5.5 | 2.1 | 3.4 | 0.53 |
| Wellington City | Wellington Central | 5.5 | 2.9 | 2.6 | 0.44 |
| Dargaville | Dargaville | 5.5 | 2.5 | 2.9 | 0.47 |
| Waiuku | Waiuku | 5.4 | 3.3 | 2.1 | 0.38 |
| Whangamata | Whangamata | 5.3 | 2.4 | 2.9 | 0.48 |
| Kapiti Coast | Raumati South | 5.3 | 3.3 | 2.0 | 0.41 |
| Te Aroha | Te Aroha | 5.3 | 2.3 | 2.9 | 0.49 |
| Lower Hutt | Lower Hutt | 5.2 | 2.4 | 2.9 | 0.46 |
| Paeroa | Paeroa | 5.1 | 2.2 | 2.9 | 0.50 |
| Morrinsville | Morrinsville | 5.1 | 2.2 | 2.9 | 0.50 |
| Otorohanga | Otorohanga | 5.1 | 2.2 | 2.9 | 0.50 |
| Kaitaia | Kaitaia | 5.1 | 2.4 | 2.7 | 0.47 |
| Karori | Karori | 4.8 | 2.2 | 2.6 | 0.48 |
| Whitianga | Whitianga | 4.8 | 1.9 | 2.9 | 0.53 |
| Helensville | Helensville | 4.8 | 2.5 | 2.3 | 0.36 |
| Reefton | Reefton | 4.7 | 3.3 | 1.4 | 0.38 |
| Kerikeri | Kerikeri | 4.5 | 1.8 | 2.7 | 0.51 |
| Beachlands-Maraetai | Beachlands | 4.4 | 2.5 | 1.8 | 0.36 |
| Waiheke Island | Waiheke | 4.3 | 3.3 | 1.0 | 0.35 |
| Riverhead | Riverhead | 4.1 | 3.0 | 1.2 | 0.34 |
| Wellsford | Wellsford | 4.0 | 2.6 | 1.3 | 0.35 |
| Nelson C | Nelson Airshed C | 3.8 | 1.6 | 2.2 | 0.50 |
| Snells Beach | Snells Beach | 3.8 | 2.5 | 1.2 | 0.36 |
| Kumeu | Kumeu | 2.9 | 1.8 | 1.2 | 0.19 |

## 3.2 Exceedances of a daily $PM_{2.5}$ standard

Table 3-2 lists the predicted number of exceedances of three possible daily standards. It should be noted that these are 'likely' exceedances, i.e. a central estimate based on average meteorological conditions and typical emissions. Actual exceedances may be higher or lower. In particular, the number of exceedances (related to peak daily concentrations) are highly sensitive to complex and locally-specific variations in wind patterns and the thermal structure of the atmosphere and are very difficult to predict. These estimates incorporate a known but currently unquantified error relating to the influence of summertime concentrations and duration of winter.

