

# Air Quality SoE Report 2005 - 2014

July 2015

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## Executive summary

Clean ambient (outdoor) air is an important resource for supporting a healthy population and environment. Ambient air quality is a combination of the amounts and types of emissions that go into the air, along with the meteorological conditions that affect their movement. Otago Regional Council (ORC) operates a State of the Environment (SoE) air quality monitoring network throughout the region and performs other investigative studies that help define the ambient air quality in Otago. Over the past 10 years, monitoring has focussed mainly on PM<sub>10</sub>, small particles with a diameter of less than 10 micrometres.

This State of the Environment report on air quality evaluates the results of the past 10 years (2005-2014) of air quality monitoring. The report assesses the current state of air quality in Otago centres and identifies the temporal and spatial trends in air quality over the reporting period. The pressures and influences on regional air quality are discussed in a section on emissions and weather.

Results of the SoE monitoring network indicate that for most of the year, air quality in Otago is very good, with baseline PM<sub>10</sub> values well within national standards and guidelines for clean air. During winter months, however, home heating emissions increase and the ability of the atmosphere to disperse them decreases mainly due to calm conditions coupled with strong temperature inversions. This scenario often leads to elevated PM<sub>10</sub> levels, particularly in Central Otago but in other areas as well.

Results show that Alexandra, Arrowtown, Clyde, Cromwell and Milton regularly exceed the daily standard for PM<sub>10</sub> set in the National Environmental Standard for Air Quality (NESAQ), anywhere from 15 to 45 days in some winters. Other centres such as Balclutha, Mosgiel, Lawrence, and Oamaru exceed the standard from one to 10 days each winter.

Central Dunedin is currently reporting very good air quality year-round where air quality has met NESAQ standards and guidelines for PM<sub>10</sub> for the past three consecutive years, a significant improvement over previous years. Improvement in Dunedin's air quality has come mainly through working with industry to lower their particulate emissions and, presumably, an increased reliance on heat pumps for domestic heating.

Recognising the challenge of improving air quality in other parts of Otago, ORC set strict emission limit rules for domestic heating appliances in Central Otago in the Otago Regional Plan: Air Plan. To assist residents in meeting those rules, Council operates the Clean Heat Clean Air programme, a financial incentive package that has improved insulation and heating appliances in well over a thousand homes. Long-term trend analysis shows that air quality has improved somewhat in Alexandra, Arrowtown and Clyde; however, at current rates of change, the NESAQ is unlikely to be met and there are still far too many days each winter with poor air quality.

Long-term trends in areas of Otago that are growing indicate that PM<sub>10</sub> levels may actually be rising slowly; this is the case in Mosgiel and Cromwell.

Results from this report will be used to inform future work on air quality management strategies and programmes in Otago.



# 1. Introduction

## 1.1 Report purpose

Clean ambient (outdoor) air is an important resource for supporting a healthy population and environment. Ambient air quality is a combination of the amounts and types of emissions that go into the air, along with the meteorological conditions that affect their movement. Otago Regional Council (ORC) operates a State of the Environment (SoE) air quality monitoring network throughout the region and performs other investigative studies that help define the ambient air quality in Otago. Over the past 10 years, monitoring has focussed on PM<sub>10</sub>, particulate matter with an aerodynamic diameter of 10 micrometres or less.

Three previous SoE reports have evaluated air quality in Otago. Two reports described the period from 1997 through 2004; one evaluated results for PM<sub>10</sub> (ORC, 2005) and the other reported on other ambient pollutants including sulphur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>) and carbon monoxide (CO) (ORC, 2005a). A third report evaluated PM<sub>10</sub> results for the 4-year period from 2005 through 2008 (ORC, 2009).

This report evaluates results of SoE air quality monitoring performed over the 10-year period from 2005 through 2014. This period encompasses ORC's entire continuous monitoring record; prior to 2005, monitoring was done on an intermittent basis due to the limitations of the technology in use at the time. By using the entire continuous monitoring dataset, this report describes the current state of air quality in the Otago region and also evaluates trends in air quality.

## 1.2 Report scope

The report relies on data measured at the continuous air quality monitors throughout the region. In addition, relevant information from other investigations, including source apportionment studies, emissions inventories, and other special studies is included.

## 1.3 Report outline

The following sections are included in this report:

- Section 2 describes the current air quality assessment framework including guidelines, standards and local management areas
- Section 3 describes Otago's monitoring network
- Section 4 discusses the pressures and influences on air quality
- Section 5 presents the current state of air quality. Analyses of the three most recent years' data (2012-2014) are presented for sites used in reporting on the National Environmental Standard for Air Quality (NESAQ). Results of shorter term monitoring, used for tracking seasonal pollution or in screening campaigns are also presented

- Section 6 provides analyses of the temporal trends in air quality from 2005-2014 and describes the spatial distribution of PM<sub>10</sub> in various towns
- Section 7 discusses the results of the analyses done in Sections 5 and 6 and the implications for compliance with the NESAQ.

## 2. Air quality assessment framework

### 2.1 National air quality indicators

National air quality guidelines were first established in 1994 by the Ministry for the Environment (MfE), based on international public health information (1994). In 2002, MfE revised these health-based guidelines and set suggested limits on concentrations of various ambient air pollutants (MfE 2002).

The National Environmental Standards for Air Quality (NESAQ), adopted in 2004 and revised in 2011, establish minimum requirements for five ambient air pollutants (2004, 2011). The objectives of these standards are to provide an acceptable level of protection to human health and the environment.

Table 1 provides the current New Zealand ambient air quality standard and guideline values for relevant pollutants. Guideline values are recommended; standard values are to be met by 2020.

**Table 1. New Zealand guidelines and standards for ambient air pollutants.**

| Pollutant                           | Status    | Threshold concentration (micrograms/m <sup>3</sup> ) | Averaging period | Number of Allowable Exceedances |
|-------------------------------------|-----------|------------------------------------------------------|------------------|---------------------------------|
| PM <sub>10</sub>                    | Standard  | 50                                                   | 24-hour          | 1 per year                      |
|                                     | Guideline | 20                                                   | Annual           | n/a                             |
| Nitrogen dioxide (NO <sub>2</sub> ) | Standard  | 200                                                  | 1-hour           | 9 per year                      |
|                                     | Guideline | 100                                                  | 24-hour          | n/a                             |
| Carbon monoxide (CO)                | Standard  | 10                                                   | 8-hour running   | 1 per year                      |
|                                     | Guideline | 30                                                   | 1-hour           | n/a                             |
| Ozone (O <sub>3</sub> )             | Standard  | 150                                                  | 1-hour           | none                            |
|                                     | Guideline | 100                                                  | 8-hour running   | n/a                             |
| Sulphur Dioxide (SO <sub>2</sub> )  | Standard  | 350                                                  | 1-hour           | 9 per year                      |
|                                     | Standard  | 570                                                  | 1-hour           | none                            |
|                                     | Guideline | 120                                                  | 24-hour          | n/a                             |

ORC's current monitoring programme focuses principally on measuring PM<sub>10</sub>, the most common and significant pollutant found regionally as well as nationally. Earlier, targeted monitoring of NO<sub>2</sub>, SO<sub>2</sub>, and CO indicated that these pollutants were not present in significant amounts. Ozone is considered a secondary pollutant formed during a



photochemical reaction that occurs when oxygen (O<sub>2</sub>) and nitrogen dioxide (NO<sub>2</sub>) are exposed to bright light. In a study on photochemical pollution potential in New Zealand by McKendry (1996), Dunedin was not identified as a city with atmospheric conditions conducive to the formation of ozone.

## **2.2 Regional goal levels**

The NESAQ values are integrated into the Regional Plan: Air for Otago (Air Plan) (2009). In addition, the Air Plan set Otago Goal Levels (OGLs) at approximately 66% of NESAQ values as “alert” levels as advocated by the MfE in the Environmental Performance Indicators Programme (1997). The Otago Goal Level for daily mean PM<sub>10</sub> is 35 µg/m<sup>3</sup>.

## **2.3 Ambient pollutants**

The emphasis over the past 10 years has been on measuring PM<sub>10</sub>. Earlier measurements of other pollutants by ORC (2005a) indicated that while they are present, concentrations of NO<sub>2</sub>, SO<sub>2</sub>, and CO are generally expected to be below guideline and standard levels. Ozone has not been measured in Otago.

### **2.3.1 Particulate matter**

Particulate matter (PM) refers to particles, or aerosols, that are suspended in the atmosphere. PM originates from a variety of anthropogenic mobile and stationary combustion sources including solid-fuel burners, vehicles and industrial discharges. It also occurs naturally as agricultural dust, entrained road dust, airborne marine aerosol, and pollen.

PM comprises a wide variety of physical and chemical composition depending on the source and size of the particles. Regardless of shape or composition, aerosols generally occur in one of two size categories. They are referred to as the “fine” fraction” for particles with an equivalent aerodynamic diameter smaller than 2.5 micrometres, and the “coarse” fraction which encompasses all particles with aerodynamic diameters between 2.5 and 10 micrometres. PM<sub>10</sub> refers to the fine and coarse fractions together.

Generally, the fine fraction (PM<sub>2.5</sub>) is emitted from anthropogenic sources and is a result of incomplete combustion. PM<sub>2.5</sub> includes a large number of organic and inorganic compounds, metals, and black carbon, i.e. soot. These particles can remain suspended in the air for many days or weeks and can be transported hundreds of kilometres.

Coarse fraction PM typically originates where mechanical forces are at play. This includes wind action for natural sources such as pollen and sea salt; abrasive and crushing actions contribute to the suspension of road dust. Particles in this fraction tend to fall out of suspension within minutes or hours and can travel anywhere from a few hundred metres to 50 kilometres.

Large-scale epidemiological health studies conducted by Pope and Dockery (2006) implicate both short-term (hourly/daily) and long-term (annual) exposure to PM<sub>10</sub> with adverse health effects. Due to its small size, PM<sub>10</sub> is easily inhalable and the smaller the particle size, the deeper into the respiratory system it can travel. More recent research by the World Health Organisation (2013) indicates that adverse health effects are more closely related to the fine and “ultra-fine” (less than 1.0 µm) fractions. This evidence was recently noted by the Parliamentary Commissioner for the Environment (2015).

Adverse health effects cross a wide spectrum from irritation to respiratory systems to, at the extreme end of the spectrum, cases of premature death. The most common adverse health associations with PM are increased rates of respiratory and cardio-pulmonary events. Most affected are young children, the elderly, and people with relevant pre-existing conditions.

### **2.3.2 Carbon monoxide**

Carbon monoxide is a colourless, odourless and tasteless gas, most commonly caused by human activities. Breathing carbon monoxide affects the oxygen-carrying capacity of blood and can result in mental confusion, heart problems, and a general decline in a person's wellbeing, depending on the concentrations.

Prominent sources include vehicle exhaust along with wood and coal combustion.

### **2.3.3 Nitrogen dioxide**

Nitrogen dioxide is a brownish acidic gas and is highly corrosive. It forms from chemical reactions involving nitrogen oxide (NO) and other oxides, typically during combustion of fossil fuels. Inhalation is associated with aggravating respiratory diseases such as asthma, lung infections with resulting increases in hospital admissions.

Vehicle emissions are the main source of NO<sub>2</sub> in urban areas.

### **2.3.4 Sulphur dioxide**

Sulphur dioxide gas is colourless and has a characteristically pungent smell. It is produced during the combustion of sulphur-containing fossil fuels such as coal. Respiratory problems are the most common complaint with increased inhalation of SO<sub>2</sub>. It also has links to cardiovascular disease.

Common sources in Otago include coal-burning combustion sources such as industrial emissions and coal burners used in domestic heating.

### **2.3.5 Ozone**

Lower-level ozone is a secondary pollutant formed from other compounds during photochemical reactions and it results in smog. Effects of high ozone levels include increased respiratory and cardiovascular disease. Short-term effects include irritation of the eyes, nose, and throat as well as headaches.

Ozone is not readily formed in Otago as it requires an abundance of sunlight.

## **2.4 International air quality indicators**

New Zealand standards and guidelines are generally consistent with the World Health Organisation (WHO) recommendations (2006). In the cases of PM and SO<sub>2</sub>, however, there are some significant differences.

As regards particulate matter, international researchers accept the evidence that adverse health effects associated with PM<sub>2.5</sub> are greater than those associated with PM<sub>10</sub>. As a result, many agencies, including the World Health Organisation, the European Union, and the United States have introduced PM<sub>2.5</sub> standards alongside their PM<sub>10</sub> standards. In formulating PM guidelines and standards, the WHO assumes that the ratio of PM<sub>2.5</sub> to PM<sub>10</sub>

is 0.5, thereby setting equivalent  $PM_{2.5}$  and  $PM_{10}$  daily mean guideline values of  $25 \mu\text{g}/\text{m}^3$  and  $50\mu\text{g}/\text{m}^3$ , respectively.

The WHO lowered the  $SO_2$  24-hour guideline value from  $120 \mu\text{g}/\text{m}^3$  to  $20 \mu\text{g}/\text{m}^3$  in 2005 (Krzyanowski, 2008). The lowered value may be relevant in areas with coal-powered industrial plants and in areas where coal-burning is heavily used for domestic heating. To date, New Zealand has not revised the NESAQ  $SO_2$  standard.

Table 2 lists relevant WHO guideline values for various ambient air pollutants where they differ significantly from the NESAQ.

**Table 2. World Health Organisation guideline values for  $PM_{2.5}$ , nitrogen dioxide and sulphur dioxide**

| Pollutant        | Threshold concentration ( $\mu\text{g}/\text{m}^3$ ) | Averaging period |
|------------------|------------------------------------------------------|------------------|
| $PM_{2.5}$       | 25                                                   | 24-hour          |
|                  | 10                                                   | annual           |
| Nitrogen dioxide | 40                                                   | annual           |
| Sulphur dioxide  | 20                                                   | 24-hour          |
|                  | 500                                                  | 10-minute        |

National and international standards and guidelines continue to evolve over time as advances are made in health research.

## 2.5 Otago air management designations

### 2.5.1 Airsheds

The Otago region has four designated Local Air Management Areas (LAMAs) which were gazetted as airsheds in 2005 in accordance with requirements of the NESAQ. Airsheds are used to determine whether areas are considered to be polluted by NESAQ standards.

Airshed 1 is deemed to have the most degraded air quality in winter with excessive numbers of days with unacceptable levels of pollution; Airshed 4 comprises areas where air quality could potentially be, but is not currently expected to be, degraded. Continuous, standard monitoring and reporting is required by the NESAQ for each airshed with degraded air quality.

Twenty-two towns and cities have been allocated to one of these four airsheds. Where monitoring data were available, those data were used to assign towns to the most appropriate airshed. In the absence of monitoring data, climate and topography data were used in conjunction with functional boundaries to determine the most appropriate airshed border.

Rural areas outside of town boundaries are considered a fifth, undesignated airshed encompassing the rest of Otago where air quality is expected to be good.

### **2.5.2 Air zones**

ORC placed the 22 towns and cities into one of three air zones for air quality management purposes in the Air Plan. Towns were allocated based on the following criteria:

- Air Zone 1 - Towns expected to exceed national standards more than 10 days a year;
- Air Zone 2 - Towns expected to exceed the national standards fewer than 10 days a year; and
- Air Zone 3 - Areas that are not expected to experience degraded air quality.

Air zones are used for planning purposes and provide a simplified framework for air quality management in the community. More stringent rules regarding emissions are in effect for Air Zone 1 than for the other air zones.

Initially, inland towns were assigned to Air Zone 1 and coastal towns to Air Zone 2 based on limited monitoring and assumptions about climate and topography. Where monitoring has shown that some of those original designations were not appropriate, towns have been re-allocated to the most suitable zone.

Boundaries for airsheds and air zones do not always coincide because air zones normally encompass a smaller, more urban footprint than do some of the airshed boundaries.

Table 3 lists the airshed and air zone designations for Otago. Maps of airshed and air zone boundaries are shown in Figures 1-14 in Appendix 1.

**Table 3. Airshed and air zone designations for Otago. Key indicator sites for reporting compliance with the NESAQ are shown with an asterisk ( \* ).**

| <b>Designation</b> | <b>Airsheds</b>  | <b>Air Zones</b> |
|--------------------|------------------|------------------|
| <b>1</b>           | Alexandra*       | Alexandra        |
|                    | Arrowtown*       | Arrowtown        |
|                    | Clyde            | Clyde            |
|                    | Cromwell         | Cromwell         |
|                    | Naseby           |                  |
|                    | Ranfurly         |                  |
|                    | Roxburgh         |                  |
| <b>2</b>           | Palmerston       | Balclutha        |
|                    | Mosgiel*         | North Dunedin    |
|                    | South Dunedin    | Central Dunedin  |
|                    | Green Island     | South Dunedin    |
|                    | Milton           | Green Island     |
|                    |                  | Hawea            |
|                    |                  | Kingston         |
|                    |                  | Milton           |
|                    |                  | Mosgiel          |
|                    |                  | Naseby           |
|                    |                  | Oamaru           |
|                    |                  | Palmerston       |
|                    |                  | Port Chalmers    |
|                    |                  | Queenstown       |
|                    |                  | Ranfurly         |
|                    | Roxburgh         |                  |
|                    | Waikouaiti       |                  |
|                    | Wanaka           |                  |
| <b>3</b>           | Balclutha        | Rest of Otago    |
|                    | North Dunedin    |                  |
|                    | Central Dunedin* |                  |
|                    | Oamaru           |                  |
|                    | Port Chalmers    |                  |
|                    | Waikouaiti       |                  |
| <b>4</b>           | Hawea            | N/A              |
|                    | Kingston         |                  |
|                    | Queenstown       |                  |
|                    | Wanaka           |                  |
| <b>5</b>           | Rest of Otago    | N/A              |

## **3. Air Quality Monitoring Network**

### **3.1 Background**

ORC operates a long-term air quality monitoring network in the region. Monitoring began in 1997 and since that time, ambient pollutants including PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub> and CO have been monitored in over 50 locations throughout Otago. Most of the monitoring performed over the past 10 years has been in response to the requirements of the NESAQ.

A variety of monitors and monitoring techniques have been employed to define and characterise air quality both temporally and spatially. During this 10-year reporting period (2005-2014), monitoring has focussed primarily on PM<sub>10</sub>.

Otago's large area with varying terrain and climate make it challenging to provide a true and complete representation of ambient air quality. In accordance with the NESAQ (2011), monitors are situated with consideration given to where the most people may experience the most pollution.

### **3.2 Monitoring objectives**

The objective of Otago's air quality monitoring programme is to provide scientifically robust data for the following purposes:

- to manage the region's air resource;
- to measure the effects of Council's air quality management initiatives;
- to fulfil the statutory requirements of RMA 1991 (Resource Management Act); and
- to measure and report on compliance with the NESAQ.