**Table 3-2: Predicted number of likely exceedances of different daily $PM_{2.5}$ standards.**

| Represented airshed | Representing monitoring site | daily $PM_{2.5}$ limit value ($\mu g\ m^{-3}$) | | |
|---|---|---|---|---|
| | | **20** | **25** | **30** |
| Invercargill | Invercargill Pomona | 100 | 89 | 75 |
| Richmond | Richmond | 84 | 74 | 61 |
| Gore | Gore | 76 | 66 | 53 |
| Taihape | Taihape | 76 | 66 | 53 |
| Blenheim | Blenheim Redwoodtown | 65 | 56 | 44 |
| Awatoto | Awatoto | 48 | 40 | 29 |
| Nelson A | Nelson Airshed A | 48 | 40 | 29 |
| Timaru | Timaru | 34 | 27 | 17 |
| Tokoroa | Tokoroa | 34 | 27 | 17 |
| Otago 1 | Alexandra | 33 | 26 | 16 |
| Masterton | Masterton | 31 | 24 | 14 |
| Kaiapoi | Kaiapoi | 29 | 22 | 12 |
| Geraldine | Geraldine | 27 | 20 | 10 |
| Rotorua | Rotorua Edmond Road | 26 | 19 | 10 |
| Ashburton | Ashburton | 18 | 12 | 2 |
| Otago 2 | Mosgiel | 15 | 9 | 0 |
| Te Kuiti | Te Kuiti | 13 | 7 | 0 |
| Napier | Napier | 9 | 3 | 0 |
| Warkworth | Warkworth | 8 | 3 | 0 |
| Auckland Urban | Takapuna | 0 | 0 | 0 |
| Beachlands-Maraetai | Beachlands | 0 | 0 | 0 |
| Cambridge | Cambridge | 0 | 0 | 0 |
| Christchurch | Christchurch St Albans | 5 | 0 | 0 |
| Dargaville | Dargaville | 0 | 0 | 0 |
| Hamilton City | Hamilton | 0 | 0 | 0 |
| Hastings | Hastings | 0 | 0 | 0 |
| Helensville | Helensville | 0 | 0 | 0 |
| Huntly | Huntly Croft Tce | 0 | 0 | 0 |
| Kaitaia | Kaitaia | 0 | 0 | 0 |
| Kapiti Coast | Raumati South | 0 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Karori | Karori | 0 | 0 | 0 |
| Kerikeri | Kerikeri | 0 | 0 | 0 |
| Kumeu | Kumeu | 0 | 0 | 0 |
| Lower Hutt | Lower Hutt | 0 | 0 | 0 |
| Matamata | Matamata | 0 | 0 | 0 |
| Morrinsville | Morrinsville | 0 | 0 | 0 |
| Nelson B | Nelson Airshed B | 0 | 0 | 0 |
| Nelson C | Nelson Airshed C | 0 | 0 | 0 |
| Ngaruawahia | Ngaruawahia | 0 | 0 | 0 |
| Otorohanga | Otorohanga | 0 | 0 | 0 |
| Otago 3 | Dunedin | 0 | 0 | 0 |
| Paeroa | Paeroa | 0 | 0 | 0 |
| Porirua | Porirua | 0 | 0 | 0 |
| Pukekohe | Pukekohe | 0 | 0 | 0 |
| Putaruru | Putaruru | 0 | 0 | 0 |
| Rangiora | Rangiora | 0 | 0 | 0 |
| Reefton | Reefton | 0 | 0 | 0 |
| Riverhead | Riverhead | 0 | 0 | 0 |
| Snells Beach | Snells Beach | 0 | 0 | 0 |
| Taumarunui | Taumarunui | 0 | 0 | 0 |
| Taupo | Taupo | 0 | 0 | 0 |
| Te Aroha | Te Aroha | 0 | 0 | 0 |
| Te Awamutu and Kihikihi | Te Awamutu | 0 | 0 | 0 |
| Thames | Thames | 0 | 0 | 0 |
| Tuakau | Tuakau | 0 | 0 | 0 |
| Turangi | Turangi | 0 | 0 | 0 |
| Upper Hutt | Upper Hutt | 0 | 0 | 0 |
| Waiheke Island | Waiheke | 0 | 0 | 0 |
| Waihi | Waihi | 0 | 0 | 0 |
| Waimate | Waimate | 2 | 0 | 0 |
| Wainuiomata | Wainuiomata | 0 | 0 | 0 |
| Waiuku | Waiuku | 0 | 0 | 0 |
| Wellington City | Wellington Central | 0 | 0 | 0 |
| Wellsford | Wellsford | 0 | 0 | 0 |
| Whangamata | Whangamata | 0 | 0 | 0 |
| Whangarei | Whangarei | 0 | 0 | 0 |
| Whitianga | Whitianga | 0 | 0 | 0 |

Figure 3-1 shows the expected number of exceedances of a daily $PM_{2.5}$ standard of 25$\mu$g $m^{-3}$ compared with current exceedances of the NESAQ daily $PM_{10}$ standard of 50 $\mu$g $m^{-3}$. A list of exceedances of the NESAQ $PM_{10}$ standard are given in Appendix B.

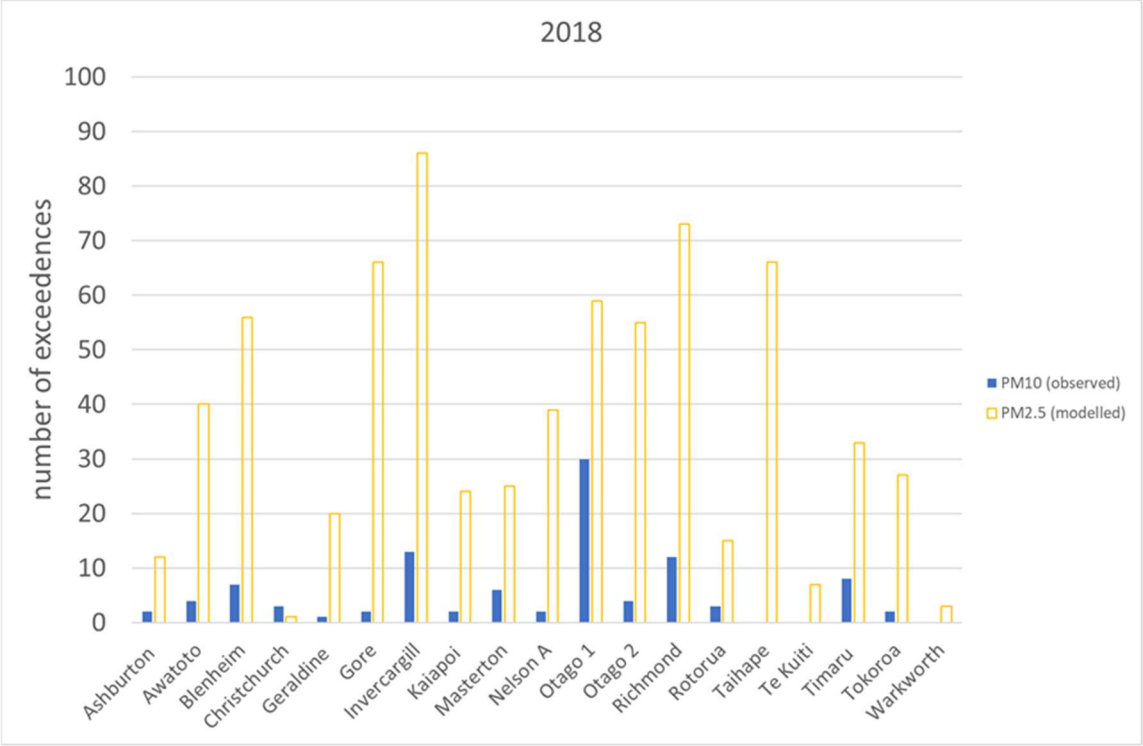



**Figure 3-1: Modelled number of exceedances of a PM2.5 standard of 25ugm-3 per year compared to the number of exceedances of the current PM10 standard in 2018.**

## 3.3 Health outcomes attributable to $PM_{2.5}$

**Table 3-3: Estimated health outcomes for $PM_{2.5}$ in 2018.**

| RESULTS | | Health Effects All Anthropogenic Sources (cases) |
|---|---|---|
| **Mortality** | | |
| Mortality: 30+ yrs | | 646 |
| | Total Mortality | |
| **Morbidity** | | |
| Cardiac Hospital Admissions: All ages | | 215.3 |
| Respiratory Hospital Admissions: All ages | | 422.4 |
| Restricted Activity Days | | 1,600,647 |

**Table 3-4: Results of sensitivity testing of mortality concentration-response functions.** 0.04 and 0.083 values recommended by the WHO (2013). Other values have been chosen to represent a range of possible outcomes.

| CRF | mortality cases per annum |
|---|---|
| 0.02 | 221 |
| 0.04 | 439 |
| 0.062 | 646 |
| 0.083 | 841 |
| 0.11 | 1,077 |