A range of monitoring activities and special investigations are needed to fulfil these objectives and in addition to continuous site monitoring, other activities include emissions inventories, source apportionment studies, and spatial studies.

Results from all monitoring programme activities help to inform on the overall, ambient air quality in Otago.

### **3.3 Monitoring scheme**

There are four categories of air quality monitoring used in the network:

1. Key Indicator Monitoring – Performed at long-term sites that run continuously and are designed to operate year-round. Results from these sites are used to report to the Ministry for the Environment on compliance with the NESAQ and to track long-term trends.

These sites have different topographical and climatological features, resulting in distinct patterns of particulate pollution. They were chosen as key sites because they are considered representative of Otago's townships.

2. Survey Monitoring – Performed at permanent sites that operate continuously during winter months only. Results are used to quantify wintertime air quality and assist in tracking trends. These sites have more than five years of data.
3. Screening Monitoring – Operated as relatively short-term monitoring campaigns (less than three years) to identify the magnitude of particulate pollution in various centres.
4. Special Investigations – Outside of the regular network, these are short-term, targeted studies to answer specific questions regarding air quality.

Table 4 lists the sites monitored during this 10-year reporting cycle, their purpose in the monitoring network and their lengths of record. Monitoring locations are shown in Figure 1.

**Table 4. Air monitoring sites and their purpose in the network. Sites noted with an asterisk have been the subject of special investigations. Length of record is measured from the start of monitoring to the end of 2014.**

| Site             | Air Zone | Airshed | Purpose                    | Length of Record |
|------------------|----------|---------|----------------------------|------------------|
| Alexandra*       | 1        | 1       | Key indicator – Year-round | 10 years         |
| Mosgiel*         | 2        | 2       | Key indicator – Year-round | 10 years         |
| Central Dunedin* | 2        | 3       | Key indicator – Year-round | 9 years          |
| Arrowtown*       | 1        | 1       | Survey : winter focus      | 8 winters        |
| Clyde            | 1        | 1       | Survey : winter focus      | 7 winters        |
| Cromwell*        | 1        | 1       | Survey : winter focus      | 7 winters        |
| Milton*          | 2        | 2       | Survey : winter focus      | 7 winters        |
| Balclutha*       | 2        | 3       | Survey : winter focus      | 6 winters        |
| Naseby           | 2        | 1       | Screening                  | 1 winter         |
| Roxburgh         | 2        | 1       | Screening                  | 1 winter         |
| Ranfurly         | 2        | 1       | Screening                  | 2 winters        |
| Palmerston*      | 2        | 2       | Screening                  | 2 winters        |
| Oamaru           | 2        | 3       | Screening                  | 2 winters        |
| Lawrence*        | 3        | 5       | Screening                  | 2 winters        |

## 3.4 Monitoring methods

### 3.4.1 PM<sub>10</sub> monitoring and measurement

Two types of air quality monitors are deployed in ORC's air quality network; both are beta attenuation monitors (BAMs) manufactured by MetOne in the United States and both measure PM<sub>10</sub> continuously. Beta attenuation monitors collect hourly samples of PM<sub>10</sub> and calculate an hourly mass concentration reported in micrograms per cubic metre of air (µg/m<sup>3</sup>) using standardised air flow measurements. A daily average PM<sub>10</sub> value is calculated using hourly values from midnight to midnight.

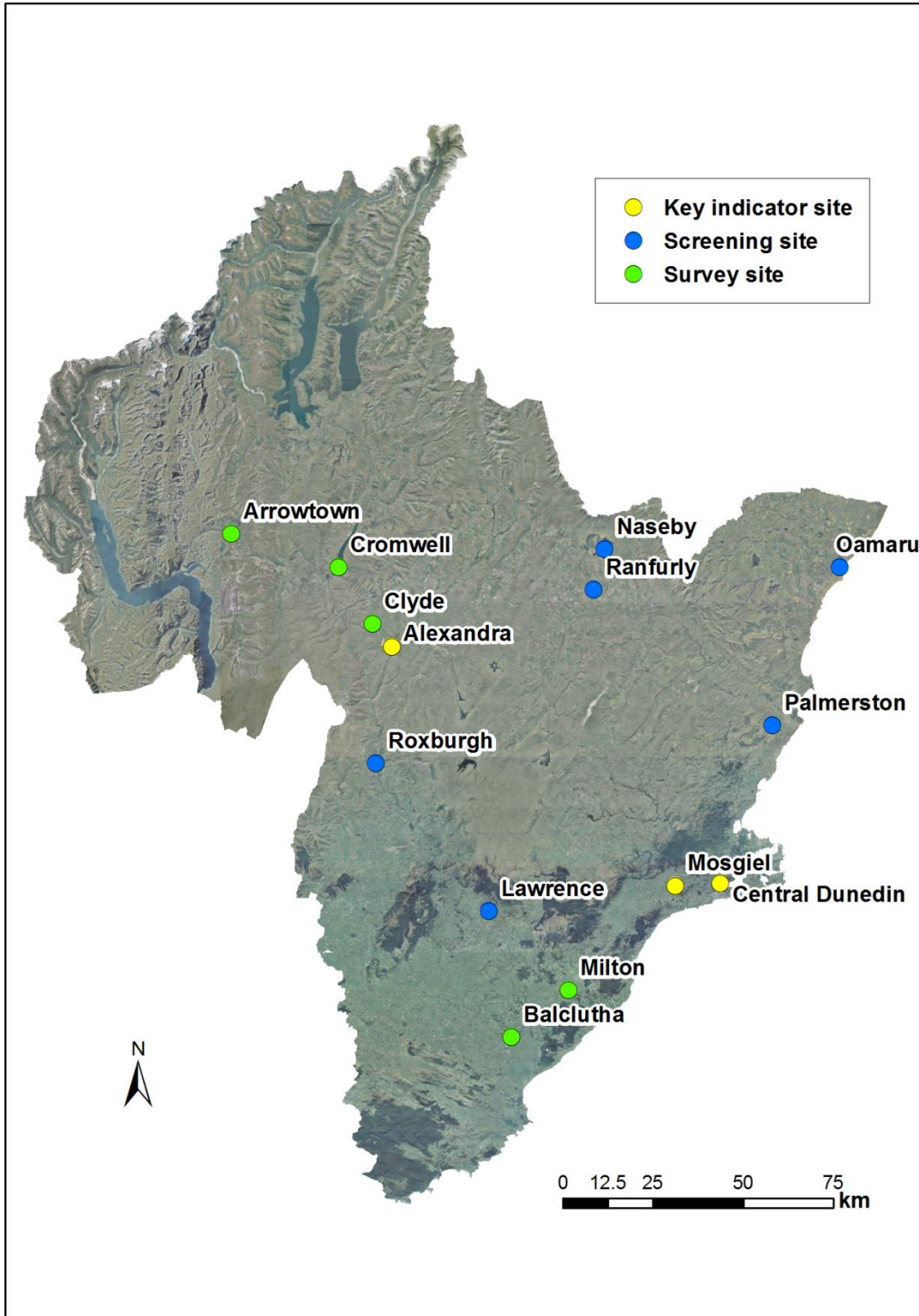


Figure 1. Otago air quality monitoring network during 2005-2014.



Standard sampling methods are required for reporting on compliance with the NESAQ. The BAM1020 is accepted by the US Environmental Protection Agency (USEPA) as an equivalent-reference standard method for measuring  $PM_{10}$  due to its automated hourly self-calibration, the data processing algorithms employed in its calculations, and the pre-conditioning of the airstream being sampled. These monitoring methods are employed at Alexandra, Arrowtown, Dunedin, and Mosgiel with results reported to the MfE on an annual basis.

The Dunedin BAM1020 installation is shown in Figure 2.



**Figure 2. A typical BAM1020 installation. The station at Dunedin measures  $PM_{10}$ , air temperature, wind speed and direction. The  $PM_{10}$  sampling inlet is shown at the top.**

The remainder of sites are monitored using an Environmental Beta Attenuation Monitor (EBAM). The EBAM is currently not considered an equivalent-reference standard method by the USEPA but it is designed to provide average daily PM<sub>10</sub> information accurate enough for tracking daily PM<sub>10</sub>.

All stations are sited and operated using the appropriate Australia and New Zealand standards (2007, 2008) as far as practicable.

Other monitoring technologies such as nephelometers, which measure light-scattering properties of particulate samples, and stacked-filter unit (GENT) samplers, have been deployed in special studies where applicable.

### **3.4.2 Meteorological monitoring**

Air temperature, wind speed, and wind direction all influence the accumulation and dispersion of pollutants. These parameters are recorded continuously at most PM<sub>10</sub> monitoring sites. Wind sensor heights are generally located at no more than 4 metres above the ground, below the World Meteorological Organisation (WMO, 1983) standard of 10 metres. As a result, the data have limited value in terms of dispersion modelling, but can be used to describe localised meteorological effects at the sites.

The National Institute of Water and Atmospheric Research (NIWA) and the MetService have meteorological datasets that can be used to augment the meteorological data collected at PM<sub>10</sub> monitoring sites.

## **4. Pressures and influences on air quality**

Ambient air quality at any location is the result of a complex relationship between emissions – both their type and amount – and meteorology.

Emissions come from a variety of sources such as solid-fuel home heating, vehicle exhaust, industrial and commercial discharges, and outdoor burning. These anthropogenic sources generally emit particulates that fall within the smaller size fraction of PM<sub>2.5</sub> and contain a multitude of chemical contaminants such as nitrogen and sulphur dioxides, polycyclic aromatic hydrocarbons (PAHs) and dioxins. Particulates in the “coarse” fraction (between PM<sub>2.5</sub> and PM<sub>10</sub>) generally come from naturally-occurring sources such as pollen, marine aerosol, dust and crustal matter.

The daily weather and the longer-term climate of a locale help determine how particulates are dispersed or accumulated and can have a greater influence on ambient air quality than do emission amounts. In Otago, larger-population towns with higher mass emissions (such as Dunedin and Mosgiel) regularly have better winter air quality than do smaller, lower-emitting towns such as Alexandra and Arrowtown.

This section describes the major emission sources found in Otago and the meteorological and climatological factors that affect them.

## 4.1 Emissions

### 4.1.1 Household emissions

Two types of data provide information on the emissions profiles of Otago towns. One is the Census report on dwelling type, which includes statistics on fuel types (e.g. electricity, wood, coal, gas, etc.) used to heat homes. The second is an emissions inventory, a tool used to compile estimated emissions for a town using information on not only burner numbers, but on their ages and fuel usage as well.

#### 4.1.1.1 Wood burners

The most recent Statistics New Zealand Census (2013) provides trend information when compared to previous Census results from 2001 and 2006<sup>1</sup>. The numbers of wood burners being used for domestic heating, and the percentage of total households that that number represents, are shown for key towns in Table 5. The percentage of wood burners being used has dropped in each of these towns, but due to an increasing number of homes over time, the actual numbers of wood burners has gone up in some towns, e.g. Arrowtown, Clyde, Cromwell, and Dunedin.

Currently in Otago, the use of wood burners is reported in approximately 56% of all households, well above the national average of 37%. Much higher-than-average percentages of wood use are reported in Clyde, Milton, and Lawrence (63, 70, and 76%, respectively).

**Table 5. Census data on wood burner use for key Otago towns.**

| Wood burner use by number and percentage |                |                |                |                |                |                |
|------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Site                                     | 2001           |                | 2006           |                | 2013           |                |
|                                          | # wood burners | % wood burners | # wood burners | % wood burners | # wood burners | % wood burners |
| Alexandra                                | 1146           | 62             | 1098           | 55             | 1086           | 53             |
| Arrowtown                                | 483            | 71             | 549            | 62             | 558            | 59             |
| Clyde                                    | 264            | 74             | 252            | 63             | 273            | 63             |
| Cromwell                                 | 708            | 64             | 813            | 58             | 921            | 56             |
| Balclutha                                | 1005           | 61             | 948            | 57             | 948            | 59             |
| Dunedin                                  | 14563          | 48             | 14291          | 45             | 21,918         | 47             |
| Lawrence                                 | 153            | 77             | 144            | 73             | 144            | 76             |
| Milton                                   | 555            | 73             | 507            | 67             | 540            | 70             |
| Mosgiel                                  | 2472           | 55             | 2397           | 50             | 2397           | 47             |

The most recent emissions inventories for Otago were done by Wilton (2005, 2006). Since that time, significant changes have been made to the age-related configuration of burners, effectively changing the emissions profiles for most towns; however, up-to-date information is not available at this time. This creates a fairly large degree of uncertainty when estimating current emissions and forecasting for various emission-reduction scenarios.

<sup>1</sup> Prior to the 2001 Census, questions related to fuel use were phrased differently, thereby making comparisons to later surveys less certain.

Results of the 2005 Air Emission Inventory for Dunedin, Mosgiel and Alexandra did estimate that discharges from domestic heating sources accounted for at least 90% of PM<sub>10</sub> emissions in Dunedin and Mosgiel, and up to 99% of all emissions in Alexandra.

For comparison purposes, assessments made in 2005 of daily winter emissions estimated the following daily emission amounts under average winter conditions:

- Dunedin        2,100 kilograms PM<sub>10</sub>
- Mosgiel        600 kilograms PM<sub>10</sub>
- Alexandra      380 kilograms PM<sub>10</sub>

To compare wood burner emissions between towns, coarse estimates of PM<sub>10</sub> densities were made using general information on household burner use, an average emission rate, and the area of the town's air zone<sup>2</sup>. PM<sub>10</sub> emissions from domestic chimneys are densest in Arrowsmith, Alexandra, and Cromwell (Table 6).

**Table 6. Estimated PM<sub>10</sub> emission densities in selected Otago towns using air zone areas.**

| Town       | Air zone | PM <sub>10</sub> density<br>PM <sub>10</sub> (g/hectare) |
|------------|----------|----------------------------------------------------------|
| Alexandra  | 1        | 207                                                      |
| Arrowsmith | 1        | 398                                                      |
| Clyde      | 1        | 125                                                      |
| Cromwell   | 1        | 181                                                      |
| Balclutha  | 2        | 102                                                      |
| Milton     | 2        | 124                                                      |
| Mosgiel    | 2        | 171                                                      |

As a requirement of the NESAQ, all wood burners installed after 1 September 2005 on sections smaller than two hectares are required to have an emission rate of less than 1.5 grams of PM<sub>10</sub> for every kilogram (g/kg) of dry wood burnt and to be no less than 65% efficient.

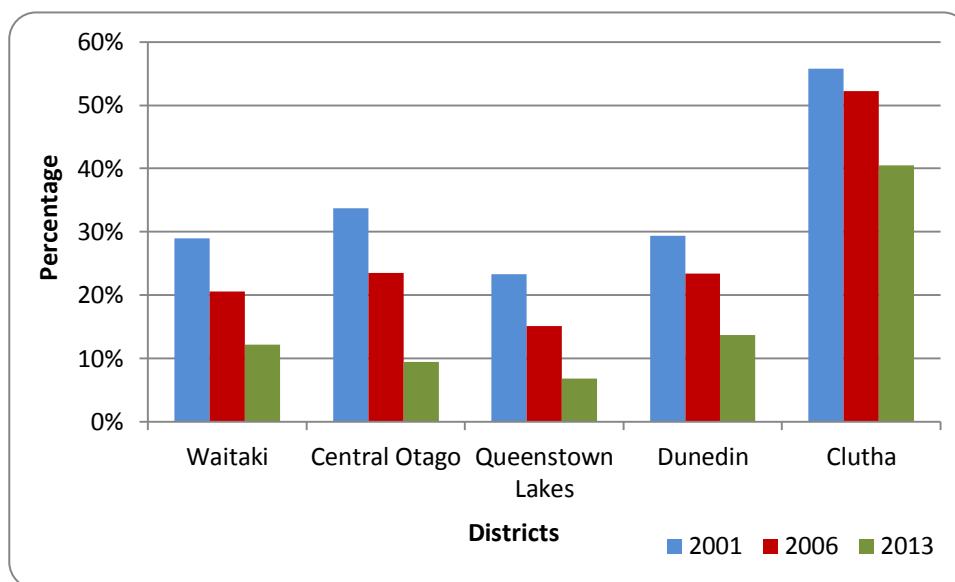
In 2009, the Otago Air Plan set stricter standards in Air Zone 1 towns, requiring all domestic heating appliances to be fully compliant with either 0.7g/kg or 1.5g/kg emission standards (depending on the date of installation) as of 1 January 2012. It was originally estimated that replacement of all older, non-compliant solid-fuel burners with new, lower-emitting efficient wood burners would lead to the required reduction in PM<sub>10</sub> emissions to achieve compliance with the NESAQ.

In Air Zone 2, it was expected that the natural rate of replacement for older heating appliances would result in the required PM<sub>10</sub> reductions.

<sup>2</sup> Emission densities based on census area unit (CAU) woodburner numbers (Census 2013), winter daily fuel use assumptions (Wilton, 2005), an average emission rate of 6g/kg, and airshed areas.

#### 4.1.1.2 Coal burners

In the 2013 Census, 14% of all Otago households (11,040 dwellings) reported using coal for domestic heating, down from 24% 2006. This is above the national average of 4% with most of the usage reported in southern areas of Otago. Of the five Otago territorial areas, the Clutha District has the highest percentage of households (39%, 2634 dwellings) using coal for home heating (Figure 3).



**Figure 3. Change in the percentage of households that use coal for domestic heating purposes from 2006 to 2013.**

#### 4.1.1.2 Other sources of heat

In addition to solid-fuel burners (wood and coal), other sources of fuel used for heating reported in the Census include electricity, mains and bottled gas, and solar power. Electricity is the most widely used fuel for heating, with anywhere from 70 to 90% of households (depending on district) reporting its use (Table 7); these percentages have not changed significantly since 2001.

Mains gas and solar power are not commonly used and bottled gas is used by anywhere from about 11% in the Clutha District to 21% in the Queenstown-Lakes District.

**Table 7. Percentage of total households using various fuels for heating (Census, 2013).**

| District         | Electricity | Mains Gas | Bottled Gas | Solar Power |
|------------------|-------------|-----------|-------------|-------------|
| Waitaki          | 78.8%       | 0.5%      | 12.9%       | 1.1%        |
| Central Otago    | 79.0%       | 0.8%      | 16.3%       | 1.5%        |
| Queenstown Lakes | 84.4%       | 7.6%      | 21.0%       | 1.9%        |
| Dunedin          | 91.4%       | 0.7%      | 13.0%       | 0.8%        |
| Clutha           | 69.6%       | 0.4%      | 11.3%       | 0.5%        |

### 4.1.2 Emissions from outdoor burning

Outdoor burning contributes PM<sub>10</sub> emissions to the atmosphere; however, its impact on regional air quality has not been quantified. The Otago Air Plan provides for most outdoor burning as a permitted activity, with rules related to nature of the material burned and distances to boundaries. The strictest rules are for residential properties in Air Zone 1 and 2 (Table 8).