## 3.4 Health outcomes attributable to $PM_{10}$

Health outcomes attributable to $PM_{10}$ were also assessed in this work. Great care should be taken in comparing these results to those estimated for $PM_{2.5}$. They were calculated using different concentration-response functions from different origins ($PM_{10}$ using the NZ-based work of Hales et al., 2010, $PM_{2.5}$ using a much larger but non-NZ body of evidence summarised by the WHO (2013) and COMEAP (2009). Both estimates, whilst in our view the best available, contain considerable uncertainty. In view of this uncertainty, it should **not** be inferred that the difference between the $PM_{10}$ and $PM_{2.5}$ health effects estimates equates to the health impacts of coarse particles ($PM_{2.5\text{-}10}$).

**Table 3-5: Estimated health outcomes for $PM_{10}$ in 2018.**

| RESULTS | | Health Effects All Anthropogenic Sources (cases) |
|---|---|---|
| **Mortality** | | |
| Mortality: 30+ yrs | | 724 |
| | Total Mortality | |
| **Morbidity** | | |
| Cardiac Hospital Admissions: All ages | | 142.6 |
| Respiratory Hospital Admissions: All ages | | 225.1 |
| | | |

# 4 Acknowledgements

We would like to thank Perry Davy of GNS Science and Travis Ancelet, formally of GNS Science for the timely provision of data, peer review and assistance. Furthermore, our thanks to Deborah Read (Ministry of Health) for additional comments on an early draft.

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# Appendix A Source Apportionment data used

Tables A-1 to A-3 show the estimated annual mean contributions of various source profiles at various locations. This is based on monthly time series provided to NIWA by GNS Science. It should be noted that the source profile definitions (e.g. 'soil', 'biomass', etc.) are strictly defined for each dataset alone and may be inconsistent between locations and should therefore be treated as indicative rather than definitive.

The original data, methods and analyses can be found in the following reports:


Ancelet, T.; Davy, P. K.; Trompetter, W. J. 2013. Source apportionment of $PM_{10}$ and $PM_{2.5}$ in Nelson Airshed A, *GNS Science Consultancy Report* 2013/146. 95 p.

Davy, P. K.; Trompetter, W. J.; Markwitz, A. 2008. Source apportionment of airborne particles at Seaview, Lower Hutt, *GNS Science Consultancy Report* 2008/160

Davy, P. K.; Trompetter, W. J.; Markwitz, A. 2009. Source apportionment of airborne particles at Wainuiomata, Lower Hutt, *GNS Science Consultancy Report* 2009/188

Davy, P. K.; Trompetter, W. J.; Markwitz, A. 2010. Source apportionment of airborne particles at Tahunanui, Nelson, *GNS Science Consultancy Report* 2010/198

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Wilton, E.; Trompetter, W. J. 2007. Source apportionment of $PM_{10}$ in Blenheim, *Prepared for Marlborough District Council*

**Table A-1: Estimates of main source contributions to annual mean $PM_{10}$ concentrations ($\mu g\ m^{-3}$) derived from data provided by GNS.** Highlighted data are winter only.