**Table 8. Key rules related to outdoor burning in Otago.**

| Rule                                                                                            | Air Zones 1 & 2 |                 | Air Zone 3  |                 |
|-------------------------------------------------------------------------------------------------|-----------------|-----------------|-------------|-----------------|
|                                                                                                 | Residential     | Non-residential | Residential | Non-residential |
| Only paper, cardboard, vegetative matter, untreated wood is to be burned                        | ✓               | ✓               | ✓           | n/a             |
| Material must be dry                                                                            | ✓               | ✓               | ✓           | n/a             |
| Material must come from property where it's being burned                                        | ✓               | ✓               | ✓           | n/a             |
| Distance to boundary from fire (metres)                                                         | 50              | 100             | n/a         | n/a             |
| Smoke or odour or PM must not be offensive or objectionable at or beyond the property boundary. | ✓               | ✓               | ✓           | ✓               |

In almost all instances<sup>3</sup>, the discharge of contaminants from a variety of materials such as tyres, treated timber, painted material, etc. is prohibited (Air Plan, Section 16.3.3.1).

Rural outdoor fires have, on occasion, been known to result in smoky conditions in and around nearby residential areas (Figure 4). Over the past four years, ORC has received, on average, approximately 600 complaints related to air quality. Of these, approximately 20% relate to rural outdoor burning.

### 4.1.3 Emissions from industrial sources

Industrial and commercial discharges to air are regulated through the Air Plan, with larger discharges requiring consent. Wilton (2005) estimates that consented combustion processes (industrial and commercial) contribute approximately 248kg of PM<sub>10</sub> per winter day to the atmosphere in Dunedin, of which about 158kg is emitted in Central Dunedin. At that time, some of the highest emissions came from coal-fired boilers. An updated emissions inventory of consented discharges for the Otago region is not available.

<sup>3</sup> Except for certain activities such as incineration and Fire Services training activities.



**Figure 4. A rural outdoor fire on the Taieri Plain.**

In 2007, ORC signalled to all industrial and commercial dischargers in Otago with permits for coal-fired boilers that upgrades would be required when renewing their permits. As a result, approximately one dozen consents have been renewed with significantly reduced emissions in Central Dunedin over the past eight years. It is estimated that approximately 10 tonnes of PM<sub>10</sub> have been removed from the Central Dunedin airshed annually due to this initiative.

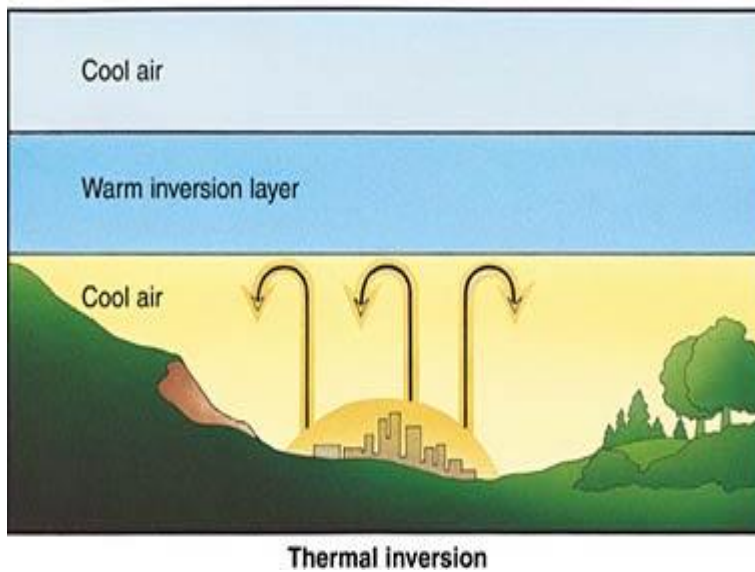
## **4.2 The role of weather on air quality**

Long-term weather patterns (climatology) and shorter-term weather features (meteorology) both affect the characteristic ambient air quality of a location. Towns in Otago have a wide range of topographical and climatological features that influence daily and seasonal particulate concentrations. This section discusses the relationship between climate/weather and air quality as illustrated in the three key indicator sites.

### **4.2.1 Alexandra**

Alexandra is a small town in Central Otago with a population of 4800 people living in 2100 houses. Despite its small size, Alexandra has very poor air quality during winter months which is, in no small part, influenced by the weather.

Alexandra has a continental climate with extreme temperatures during winter and summer. It is not unusual for overnight temperatures in winter to reach -10° C for several consecutive nights. Coupled with clear skies during periods of anti-cyclonic weather, strong temperature inversions are likely to form overnight and into the morning. During a temperature inversion, a layer of cold, dense air is trapped at the surface below warmer and more buoyant air as a result of rapid cooling of the ground surface. These events cause PM<sub>10</sub> concentrations to become trapped near the ground and escalate (Figure 5).



**Figure 5. Illustration of an inversion layer trapping cool air near the surface of the Earth.**

In Alexandra, the relationship between daily  $PM_{10}$  and air temperature (Figure 6) indicates that the highest daily averages of  $PM_{10}$  occur when daily temperatures drop below  $10-12^{\circ}C$ . Low temperatures do not necessarily result in high particulate concentrations; rather, atmospheric stability is a more important factor in determining whether particulates disperse or stagnate near ground level. The weather elements affecting stability include wind speeds and air temperature in a vertical profile. Temperature inversions that trap particulates at ground level occur when conditions are cold, winds are calm, and the sky is clear (allowing radiative loss of heat from the ground surface). These conditions can occur in Central Otago up to 60-70 days during winter months, leading to elevated  $PM_{10}$  concentrations.

Due to its location in a relatively low-lying basin surrounded by high hills, Alexandra also experiences fairly benign winds all year long, but particularly during winter months (Figure 7). This exacerbates the accumulation of  $PM_{10}$  emissions, further raising particulate levels. Not only are wind speeds generally low in winter, due to the surrounding hills, but dispersion modelling of the area by the ORC (2009) showed that cold air drainage is a significant feature with cooler, heavier air descending the hillsides at night. Cold air drainage tends to keep lower-level air cooler at night which reinforces the temperature inversion.



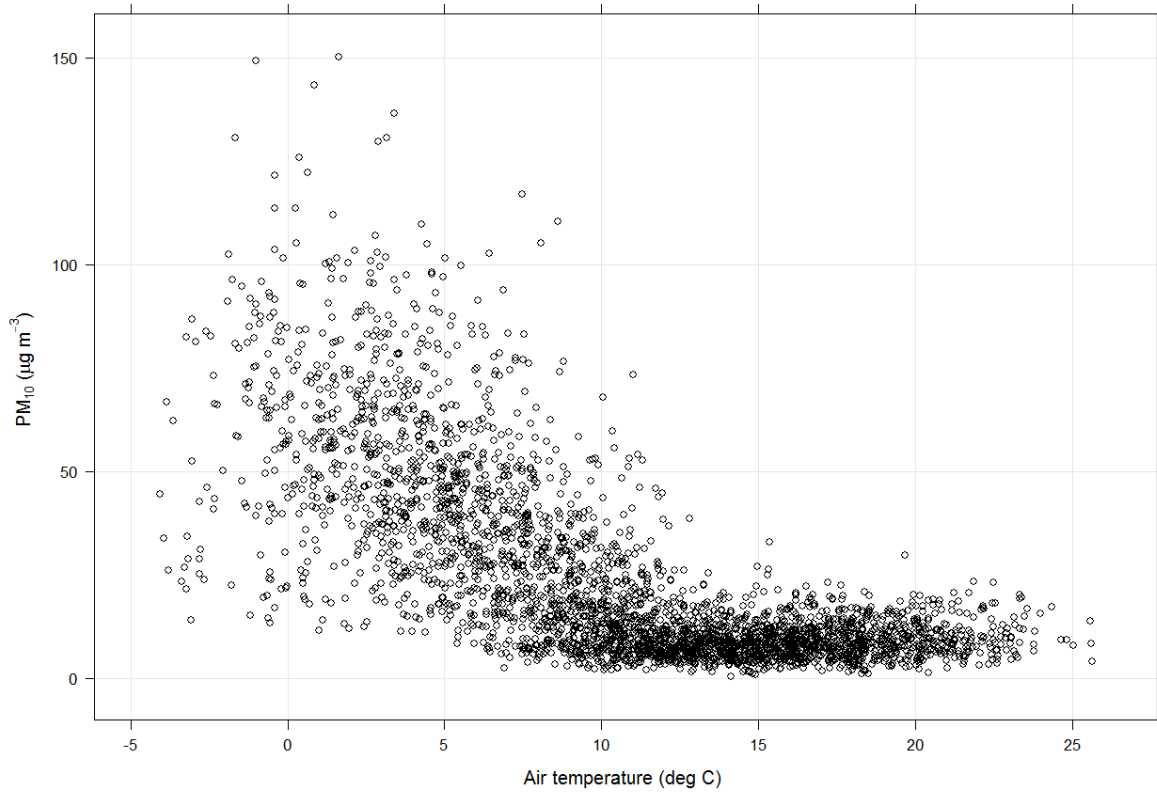


Figure 6. Plot showing the relationship between daily PM<sub>10</sub> concentrations and air temperature in Alexandria.

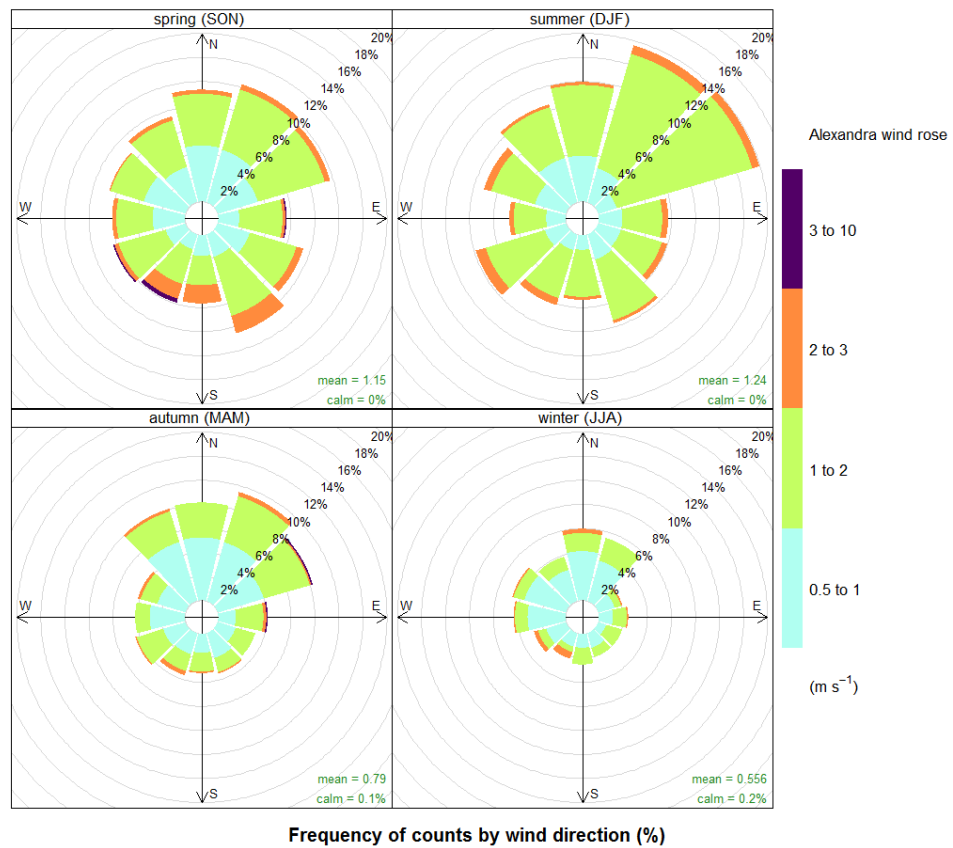


Figure 7. Seasonal wind roses for Alexandria.

### 4.2.2 Central Dunedin

Dunedin is a mid-sized city with a population of about 120,000 of which approximately 45,000 live in Central Dunedin, the area represented by the air quality monitor. Overall, Dunedin has relatively good air quality year-round despite some valley areas where emissions can accumulate.

Key to Dunedin's good air quality is its coastal location. Compared to other more inland sites, Dunedin weather is characterised by milder temperatures and windier conditions with more frequent winds of higher speeds throughout the year (Figure 8). A wind rose of hourly wind speeds and directions indicates that prevailing winds are from the northeast (down the harbour) and from the west and northwest. This ventilation helps disperse particulates, generally lowering the overall daily  $PM_{10}$  concentrations in the city.

The air quality monitor is located near sea level in an area of industrial, commercial and domestic heating discharges. A NIWA study (2009) of the spatial distribution of pollutants in Dunedin noted that in addition to the emissions of nearby surrounding sources, cold air drainage brings domestic heating emissions down from the hill suburbs, from the northwest.

Unlike Alexandra, daily  $PM_{10}$  levels in Dunedin do not correlate well to air temperatures (Figure 9). High particulate levels have occurred throughout the temperature range experienced in Dunedin.

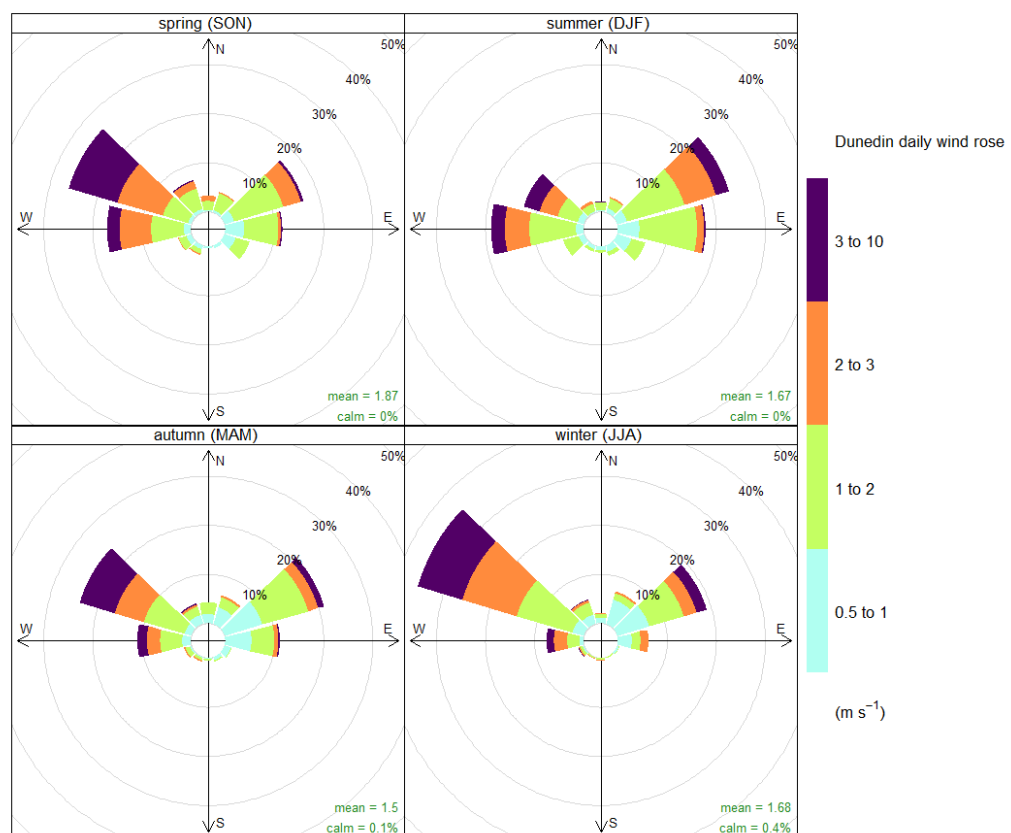
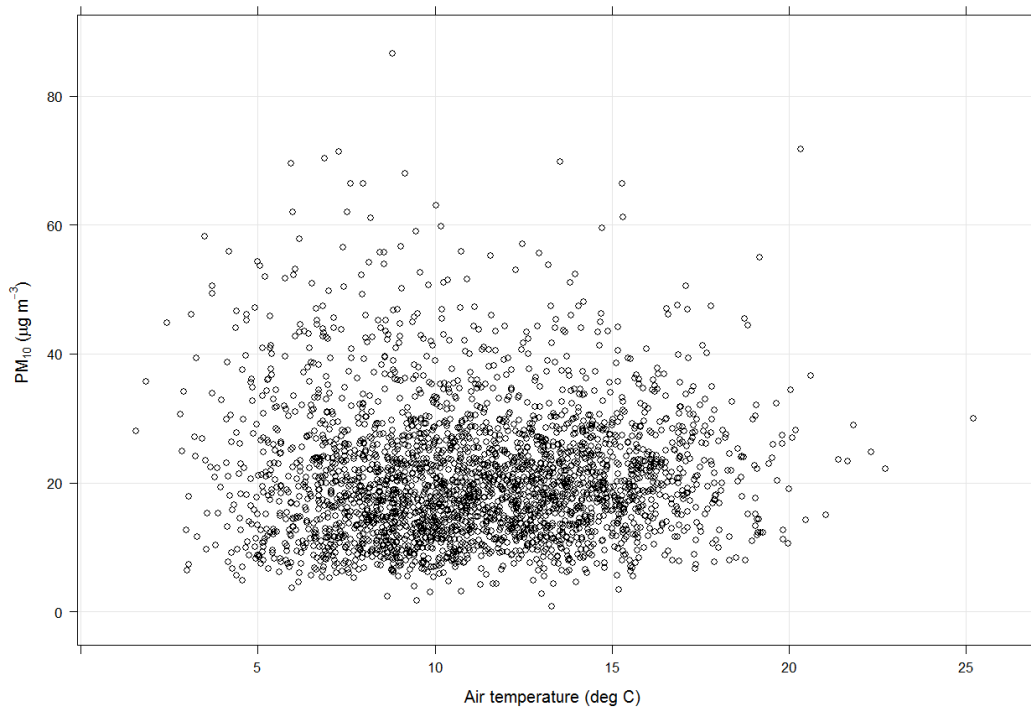


Figure 8. Seasonal wind roses for Central Dunedin.



**Figure 9. Plot showing the relationship between daily PM<sub>10</sub> concentrations and air temperature.**

### 4.2.3 Mosgiel

Mosgiel is a mid-sized town situated near the head of the Taieri Plain slightly inland from Dunedin with a population of about 6600 people living in approximately 3000 dwellings.

Mosgiel's weather has elements of both coastal and continental climates. Temperatures are generally colder/hotter than those recorded in Dunedin, but not as extreme as those in Alexandra. Temperature inversions often form on the Taieri Plain and a long, horizontal layer of smoke on winter mornings is sometimes visible (Figure 10).

Like Alexandra, Mosgiel autumns and winters are less windy (Figure 11) than either summer or spring and do experience a pattern of cold air drainage from the north.

High PM<sub>10</sub> levels are generally more correlated to colder temperatures; however, there have been days when PM<sub>10</sub> has been high with higher temperatures (Figure 12), presumably influenced by outdoor burning events.



Figure 10. Smoke trapped under the inversion layer in Mosgiel.

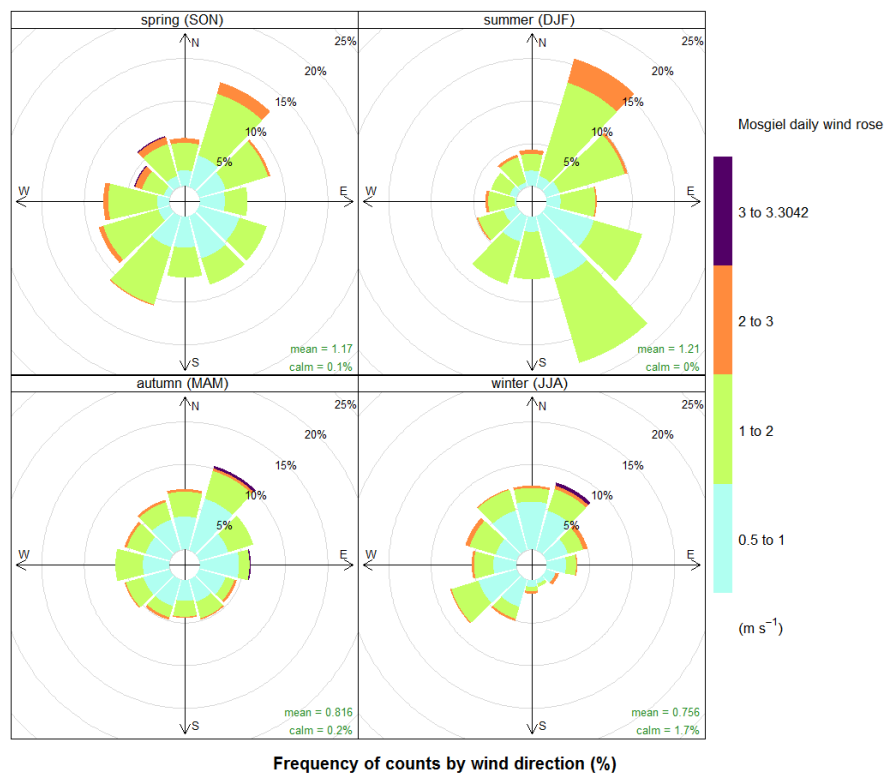
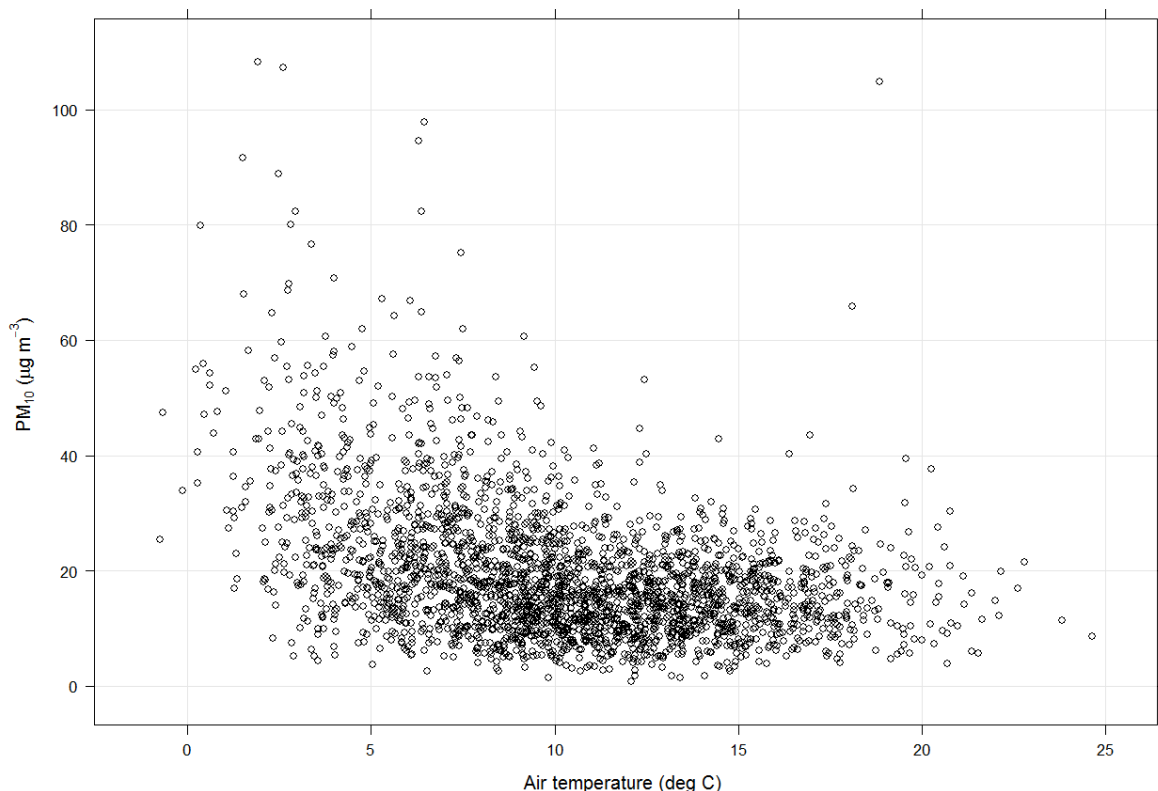


Figure 11. Seasonal wind roses for Mosgiel.



**Figure 12. Plot showing the relationship between daily PM<sub>10</sub> concentrations and air temperature in Mosgiel.**

## **5. State of the region's air quality**

This section describes the current state of Otago's air quality based on PM<sub>10</sub> monitoring data from the last three years (2012-2014) for the eight year-round and seasonal monitoring sites. A three-year period was chosen to represent the current state of air quality because it should smooth some of the variation in particulate levels due to changing weather patterns from year to year. It is also assumed that three years is too short a period to discern any significant change in air quality due to interventions designed to reduce emissions.

Results from six short-term monitoring campaigns performed for screening purposes over the past 10 years are also presented. Monitoring results are compared to the limits in national standards and guidelines set for the protection of public health. Results from additional investigations including Dunedin and Alexandra source apportionment studies and a number of spatial studies are also summarised.

Statistically significant trends in air quality are typically seen over much longer periods; trends for the three year-round sites with periods of record over the 10 year reporting period are examined in Section 6.

## 5.1 Aggregate statistics

Data from 2012-2014 were aggregated for each of the key indicator and survey sites to represent the current state of air quality at the site<sup>4</sup>. Annual and seasonal statistics were generated for key indicator sites; seasonal (winter-only) statistics are provided for the survey sites. For screening sites where one or two winters of PM<sub>10</sub> are available, those winters are compiled into single datasets and presented as a reasonable representation of current winter air quality.

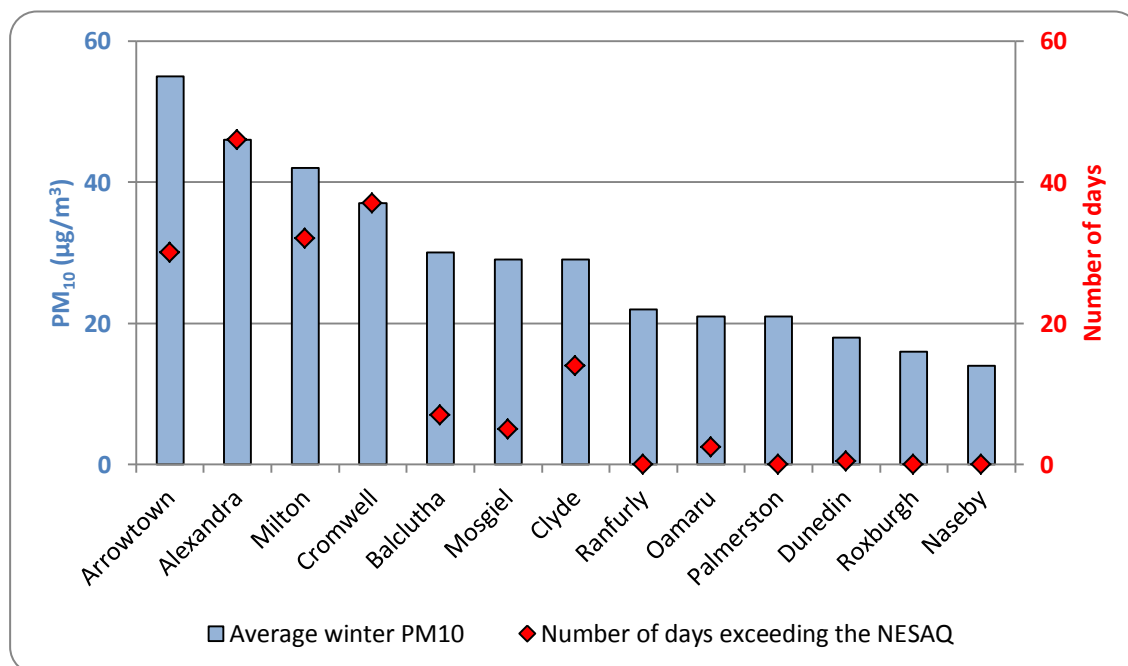
The aggregated summary statistics given in Table 9 represent the current state of air quality. Figure 13 ranks the towns in terms of average winter PM<sub>10</sub> and shows the corresponding number of days exceeding the NESAQ (exceedances). It indicates that Alexandra consistently has the highest number of exceedances each winter (46 days) and Arrowtown has the highest average winter PM<sub>10</sub> (55 µg/m<sup>3</sup>). Further detail is provided in the following sections.

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<sup>4</sup> Mosgiel does not have a complete set of data for 2012; therefore, the SoE analysis uses 2013 and 2014 data.

**Table 9. Key summary statistics aggregated over 2012-2014 provides a 'snapshot' of current ambient air quality.**

| Site            | Average annual PM <sub>10</sub> | Average winter PM <sub>10</sub> | Number of days exceeding the NESAQ (50ug/m <sup>3</sup> ) | Number of days exceeding the Otago Goal Level <sup>5</sup> (35ug/m <sup>3</sup> ) |
|-----------------|---------------------------------|---------------------------------|-----------------------------------------------------------|-----------------------------------------------------------------------------------|
| Alexandra       | 24                              | 46                              | 46                                                        | 81                                                                                |
| Mosgiel         | 21                              | 29                              | 5                                                         | 32                                                                                |
| Central Dunedin | 18                              | 18                              | <1                                                        | 11                                                                                |
| Arrowtown       | n/a                             | 55                              | 30                                                        | 66                                                                                |
| Clyde           | n/a                             | 29                              | 14                                                        | 40                                                                                |
| Cromwell        | n/a                             | 37                              | 37                                                        | 55                                                                                |
| Milton          | n/a                             | 42                              | 32                                                        | 74                                                                                |
| Balclutha       | n/a                             | 30                              | 7                                                         | 48                                                                                |
| Lawrence        | n/a                             | 22                              | 2                                                         | 13                                                                                |
| Naseby          | n/a                             | 14                              | 0                                                         | 0                                                                                 |
| Oamaru          | n/a                             | 21                              | 3                                                         | 14                                                                                |
| Palmerston      | n/a                             | 21                              | 0                                                         | 8                                                                                 |
| Ranfurly        | n/a                             | 22                              | 0                                                         | 16                                                                                |
| Roxburgh        | n/a                             | 16                              | 0                                                         | 1                                                                                 |



**Figure 13. SoE air quality sites ranked by average winter PM<sub>10</sub> (blue bars).**

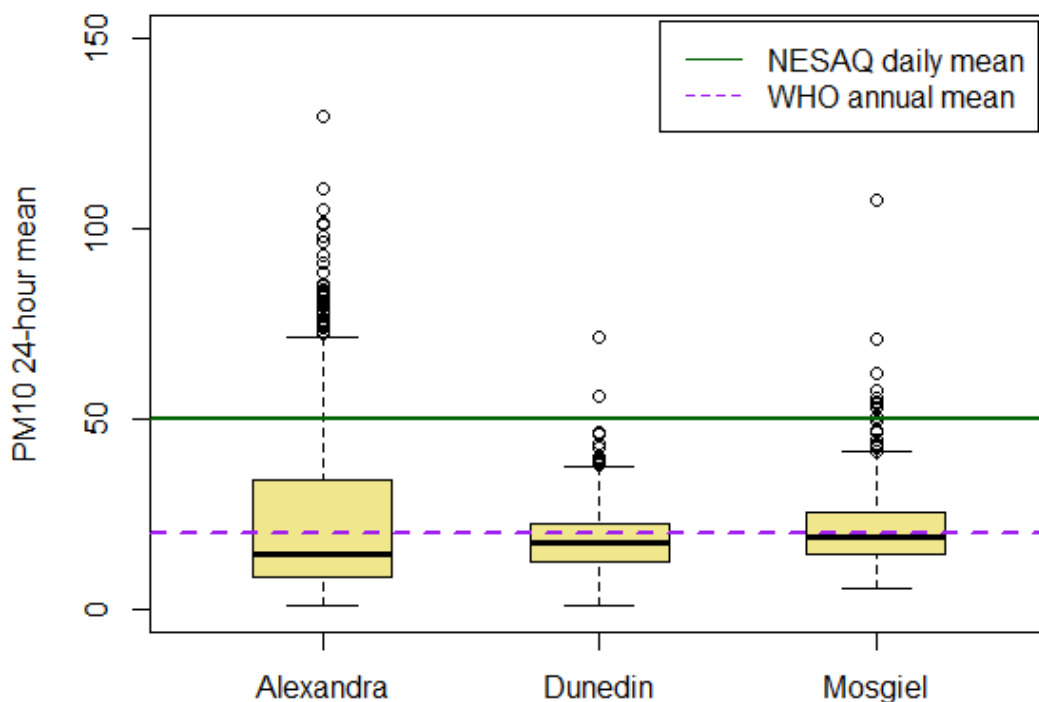
<sup>5</sup> The Otago Goal Level is set at 35µg/m<sup>3</sup> in the Regional Plan: Air.

## 5.2 Key indicator sites

Alexandra, Dunedin and Mosgiel are key indicator sites and operate continuously year-round in each of the three airsheds in accordance with requirements in the NESAQ. Results are used to measure compliance with national standards.

### 5.2.1 Distribution of PM<sub>10</sub> concentrations

The distribution of daily PM<sub>10</sub> concentrations is depicted using boxplots shown in Figure 14.



**Figure 14. Distribution of PM<sub>10</sub> at key indicator sites during 2012-2014. The median value is indicated by the horizontal line within the coloured box.**

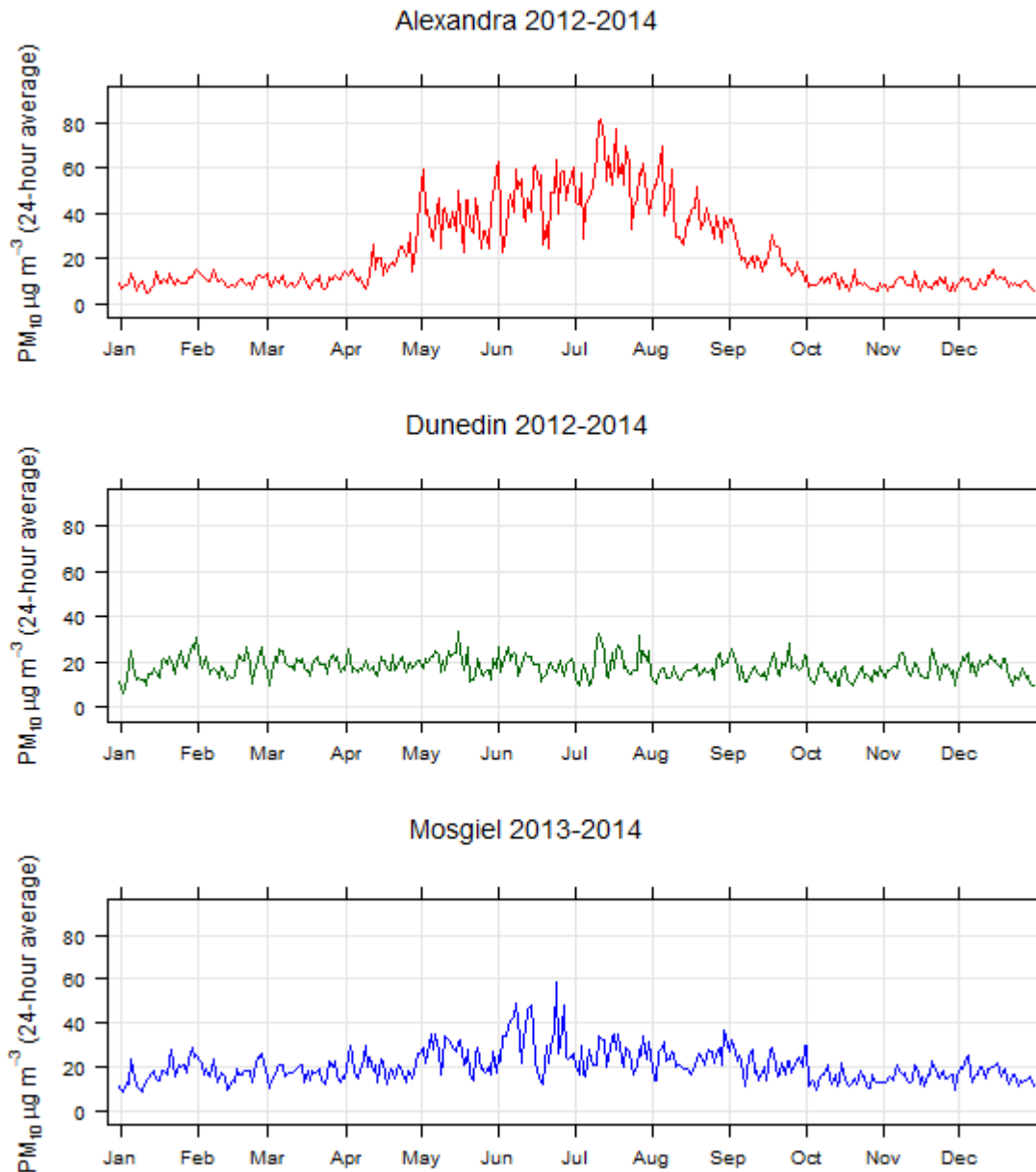
Of the three sites, Alexandra exhibits the most variability in PM<sub>10</sub> concentrations and experiences a higher frequency of days that exceed the NESAQ limit. As discussed in Section 4.2.1, the combination of emissions and meteorology in Alexandra lead to high levels of PM<sub>10</sub> during winter.