| | Total $PM_{10}$ | Biomass burning | Motor vehicles | Marine aerosol | Soil | Sulphate | Other |
|---|---|---|---|---|---|---|---|
| Alexandra CODC | 20.0 | 20.3 | 0.7 | 0.4 | 0.5 | | 0.0 |
| Alexandra GG | 34.5 | 26.2 | 2.3 | 0.2 | 0.2 | | 0.0 |
| Blenheim | 10.7 | 4.4 | 1.0 | 2.3 | 1.4 | 1.0 | 0.0 |
| Dunedin | 27.2 | 3.9 | 2.8 | 5.1 | 7.4 | 1.7 | 5.1 |
| Hastings | | | PM2.5 only | | | | |
| Henderson | 13.7 | 2.3 | 2.0 | | 1.2 | 1.4 | 0.3 |
| Kingsland | 15.8 | 2.9 | 2.8 | 6.8 | 1.0 | 1.4 | 0.0 |
| KPR | 18.2 | 1.5 | 5.0 | 7.6 | 1.5 | 1.7 | 0.0 |
| Lower Hutt | 16.3 | 1.1 | 2.2 | 6.3 | | 2.4 | 0.5 |
| Masterton | 16.6 | 7.1 | 1.0 | 4.3 | 3.4 | 0.8 | 0.0 |
| Nelson A | 19.1 | 8.4 | 1.8 | 3.9 | 2.5 | 2.3 | 0.0 |
| Nelson B | 20.6 | 7.2 | 2.2 | 3.8 | 3.1 | 1.3 | 2.6 |
| Patumahoe | 10.8 | 0.9 | | 5.3 | 2.4 | 1.1 | 0.4 |
| Penrose | 16.9 | 2.0 | 3.9 | 6.8 | 1.7 | 1.4 | 0.1 |
| Queen Str | 17.8 | 1.2 | 5.8 | 6.8 | 1.1 | 1.0 | 1.0 |
| Raumati | 22.1 | 8.9 | 1.5 | 8.5 | 1.2 | 1.6 | 0.0 |
| Takapuna | 16.2 | 2.2 | 3.4 | 6.2 | 1.0 | 2.1 | 0.5 |
| Timaru | | | PM2.5 only | | | | |
| Tokoroa | | 14.7 | | 2.5 | | 1.8 | 1.9 |
| Upper Hutt | 11.0 | 2.3 | 1.4 | 4.0 | 2.2 | 1.3 | 0.0 |
| Wainuiomata | 13.6 | 2.9 | 1.7 | 5.6 | 1.3 | 1.2 | 0.0 |
| Whangarei | 12.5 | 4.7 | 4.6 | 1.8 | | 0.8 | 0.0 |
| Woolston | 23.3 | 5.4 | 4.6 | 3.9 | 4.6 | 0.6 | 0.0 |

**Table A-2: Estimates of main source contributions to annual mean $PM_{2.5}$ concentrations (μg $m^{-3}$) derived from data provided by GNS. .** Highlighted data are winter only.

| | Total $PM_{2.5}$ | Biomass burning | Motor vehicles | Marine aerosol | Soil | Sulphate | Other |
|---|---|---|---|---|---|---|---|
| Alexandra CODC | | | | | | | |
| Alexandra GG | | | | | | | |
| Blenheim | | | | | | | |
| Dunedin | 10.4 | 4.0 | 2.9 | 1.2 | | 1.7 | 0.0 |
| Hastings | 11.9 | 6.9 | 1.0 | 1.2 | | 1.1 | 0.0 |
| Henderson | | | | | | | |
| Kingsland | 6.9 | 2.1 | 1.9 | 1.3 | | 0.8 | 0.0 |
| KPR | 8.3 | 1.3 | *4.1* | 0.9 | 0.0 | 1.3 | 0.0 |
| Lower Hutt | 4.9 | 1.1 | 0.6 | 1.1 | 0.4 | 1.1 | 0.5 |
| Masterton | 7.8 | 4.7 | 0.4 | 0.7 | 0.7 | 0.6 | 0.0 |
| Nelson A | 15.1 | 10.7 | 0.7 | 1.1 | 0.9 | 1.0 | 0.0 |
| Nelson B | | | | | | | |
| Patumahoe | 3.4 | 0.9 | 0.0 | 0.9 | 0.2 | 1.1 | 0.0 |
| Penrose | 7.0 | 1.5 | 2.5 | 0.5 | 0.3 | 1.0 | 0.5 |
| Queen Str | 9.3 | 0.8 | *3.6* | 2.1 | 0.1 | 1.0 | 1.0 |
| Raumati | *12.8* | *8.2* | *1.5* | *1.6* | | *1.6* | *0.0* |
| Takapuna | 8.0 | 1.5 | *1.7* | 2.8 | 0.2 | 1.0 | 0.0 |
| Timaru | 11.8 | 5.0 | 0.9 | 2.8 | | 0.7 | 0.8 |
| Tokoroa | | | | | | | |
| Upper Hutt | 4.6 | 1.8 | 0.9 | 0.4 | | 0.8 | 0.0 |
| Wainuiomata | 6.2 | 2.5 | 0.7 | 1.6 | | 1.4 | 0.0 |
| Whangarei | | | | | | | |
| Woolston | 9.6 | 3.2 | *2.5* | 0.5 | 0.3 | 1.2 | 0.0 |