Dunedin exhibits the most homogeneous, and the lowest overall, PM<sub>10</sub> signal throughout the year with only a small variation during winter months. Again, this reflects the influence of industrial emissions coupled with a climate conducive to dispersion of particulates.

Mosgiel is similar to Dunedin, but because the majority of sampled particulates are domestic home heating emissions, the winter signal is clearer here than it is in Dunedin. The area does experience more air movement than Alexandra does, resulting in lower concentrations.



Graphs of a typical year, developed as an aggregate of the 2012-2014 dataset (Figure 15) show the distinct seasonality of PM<sub>10</sub> concentrations in Alexandra. . The graphs are shown at the same scale for comparison between the sites.



**Figure 15. Typical daily PM<sub>10</sub> using aggregated data from 2012-2014.**

### 5.2.2 Baseline PM<sub>10</sub> levels

Baseline PM<sub>10</sub> has been defined by NIWA (2008) as PM<sub>10</sub> levels from any source (natural or anthropogenic) that “pre-exist the source, activity or receptor that we are interested in”. Since we are most interested in winter air quality due to increased emissions and winter weather conditions leading to degraded ambient air quality, baseline PM<sub>10</sub> can be estimated by averaging monthly PM<sub>10</sub> for the months that are not influenced by these two events.

Baseline values were calculated for the three indicator sites using monthly averages from January, February, March, October, November, and December over the three year SoE reporting period. Table 10 lists the baseline values and, as a comparison, the winter (May through August) values.<sup>6</sup>

**Table 10. Baseline PM<sup>10</sup> and winter PM<sup>10</sup> levels for three key indicator sites.**

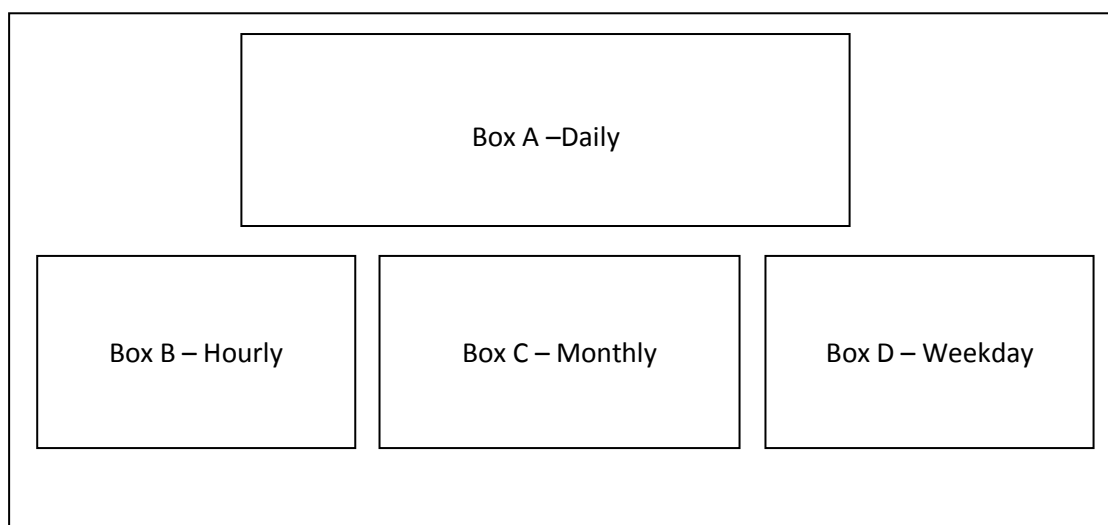
| Location        | Baseline PM <sub>10</sub><br>(µg/m <sup>3</sup> ) | Winter PM <sub>10</sub><br>(µg/m <sup>3</sup> ) |
|-----------------|---------------------------------------------------|-------------------------------------------------|
| Alexandra       | 10                                                | 46                                              |
| Central Dunedin | 17                                                | 18                                              |
| Mosgiel         | 17                                                | 29                                              |

### 5.2.3 Temporal variations of PM<sub>10</sub> concentrations

#### 5.2.3.1 Alexandra

Patterns in particulate levels can be seen at various timescales, i.e. hourly, daily, weekday and seasonal. The following series of figures depict those typical PM<sub>10</sub> patterns during winter months at the key indicator sites.

The aggregated hourly data are averaged over daily, weekly, monthly and hourly timeframes and presented in four graphs in a panel. The layout of the panel is shown below (Figure 16).



**Figure 16. Graph panel template for PM<sub>10</sub> at various timescales.**

In Alexandra (Figure 17), the hourly (Box B) graph shows the bi-modal PM<sub>10</sub> peaks common to many towns with solid-fuel domestic heating as the main source of emissions. Afternoon concentrations begin to increase at about 4pm and remain high until midnight. From then, PM<sub>10</sub> levels decrease through the early morning hours until they begin to rise again around

<sup>6</sup> April and September are considered “shoulder” months to the winter air quality season and, therefore, were not used in the computation of baseline PM<sub>10</sub>.

7am, leading to a morning 'peak.' This pattern is reproduced every day of the week (Panel A).

The morning 'peak' appears in most New Zealand centres. Recent research (Ancelet 2014) in Alexandra indicates that as opposed to there being a 9am 'peak', changes in the atmosphere lead to a 'dip' in PM<sub>10</sub> from midnight to around 6am. From his 4-point monitoring programme, it is postulated that katabatic winds from the north during early morning hours help disperse pollutants built up over the evening. He also suggests that the height of the inversion layer may be increasing during early morning hours, leading to lower concentrations.

Source apportionment work performed for the Ancelet study confirmed that biomass sources make up approximately 90% of the PM<sub>10</sub> collected during the morning and evening peaks. Throughout the day, other sources include crustal matter (up to 12%) and marine aerosol (1%) which comes from the Southern Ocean during periods of high wind.

Seasonally, PM<sub>10</sub> levels peak in July with a monthly mean of 56 µg/m<sup>3</sup> (Box C), driven by high emissions and very cold and stable weather conditions that occur during the month. On a weekly basis, Fridays and Saturdays generally have the highest average daily PM<sub>10</sub> (Box D).

These patterns are similar to those found in the other monitored Central Otago towns of Arrowtown, Clyde and Cromwell and are representative of towns with a reliance on solid-fuel heating and strong temperature inversions inhibiting dispersal of those emissions.

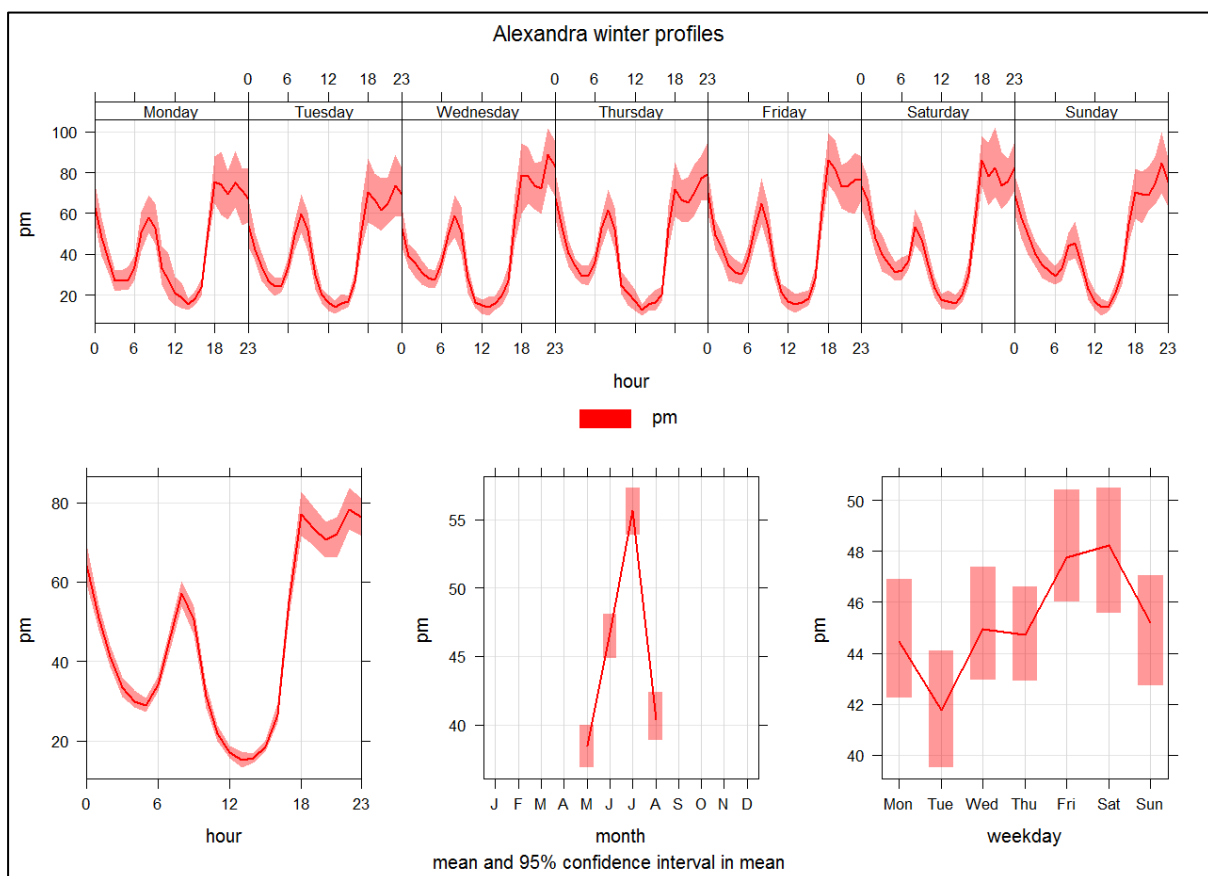


Figure 17. Temporal patterns of PM<sub>10</sub> in Alexandra during winter months.

### 5.2.3.2 Dunedin

Temporal winter PM<sub>10</sub> patterns in Dunedin (Figure 18) reveal a different ambient air quality 'signature' than that in Central Otago towns. Wintertime PM<sub>10</sub> concentrations do rise in the mornings (A) as they do in Alexandra but instead of dipping down in the afternoon, they remain relatively constant throughout the day, decreasing through the evening. Additionally, the weekly graph (D) indicates that PM<sub>10</sub> is significantly lower on Sundays than during the rest of the week.

The combination of these two temporal patterns are indicative of a mix of emission sources, including industrial, vehicular, and commercial emissions as well as solid-fuel heating. A source apportionment study by Davy et al. (2011) revealed six primary contributors to PM<sub>10</sub> in Central Dunedin (Figure 18). By far, the largest contributors at the time were soils and construction sources (29% and 20%, respectively). At the time of the study, particulates generated by a major construction project nearby heavily influenced these PM results.

In terms of PM<sub>2.5</sub>, the primary contributors are:

- Biomass burning: 41%
- Motor vehicles: 29%
- Sulphate: 18%
- Marine aerosol: 12%

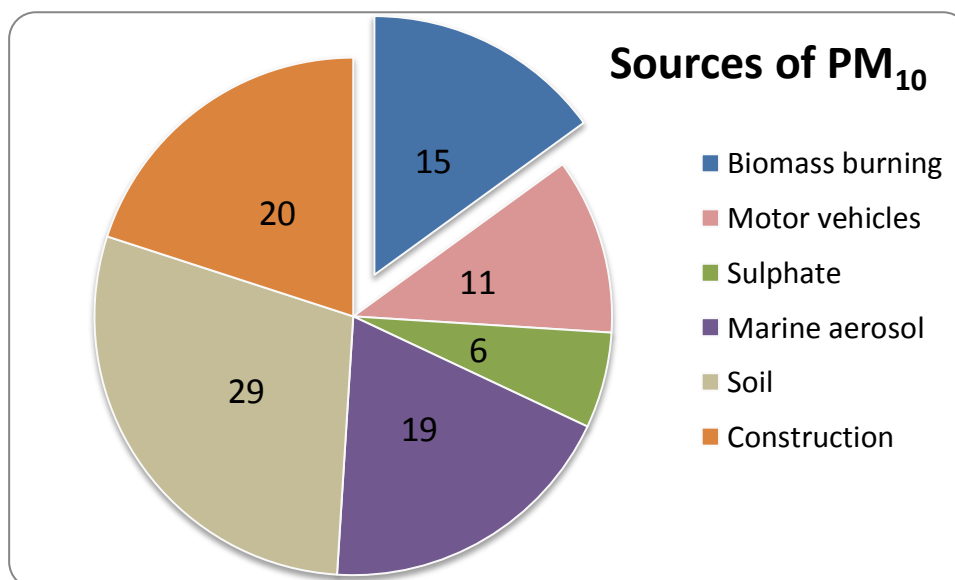
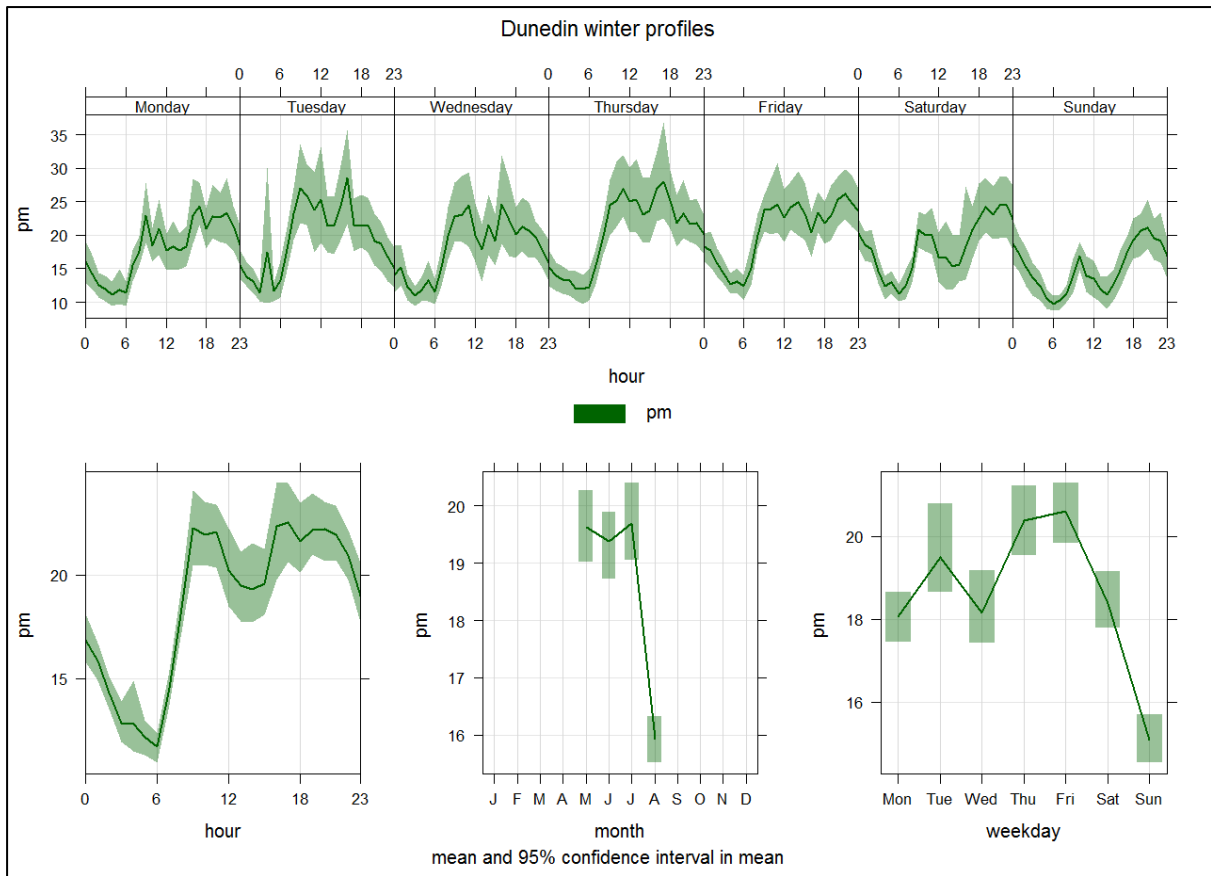


Figure 18. Percentages of the primary sources contributing to PM<sub>10</sub> in Central Dunedin. Biomass burning includes combustion of coal and wood.

Seasonally, May, June and July monthly averages are similar (19.5 µg/m<sup>3</sup>) and only slightly higher than the August average of 16 µg/m<sup>3</sup> (Figure 19).



**Figure 19. PM<sub>10</sub> patterns in Dunedin during winter months (May-August).**

### 5.2.3.3 Mosgiel

The temporal plots of PM<sub>10</sub> in Mosgiel (Figure 20) combine elements of the Alexandra and Dunedin patterns. There is a definite bi-modal hourly pattern (B) signifying solid-fuel heating as a major source of emissions, but low PM<sub>10</sub> on Sundays (D) indicate that industrial/commercial sources may be significant as well.

Monthly average PM<sub>10</sub> is highest in June (32 µg/m<sup>3</sup>) and is significantly lower in other winter months.

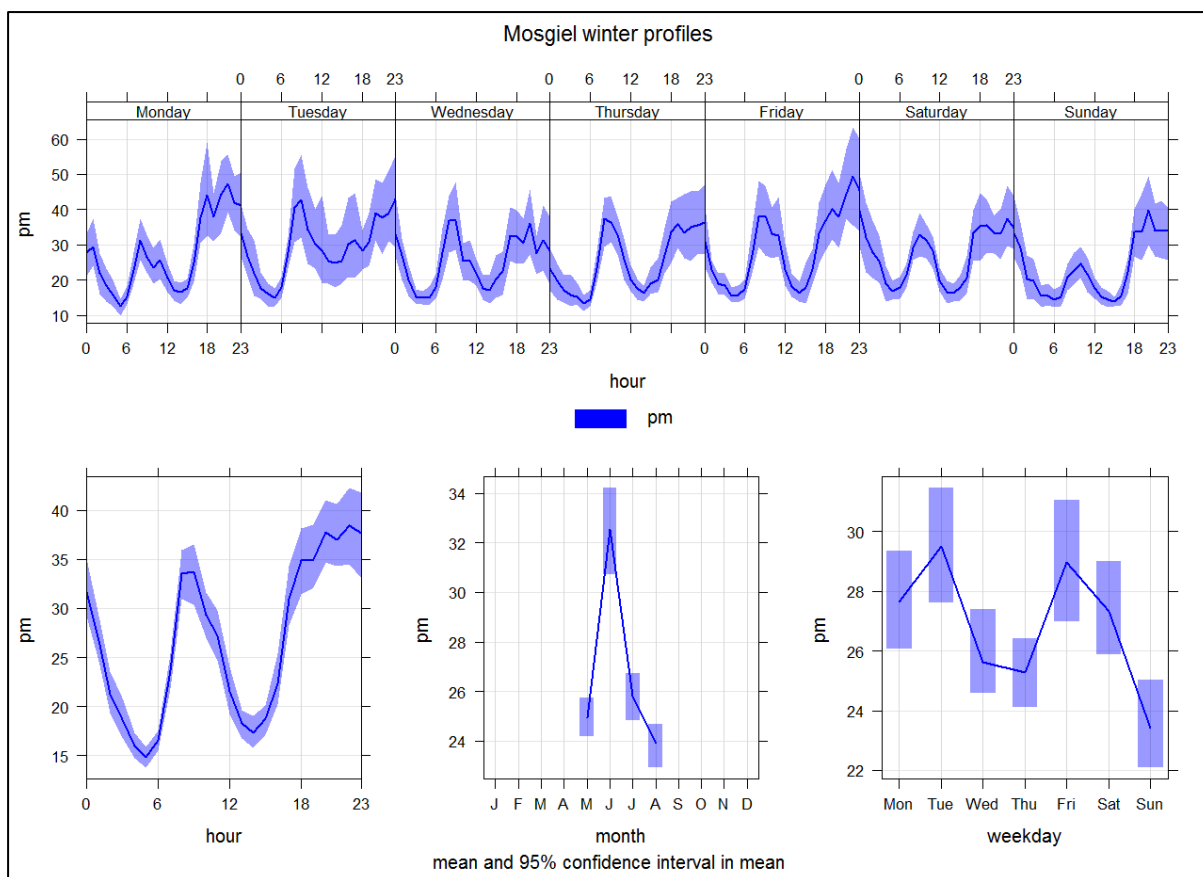


Figure 20. PM<sub>10</sub> patterns in Mosgiel during winter months (May-August).

#### 5.2.4 Relationship to NESAQ standards and WHO guidelines

Average annual PM<sub>10</sub> concentrations and the average annual number of NESAQ exceedances are shown in Table 11. Dunedin and Mosgiel both meet the WHO annual average PM<sub>10</sub> guideline of 20 µg/m<sup>3</sup>. Alexandra, due to its high winter PM<sub>10</sub> values, does not meet the WHO annual guideline.

Table 11. Average number of days that exceed the NESAQ in gazetted airsheds (2012-2014).

| Site      | MfE airshed designation | Average number of exceedances per year |
|-----------|-------------------------|----------------------------------------|
| Alexandra | 1                       | 46                                     |
| Mosgiel   | 2                       | 6                                      |
| Dunedin   | 3                       | <1                                     |

These three gazetted airsheds are currently designated as “polluted” by the Ministry for the Environment, a determination made in 2011 based on each airshed’s average number of exceedances from 2006-2011.

Two NESAQ compliance target dates (2016 and 2020) with allowable number of exceedances for each year were set depending on which exceedance category was applicable to the five-year average. Table 12 indicates the current compliance dates for the three airsheds.

**Table 12. Airsheds and their NESAQ compliance targets.**

| Location  | Airshed | Average # of exceedances (2006-2011) | Exceedance category | Compliance targets (allowable exceedances per year) |
|-----------|---------|--------------------------------------|---------------------|-----------------------------------------------------|
| Alexandra | 1       | 48                                   | 10 or more          | 3 by 2016; 1 by 2010                                |
| Dunedin   | 3       | 11                                   | 10 or more          | 3 by 2016; 1 by 2020                                |
| Mosgiel   | 2       | 9                                    | 2 to 10             | 1 by 2016                                           |

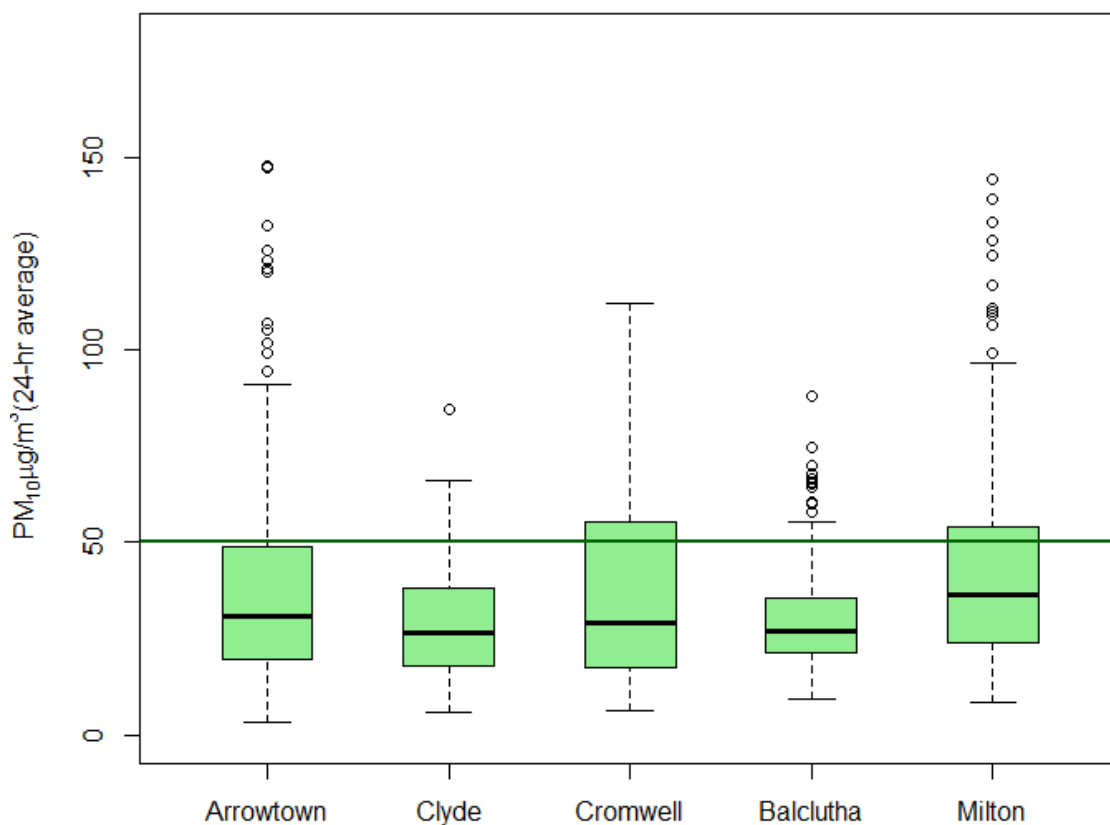
Once designated as polluted, five consecutive years of compliance with the NESAQ (no more than one exceedance per year) are required in order to attain a classification of “non-polluted”. Dunedin has now met this criterion for three consecutive years.

### 5.3 Survey sites

Five survey sites focus on seasonal air quality and capture PM<sub>10</sub> data during winter months (May-August) only. The survey sites include: Arrowtown, Clyde, Cromwell, Balclutha and Milton, with periods of record ranging from 6 to 8 winters.

#### 5.3.1 PM<sub>10</sub> concentrations

The distribution of PM<sub>10</sub> measured over three winters (2012-2014) is shown in Figure 21.



**Figure 21. Distribution of winter PM<sub>10</sub> concentrations at survey sites (2012-2014).**

All survey sites experience multiple days when average daily PM<sub>10</sub> concentrations are higher than the threshold concentration set in the NESAQ. Arrowtown, Cromwell and Milton have the highest frequency of days breaching the limit.

Arrowtown and Milton also typically record the highest daily values with maximums of 148 µg/m<sup>3</sup> and 144 µg/m<sup>3</sup>, respectively. Winter averages range from 29 µg/m<sup>3</sup> in Clyde to 55 µg/m<sup>3</sup> in Arrowtown. Milton is currently zoned in Air Zone 2, a category set in 2007 based on limited monitoring at the time.

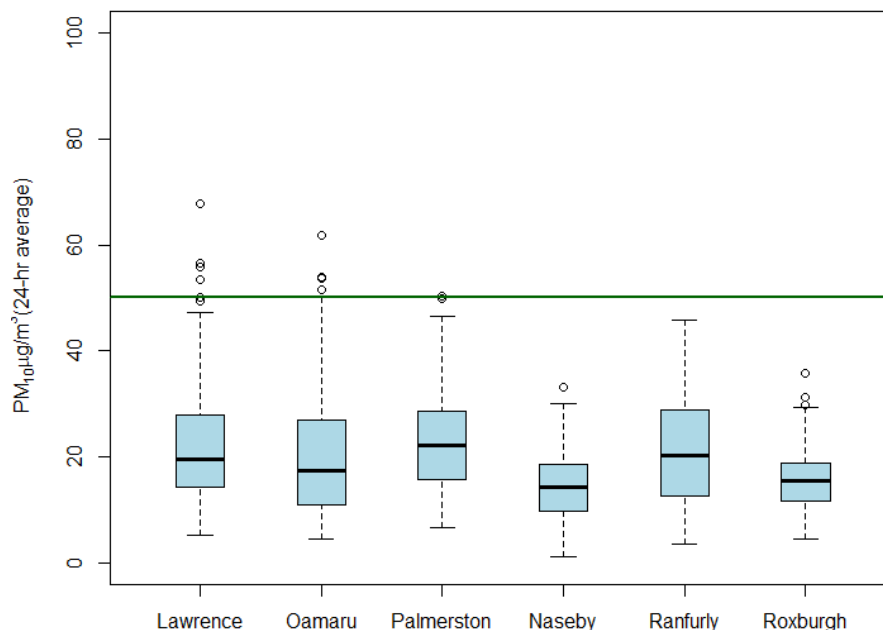
The 3-year aggregate dataset for Arrowtown includes data from two different sites due to the monitor being re-located for the 2014 season. The new, current site indicated higher PM<sub>10</sub> readings than those measured at the previous site.

## 5.4 Screening sites

PM<sub>10</sub> monitors have operated in numerous other centres around Otago for short-term monitoring campaigns in order to understand the magnitude of PM<sub>10</sub> concentrations. These monitors have been deployed for one-to-two winters at each site at some point during the last 10 years. Screening sites include Lawrence, Oamaru, Palmerston, Naseby, Ranfurly and Roxburgh.



The distribution of winter PM<sub>10</sub> concentrations (Figure 22) shows that, in all instances, PM<sub>10</sub> levels are significantly lower in the screening sites than in the key indicator or survey sites. Of the six sites, only Lawrence and Oamaru breached the NESAQ standards for PM<sub>10</sub> during the monitored winters; the other sites did not.



**Figure 22. Winter distribution of PM<sub>10</sub> concentrations at screening sites throughout Otago.**

With the exception of Oamaru, these are all relatively small communities with emissions on the order of less than about 50 kg PM<sub>10</sub> per winter day. Even though air quality is generally considered good in these towns, there are times during winter days – both morning and evening - when PM<sub>10</sub>, becomes elevated (Table 13).

**Table 13. Maximum one-hour PM<sub>10</sub> recorded at screening sites.**

| Town       | Maximum 1-hour PM <sub>10</sub> concentration (µg/m <sup>3</sup> ) | Time of day |
|------------|--------------------------------------------------------------------|-------------|
| Lawrence   | 420                                                                | 10 am       |
| Oamaru     | 189                                                                | 7 pm        |
| Palmerston | 141                                                                | 10 am       |
| Naseby     | 84                                                                 | 5 pm        |
| Ranfurly   | 150                                                                | 5 pm        |
| Roxburgh   | 90                                                                 | 11 pm       |

## 6. Long-term temporal trends in ambient air quality

Changes in a town's air quality can result from a number of factors, including:

- regulatory requirements for home heating options,
- change in way solid-fuel burners are used,
- fuel choices,
- addition or removal of particular point sources of emissions, and
- natural year-to-year variability in weather patterns, particularly as they affect atmospheric stability.

Statistical testing of consistent, long-term ambient air quality data can be used to ascertain the effectiveness of policies on emissions. Statistical hypothesis testing provides a "p-value" that represents the probability that random chance could explain a change in ambient air quality levels. A p-value of 0.10 suggests that we are 90% confident that the changes observed in PM<sub>10</sub> are not due to chance alone.

For this report, trend analyses were performed at sites having at least five years of record. These sites include the three year-round key indicator sites (Alexandra, Dunedin and Mosgiel) and the five winter survey sites (Arrowtown, Clyde, Cromwell, Balclutha, and Milton).

### 6.1 Trend analysis techniques

Trends were evaluated using a variety of statistical techniques. A TheilSen approach, customised for analysing air quality data (Carslaw & Ropkins, 2011), was performed to determine statistical significant of any changes in PM<sub>10</sub>. TheilSen analyses work best when applied to monotonic trends (i.e. straight-line trends upwards or downwards) and have a more limited value when applied to highly seasonal data. To minimise that limitation, monthly means were de-seasonalised where necessary. Where results are statistically significant, they are discussed in the following sections.

A smoothed trends technique using monthly mean values of the 50<sup>th</sup> and 95<sup>th</sup> percentile values was also applied. The smoothed trend analysis fits a smooth line to the dataset using monthly mean concentrations and shows the 95% confidence interval around the line. The line is fit to show important features and real variation in the data without including excessive 'noise' found in the dataset (Carslaw et al., 2007).

Annual box plots of daily PM<sub>10</sub> during winter months show the change of PM10 distribution from year to year. A full set of plots is shown in Appendix X.

### 6.2 Key indicator site trend results

These sites have the longest, continuous datasets in the Otago air quality monitoring network. For each site, a TheilSen analysis was performed over the entire year-round data as well as on just the winter (June – August) data. In Alexandra, where numerous breaches of the NESAQ occur each winter, a trend analysis was also applied to just those days exceeding the standard.

Results of the TheilSen analyses showing percent change in PM<sub>10</sub> per year are shown in Table 14 along with the statistical significance of the result.

**Table 14. TheilSen trend analysis results of PM<sub>10</sub> means at key indicator sites; *p*-values of 0.1 or greater were taken to be ‘not significant’.**

| Site      | Period of Record | PM <sub>10</sub> value evaluated | Percent change per year | Statistical significance |
|-----------|------------------|----------------------------------|-------------------------|--------------------------|
| Alexandra | 2005-2014        | Year-round                       | +1.1                    | Not significant          |
|           |                  | Winter                           | -0.5                    | Not significant          |
|           |                  | Exceedance values                | -0.7                    | <i>p</i> <0.1            |
| Dunedin   | 2006-2014        | Year-round                       | -1.9                    | Not significant          |
|           |                  | Winter                           | -2.5                    | <i>p</i> <0.1            |
| Mosgiel   | 2005-2014        | Year-round                       | +3.4                    | <i>p</i> <0.01           |
|           |                  | Winter                           | +3.0                    | <i>p</i> <0.1            |

### 6.2.1 Alexandra

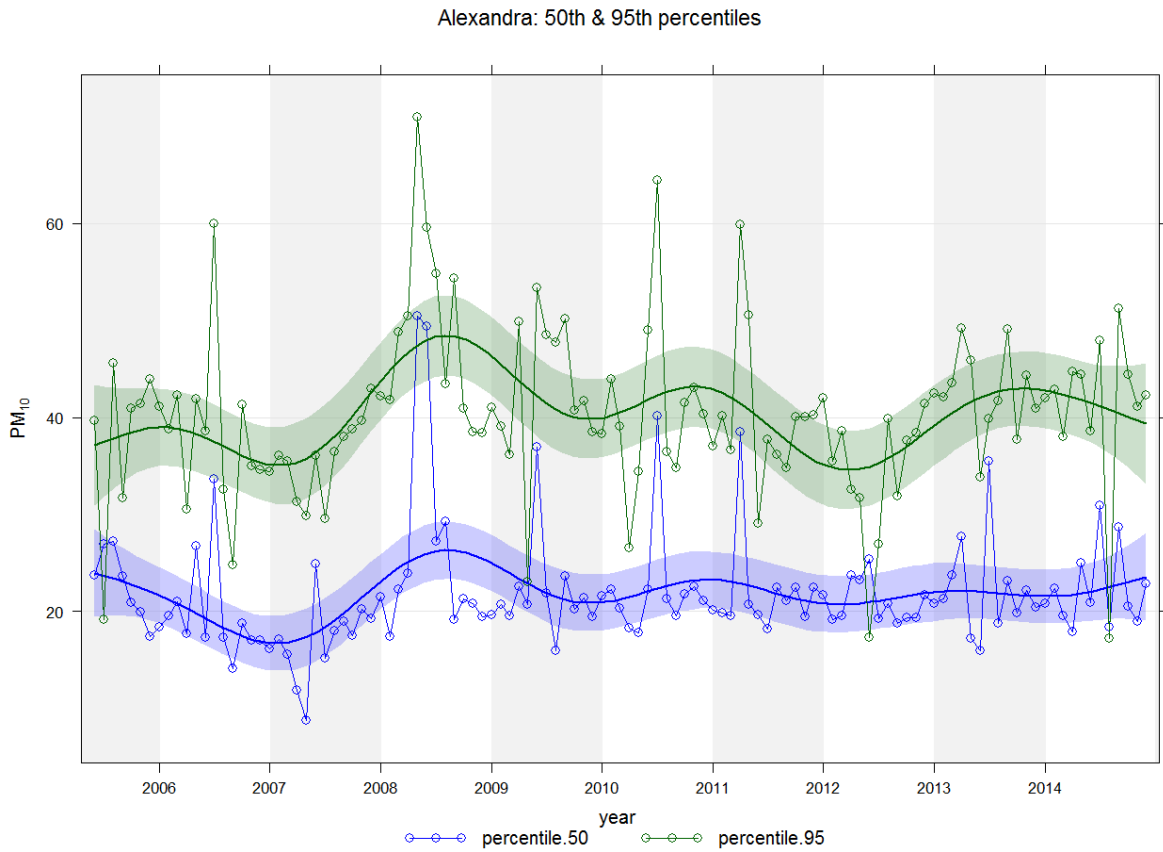
There has been a statistically significant decrease in PM<sub>10</sub> values in Alexandra on those days that exceed the NESAQ. On average, the monthly means of the exceedance values have decreased approximately 0.7% each year. Over nine years, the decrease is just over 6%. Despite this lowering of the highest PM<sub>10</sub> values, neither the year-round nor the wintertime trend in PM<sub>10</sub> is statistically significant over the period of record.

The smoothed trend analysis (Figure 23) on the year-round data shows the variability in PM<sub>10</sub> over time, particularly for values in the 95<sup>th</sup> percentile range. From the graph, it is apparent that 2008 was prominent in terms of PM<sub>10</sub> levels.