**Table A-3: Estimates of main source contributions to annual mean $PM_{2.5-10}$ concentrations (μg $m^{-3}$) derived from data provided by GNS** Black text is measured data. Red text is calculated from $PM_{10}$ - $PM_{2.5}$. Highlighted data are winter.

| | $PM_{2.5-10}$ | Wood Burning | Road Dust | Seasalt | Soil | Sulphate | Fertiliser soil |
|---|---|---|---|---|---|---|---|
| Alexandra CODC | | | | | | | |
| Alexandra GG | | | | | | | |
| Blenheim | | | | | | | |
| Dunedin | 16.9 | 0.0 | | 3.9 | 7.4 | 0.0 | 5.1 |
| Hastings | | | | | | | |
| Henderson | | | | | | | |
| Kingsland | 8.9 | 0.8 | | 5.5 | | 0.6 | |
| KPR | 9.9 | 0.2 | | 6.7 | 1.4 | 0.5 | |
| Lower Hutt | 11.2 | -0.1 | 1.6 | 5.2 | 2.6 | 1.2 | |
| Masterton | 7.7 | 1.5 | 0.5 | 3.3 | 1.9 | 0.1 | |
| Nelson A | 4.0 | -2.4 | | 2.8 | 1.7 | 1.3 | |
| Nelson B | | | | | | | |
| Patumahoe | 7.3 | 0.0 | | 4.3 | 2.2 | 0.0 | 0.4 |
| Penrose | 9.9 | 0.6 | | 6.3 | 1.4 | 0.4 | |
| Queen Str | 8.5 | 0.4 | | 4.7 | 0.9 | 0.0 | |
| Raumati | 9.3 | 0.7 | | 6.9 | 1.2 | 0.0 | |
| Takapuna | 8.1 | 0.6 | | 3.5 | 0.9 | 1.1 | |
| Timaru | | | | | | | |
| Tokoroa | | | | | | | |
| Upper Hutt | 6.1 | 0.5 | 0.7 | 3.6 | 1.5 | 0.4 | |
| Wainuiomata | 7.4 | 0.4 | 0.7 | 4.4 | 1.7 | -0.2 | |
| Whangarei | | | | | | | |
| Woolston | 13.7 | 2.2 | | 3.4 | 4.3 | -0.6 | |

# Appendix B $PM_{10}$ exceedances 2015 - 2018

Table B-1 shows the annual mean $PM_{10}$ concentration and number of exceedances of the National Environmental Standards for Air Quality 24-hour limit value (50 µg $\mathbf{m^{-3}}$). The data are taken from Land Air Water Aotearoa (LAWA) (https://www.lawa.org.nz/). Note: empty cells in the table result from there being no corresponding data recorded in LAWA.