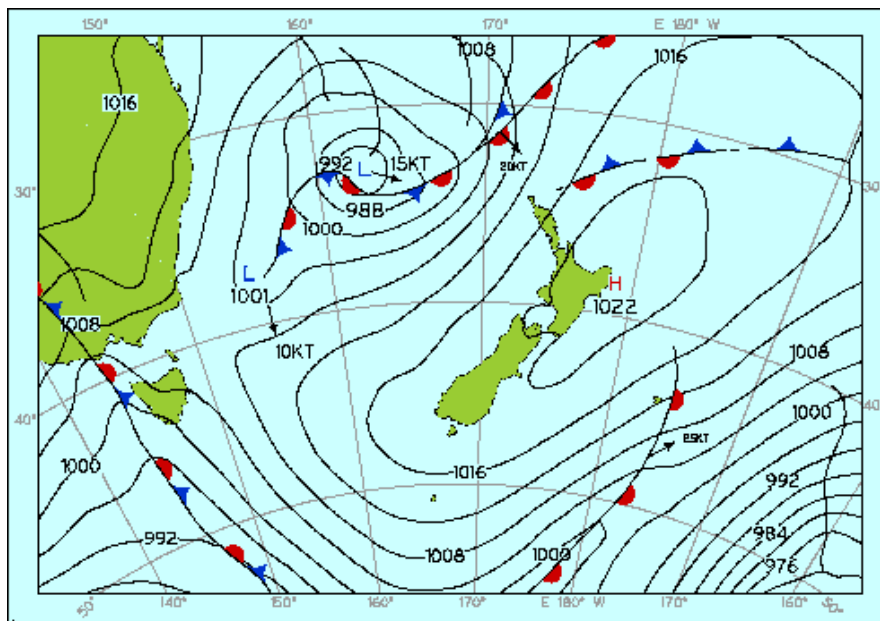
Daily weather and seasonal climate patterns are strong determinants for ambient air quality, particularly in Alexandra. A trend analysis has been developed to examine PM<sub>10</sub> levels giving consideration to the influence of winter weather.

For this analysis, common weather elements were identified for days that exceeded the NESAQ standard for PM<sub>10</sub><sup>7</sup>. The weather on those days was calm, with clear skies, and cold overnight temperatures. A typical synoptic condition that produces such conditions is shown in Figure 24.

<sup>7</sup> This work was done using 2006 data before any significant emissions reductions due to ORC’s air quality strategy of burner replacement were anticipated.



**Figure 23. Smoothed trend analysis for Alexandra PM<sub>10</sub> concentrations.**



**Figure 24. Winter synoptic weather condition that results in clear, calm and cold conditions.**

Conditions during these periods lead to overnight temperature inversions and minimal dispersion, resulting in what can be termed High Pollution Potential (HPP) days. HPP days can be simulated using a few key meteorological variables (as shown in Table 15), making this model more physically-based than other purely statistical relationships.

**Table 15. Meteorological parameters and their conditions necessary for a high-pollution potential day.**

| Parameter                 | Condition          |
|---------------------------|--------------------|
| Minimum daily temperature | < 0.0 degrees      |
| Temperature range         | > 7.0 degrees      |
| Average wind speed        | < 1.0 metre/second |
| Maximum hourly wind speed | <2.0m/s            |

Tracking the numbers of High Pollution Potential days and their PM<sub>10</sub> characteristics from one year to the next may give an indication of whether or not air quality is improving due to changes in emissions. Indications of improving air quality are:

- Reducing the number of *measured* exceedances versus the *predicted* number of exceedances (High Pollution Potential days)
- Reducing the PM<sub>10</sub> average of the High Pollution Potential day subset
- Lowering of the upper range of PM<sub>10</sub> values of the High Pollution Potential day subset.

Table 16 shows the number of days when exceedances of the NESAQ are predicted versus the number of days when exceedances were measured. It appears that there was some improvement in air quality, given the weather, between 2009 and 2012; however, that trend was broken in 2013 when more high-pollution days were measured than expected. This analysis corroborates the ThielSen trend results in that a significant trend is not yet apparent in the data. It also illustrates the inter-annual variability that occurs in both PM<sub>10</sub> and the weather.

**Table 16. Number of predicted NESAQ exceedances versus the actual number of exceedances for Alexandria.**

| Year | Number of predicted exceedances | Number of actual exceedances |
|------|---------------------------------|------------------------------|
| 2006 | 50                              | 45                           |
| 2007 | 37                              | 33                           |
| 2008 | 63                              | 70                           |
| 2009 | 44                              | 37                           |
| 2010 | 61                              | 51                           |
| 2011 | 51                              | 39                           |
| 2012 | 64                              | 40                           |
| 2013 | 40                              | 47                           |
| 2014 | 60                              | 48                           |

An annual summary of PM<sub>10</sub> characteristics for the subset of HPP days (Figure 25) indicates a slight downward trend in average PM<sub>10</sub> on those days from 2008-2012. There was a concurrent decrease in the average of the highest 10 days each year during those years. After 2012, PM<sub>10</sub> averages appear to have plateaued.

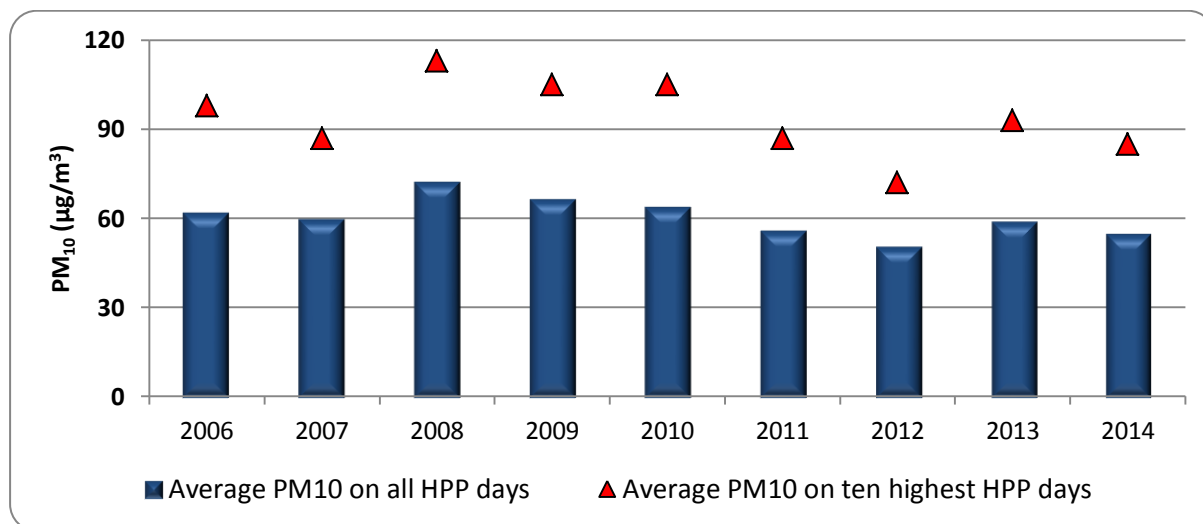
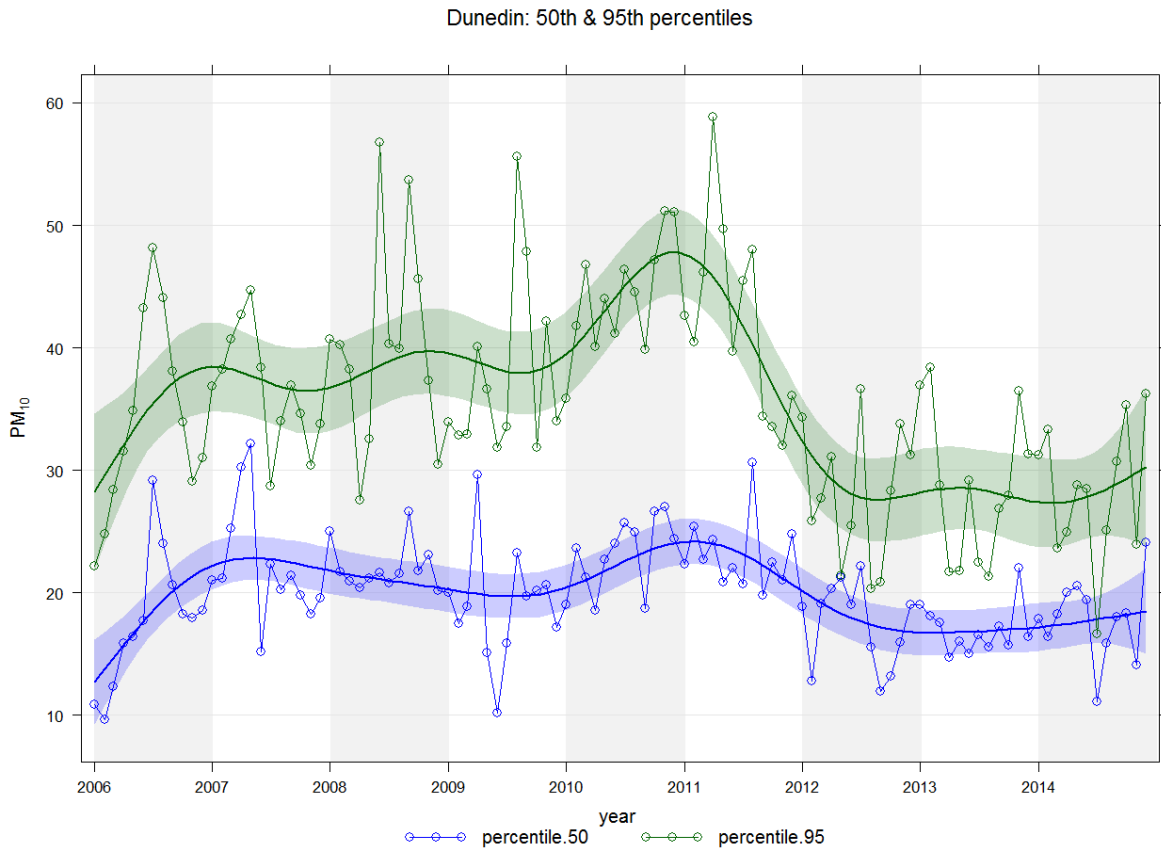


Figure 25. PM<sub>10</sub> characteristics on High Pollution Potential (HPP) Days.

### 6.2.2 Dunedin

According to the TheilSen results, there has been a statistically significant decrease in particulate levels in Dunedin over the last 10 years. On average, PM<sub>10</sub> levels have declined 2.5% per year from 26.3 µg/m<sup>3</sup> in 2006 to 17.3 µg/m<sup>3</sup> in 2014. This trend has likely had the indirect effect of reducing the number of annual exceedances of the NESAQ to zero in the last two years.

The smoothed trend of the 95<sup>th</sup> percentile (Figure 26) shows a fairly sharp decrease from 2011 to 2013 and a corresponding but smoother decrease in the 50<sup>th</sup> percentile values. According to the 2011 source apportionment study, PM<sub>10</sub> was dominated by particulates in the coarse fraction, i.e. crustal matter, construction-related materials and marine aerosols. The highest values occurred during calm conditions and were likely caused by the entrainment of road dust generated by vehicle movements near to the monitoring site. Major construction activity near the monitoring site throughout most of 2011 was the source of increased truck and vehicle movements and the presence of crustal material.



**Figure 26. Smoothed trend in PM<sub>10</sub> concentrations in Central Dunedin.**

### 6.2.3 Mosgiel

Mosgiel has the strongest statistical trend of the three sites, an *increase* in PM<sub>10</sub> levels of 3.4% per annum. This equates to an increase of just over 0.5 µg/m<sup>3</sup> each year, and brings this past year's annual PM<sub>10</sub> average to 20 µg/m<sup>3</sup>.

Though some of the increase is driven by a 3% increase per annum in wintertime values, a seasonal TheilSen analysis reveals strong upward trends exist in spring (+6.4% per year, p<0.001) and summer months (+9.2% per year, p<0.05). The implication of this result is that sources of PM<sub>10</sub> other than solid-fuel burners are becoming more significant in the airshed.

The smoothed trend (Figure 27) shows relatively little variability in the 50<sup>th</sup> percentile values. The dip seen in the trend line during 2012 may be artificial due to the interpolation of data by the smoothed trend function to account for the missing data during the year.

Mosgiel: 50th & 95th percentiles

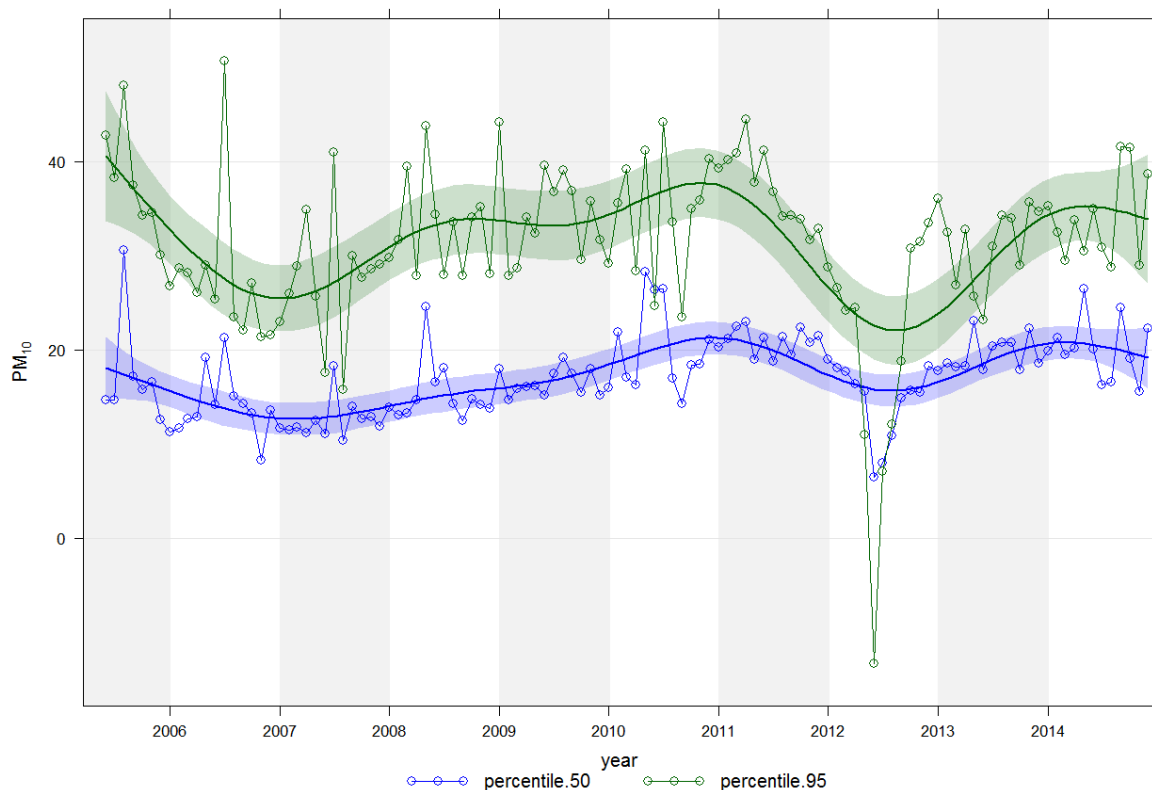


Figure 27. Smoothed trend of PM<sub>10</sub> concentrations in Mosgiel.

### 6.3 Survey site results

Statistically significant downward trends have been reported for wintertime PM<sub>10</sub> levels in Dunedin, Clyde and Arrowtown with varying degrees of certainty. Table 17 gives the annual percent change in PM<sub>10</sub> means along with the statistical significance for each result.

Table 17. ThielSen trend analysis results of PM<sub>10</sub> means at survey sites.

| Site                      | Period of Record | PM <sub>10</sub> values evaluated | Percent change per year | Statistical significance         |
|---------------------------|------------------|-----------------------------------|-------------------------|----------------------------------|
| Arrowtown (all years)     | 2006-2014        | Winter                            | -2.5                    | $p < 0.01$                       |
|                           |                  | Exceedance values                 | +1.1                    | Not significant                  |
| Arrowtown (original site) | 2006-2013        | Winter                            | -4.0                    | <b><math>p &lt; 0.001</math></b> |
|                           |                  | Exceedance values                 | -1.5                    | Not significant                  |
| Clyde                     | 2008-2014        | Winter                            | -3.1                    | $p < 0.1$                        |
|                           |                  | Exceedance values                 | -3.0                    | <b><math>p &lt; 0.001</math></b> |
| Cromwell                  | 2008-2014        | Winter                            | +3.1                    | $p < 0.1$                        |
|                           |                  | Exceedance values                 | -0.5                    | Not significant                  |
| Balclutha                 | 2009-2014        | Winter                            | +5.0                    | Not significant                  |
| Milton                    | 2008-2014        | Winter                            | -1.2                    | Not significant                  |
|                           |                  | Exceedance values                 | -0.2                    | Not significant                  |

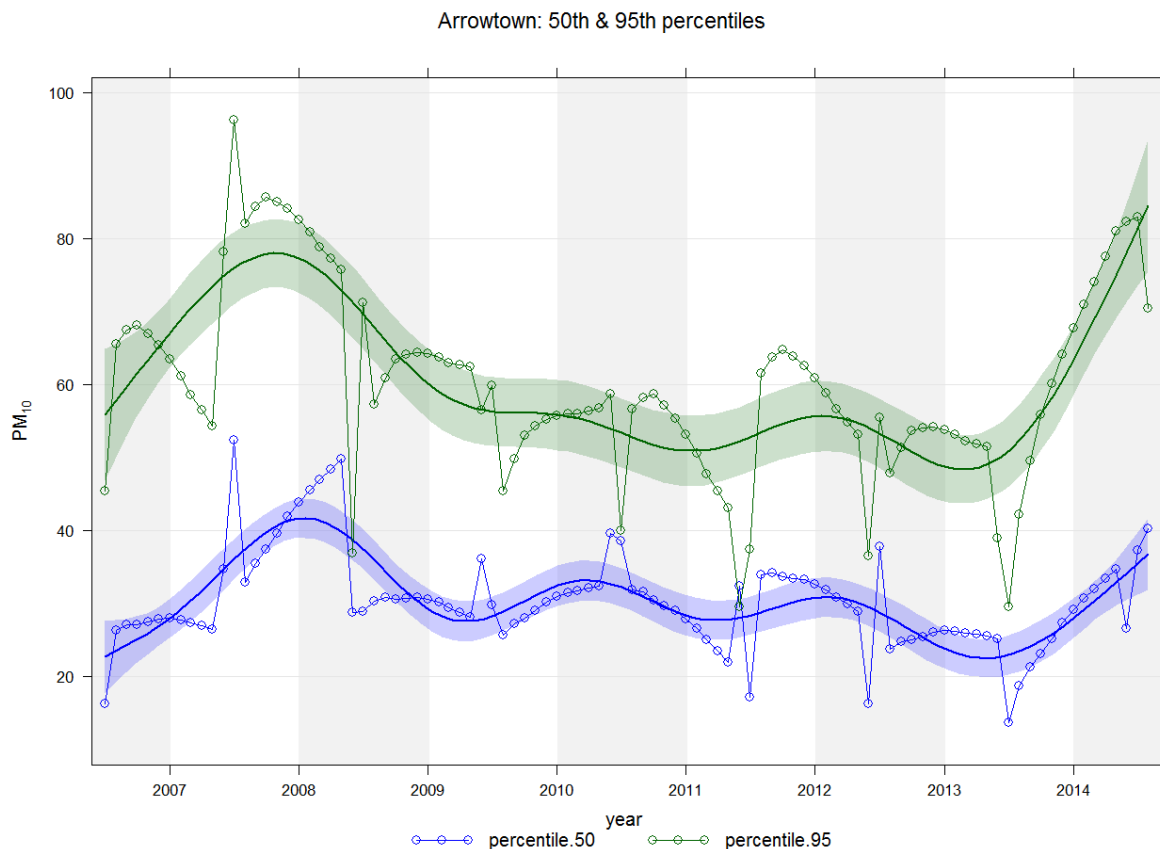


### 6.3.1 Arrowtown

Two datasets were developed for Arrowtown; the first contains data collected at the original site on the original site at Cotter Avenue (2006-2013), and the second dataset (2006-2014) includes the 2014 data with the monitor at its new location at the Queenstown-Lakes District pump station, approximately 400 metres east of its original position. Due to time constraints, no co-location study linking the two sites was possible

A downward winter trend of -2.5% per annum ( $p < 0.01$ ) is reported over the entire dataset. Prior to the monitor's re-location for the 2014 season, a statistically significant downward trend of -4.0% ( $p < 0.001$ ) is found in the data. Any change in exceedance values is not statistically significant.