**Table B-1: PM10 exceedances of NESAQ in New Zealand 2015 - 2018.**

| | Annual Mean $PM_{10}$ (µg $m^{-3}$) | | | | Number of NES exceedances | | | |
|---|---|---|---|---|---|---|---|---|
| | **2018** | **2017** | **2016** | **2015** | **2018** | **2017** | **2016** | **2015** |
| Arrowtown | 18.5 | 22.2 | 19.8 | 21.4 | 30 | 45 | 32 | 29 |
| Invercargill | 21 | 20.3 | 19.8 | 20.7 | 13 | 14 | 12 | 11 |
| Richmond | 18.8 | 16.7 | 18.7 | 18 | 12 | 2 | 5 | 3 |
| Timaru | 19.5 | 21 | 23.1 | 26.2 | 8 | 17 | 27 | 26 |
| Blenheim | 17.8 | 18.9 | 17.3 | 15.1 | 7 | 11 | 4 | 4 |
| Masterton East | 14.2 | 15.2 | 15 | 14.8 | 6 | 5 | 10 | 4 |
| Awatoto | 19.7 | 18 | 18.4 | 19.6 | 4 | 1 | 0 | 3 |
| Mosgiel | 19.2 | 18.6 | | 19.5 | 4 | 8 | 9 | 7 |
| Masterton West | 14 | 13.9 | 13.8 | 11.8 | 3 | 3 | 1 | 1 |
| Rotorua | 13.7 | 16.6 | | | 3 | 0 | | |
| Hastings | 13.5 | 13.4 | 15.3 | 14.8 | 3 | 2 | 7 | 1 |
| Christchurch (St Albans) | | | | | 3 | 4 | 3 | 4 |
| Gore | 18.5 | 18.6 | 18.4 | 19.5 | 2 | 2 | 5 | 2 |
| Nelson South StVincent | 17 | 17 | 17 | 17 | 2 | 1 | 1 | 2 |
| Kaiapoi | 16.6 | 17.4 | 17.8 | 19.6 | 2 | 10 | 7 | 13 |
| Ashburton | 16 | 17.5 | 17.8 | 19.5 | 2 | 3 | 2 | 1 |
| Tokoroa | 14.7 | 15.6 | 15.1 | 16.6 | 2 | 10 | 5 | 10 |
| Alexandra | 14.2 | | | 20.4 | 2 | 43 | 38 | 22 |
| Geraldine | 16 | 17 | 17 | 19 | 1 | 1 | 1 | 3 |
| Dunedin | 15 | 14.1 | 16.1 | 16.9 | 1 | 0 | 0 | 0 |
| Napier | 13 | 12.8 | 13 | 13.8 | 1 | 0 | 0 | 1 |
| Tahunanui Blackwood | 18 | 20 | 18 | 18 | 0 | 3 | 0 | 0 |
| Rangiora | 15.5 | 16.9 | 17.1 | 17.9 | 0 | 6 | 7 | 3 |
| Waimate | 14 | 16.1 | 16.2 | | 0 | 2 | 0 | |
| Takapuna | 13.5 | 14.3 | 13.5 | 14.9 | 0 | 1 | 3 | 0 |
| Te Kuiti | 13.4 | 14.1 | 15.2 | 15.4 | 0 | 0 | 0 | 0 |
| Wellington | 12.4 | 11.3 | 11.3 | | 0 | 0 | 0 | |
| Hamilton - Bloodbank | 12.1 | 12.3 | 12.5 | 12.9 | 0 | 0 | 0 | 0 |
| Nelson Centre Brook | 12 | 13 | 14 | 11 | 0 | 0 | 0 | 0 |
| Hamilton - Claudelands | 11.6 | 11.1 | 11.5 | 11.3 | 0 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lower Hutt | 11.3 | 11.4 | 11.2 | 11.3 | 0 | 0 | 0 | 0 |
| Putaruru | 11.2 | 11.6 | 11.7 | 14.1 | 0 | 1 | 0 | 0 |
| Taupo | 11.2 | 13.8 | 12 | 12.5 | 0 | 1 | 0 | 0 |
| Wainuiomata | 10.9 | 11.3 | 10.6 | 10.3 | 0 | 0 | 0 | 0 |
| Tauranga | 10.7 | 9.7 | 10.2 | | 0 | 0 | 0 | |
| Upper Hutt | 10.4 | 10.7 | 10.5 | 10.1 | 0 | 0 | 0 | 0 |
| Thames | 5.4 | 8.6 | | | 0 | 0 | 0 | 0 |
| Taihape | 18.6 | 16.2 | 11.4 | 14.6 | | | | |
| Reefton | 12.4 | 13 | 16.4 | 20.2 | | | | |
| Taumaranui | 10.5 | 12 | 11.4 | 13.4 | | | | |
| Stoke Green Meadows | | 10 | 11 | | | 0 | 0 | |
| Ruakaka | | | | 11.5 | | | | 0 |
| Whangarei | | | | 13.4 | | | | 0 |
| Morrinsville | | 11.3 | | | | | 0 | |