The smoothed trend (Figure 28) in the 95<sup>th</sup> percentile range evaluated over the entire dataset does show a downward sloping trend from 2007-2013; however, the 2014 results from the monitor's new location were much higher than those reported in previous years, serving to pull the trend upwards.



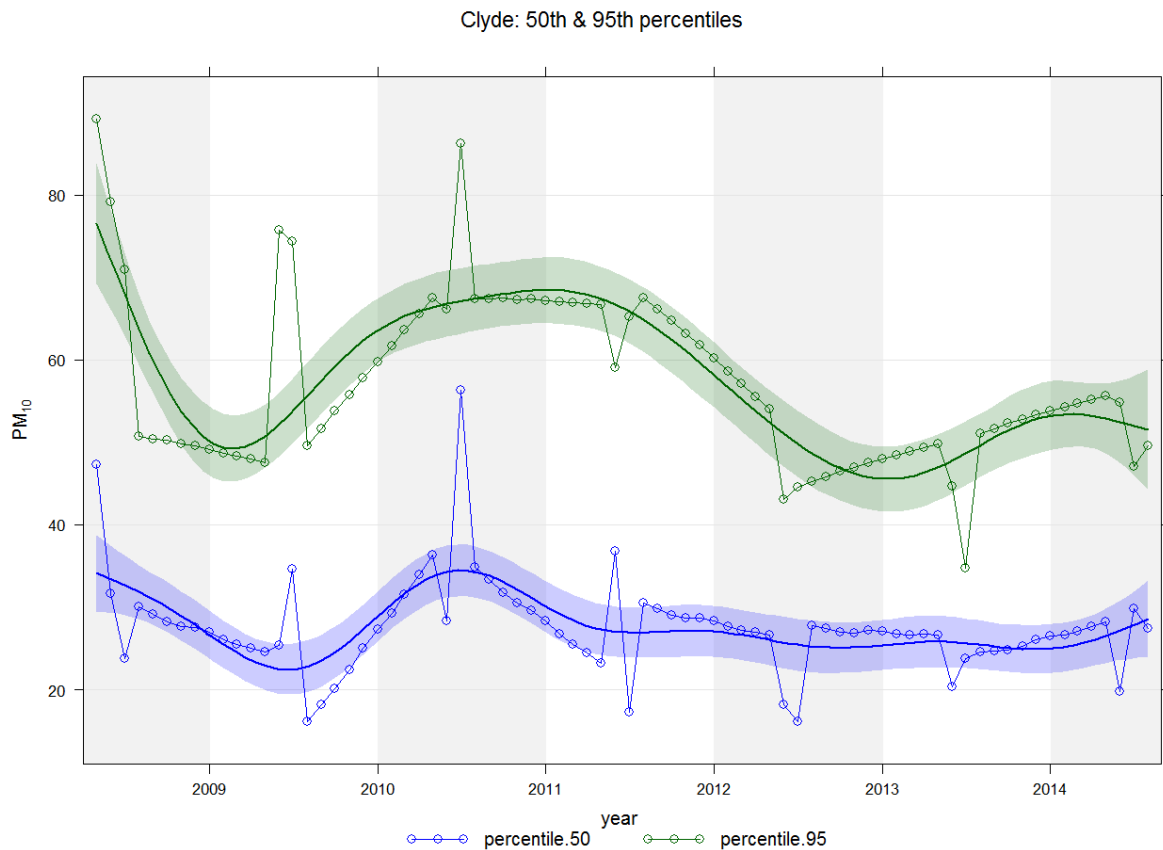
**Figure 28. Smoothed trend in PM<sub>10</sub> concentrations in Arrowtown.**

### 6.3.2 Clyde and Cromwell

Clyde and Cromwell have shown very different PM<sub>10</sub> trends since 2008, with concentrations decreasing in Clyde and increasing in Cromwell.

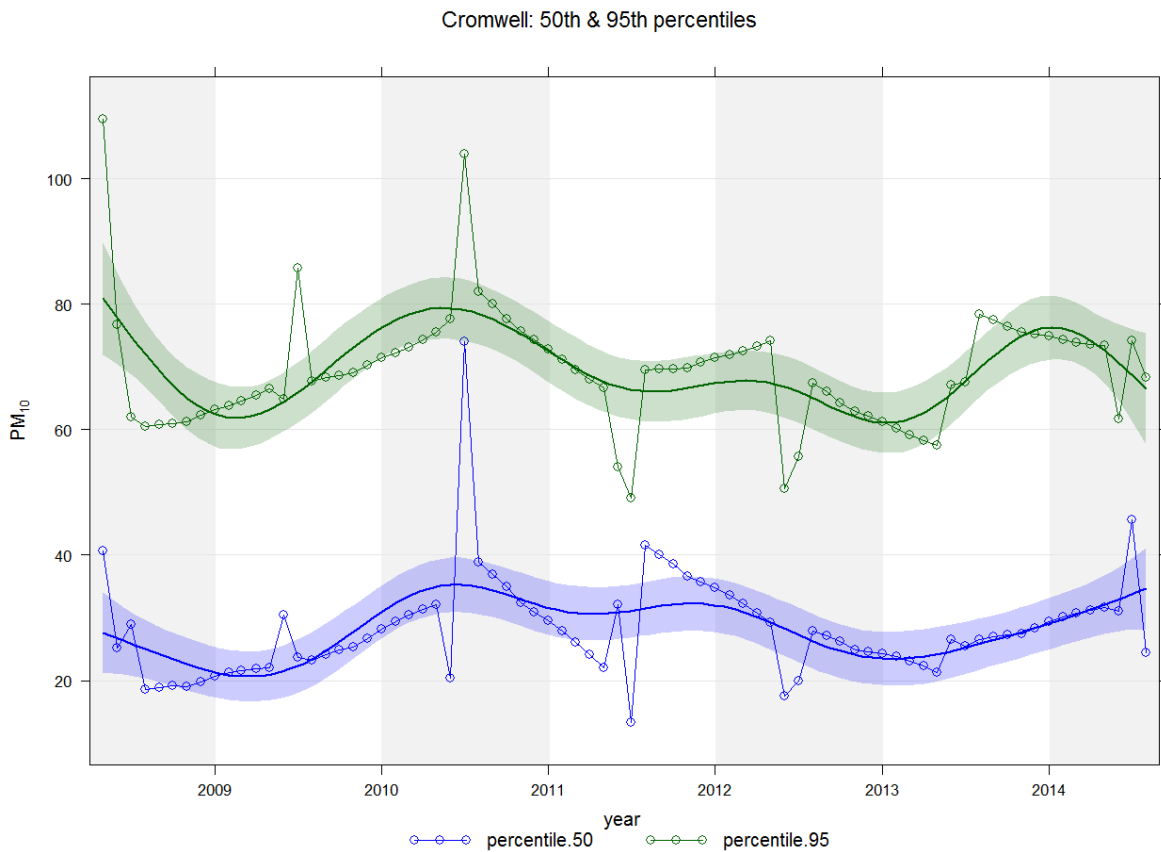
In Clyde, a downward annual trend of -3.1% in wintertime  $PM_{10}$  has resulted in winter means decreasing to approximately  $34 \mu\text{g}/\text{m}^3$ . Exceedance values have also decreased over the monitoring timeframe by about -3% each year.

Results of the smoothed trend analysis (Figure 29) show a marked decrease in the upper 95<sup>th</sup> percentile monthly means which has likely led to the reduction in the number of days exceeding the NESAQ



**Figure 29. smoothed trend analysis for  $PM_{10}$  concentrations in Clyde.**

Cromwell's winter  $PM_{10}$  levels (Figure 30) show an overall upward trend, increasing about +3% each year from 2008 to 2014. The smoothed trend reveals increases in both the 50<sup>th</sup> and 95<sup>th</sup> percentile during 2010 and 2014.



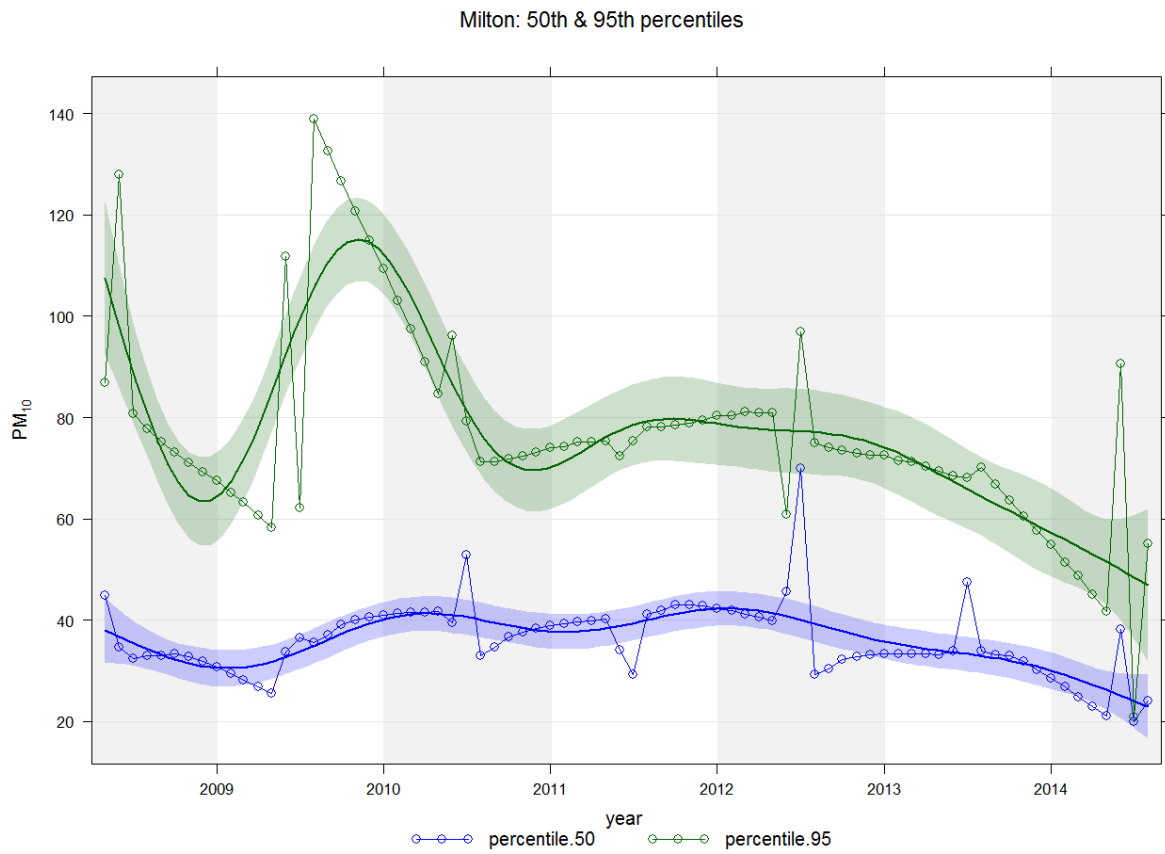
**Figure 30. Smoothed trend analysis of PM<sub>10</sub> concentrations in Cromwell.**

### 6.3.3 Balclutha and Milton

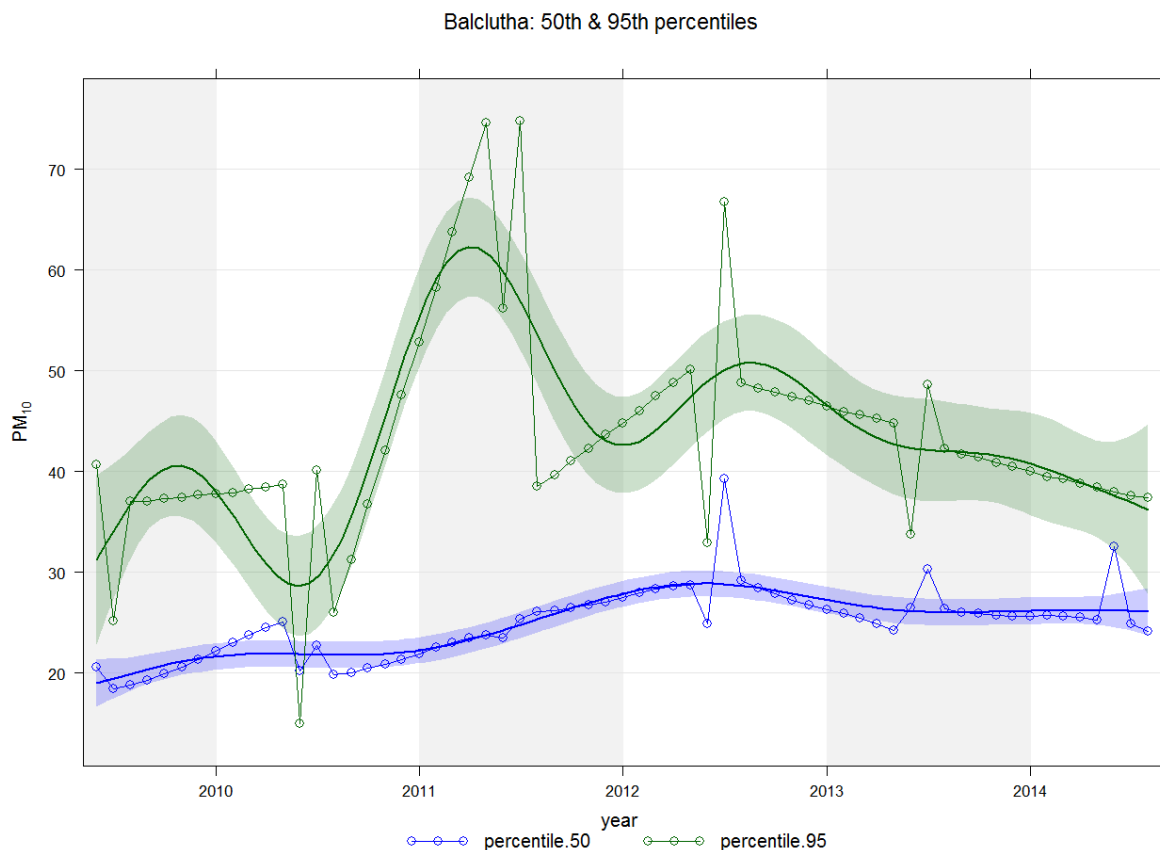
No statistically significant trends have been noted in either Balclutha or Milton.

The smoothed trend for Milton (Figure 31) does indicate a recent downward trend in winter monthly means; however, additional monitoring is required to evaluate with whether that change is statistically significant or not.

In Balclutha's smoothed trend (Figure 32), 2012 appears as a prominent year; however, no real trend is apparent.



**Figure 31. Smoothed trend analysis of PM<sub>10</sub> concentrations in Milton.**



**Figure 32. Smoothed trend analysis of PM<sub>10</sub> concentrations in Balclutha.**

## 6.4 Spatial distribution of PM<sub>10</sub>

Stationary monitors in the air quality network provide long-term PM<sub>10</sub> readings at a single point in each town. Depending on the size of the town and the complexity of its terrain, results from a single monitor point may not be representative of the entire area. The NESAQ addresses this issue by requiring monitoring in what is considered the ‘worst’ part of the airshed. This is the area that has either the highest PM<sub>10</sub> levels, or high PM<sub>10</sub> levels that affect the greatest number of people.

Mobile monitoring across a town using a portable air sampler offers a spatial “snapshot” of ambient air quality. During the period 2004 to 2015, ORC has performed 11 spatial studies<sup>8</sup> in order to either 1) provide context to existing monitoring, or 2) assess relative PM<sub>10</sub> levels in towns without monitors. Studies are typically performed over 3-to-4 winter days during a period when concentrations are expected to be relatively high. In each study, numerous monitoring runs of approximately 20-25 sampling points are performed during both morning and evening periods. Taken as an average ambient condition, maps with snapshot views of relative PM<sub>10</sub> are produced (Appendix 3).

While each town has its own ambient air quality “signature”, some general conclusions can be drawn based on the studies done to date:

<sup>8</sup> Alexandra (2015), Arrowtown (2014), Balclutha (2011), Cromwell (2015), Dunedin (2009), Lawrence (2013), Milton (2011), Mosgiel (2009), Palmerston (2011), Queenstown (2013), Wanaka (2014)

1. Ambient air quality can, at times, vary significantly from one street to the next. As an illustration, in central Wanaka relative PM<sub>10</sub> values ranged from 10 to 73ug/m<sup>3</sup> between two adjacent streets.
2. Topography can have a significant influence on particulate movement as exhibited in Palmerston where a corridor of low-lying land through the middle of town enables particulates to move from south to north towards the lower-lying Shag River.
3. Particulates are often elevated where older housing is the densest. This was observed in Cromwell, with the older, central section of town generally having the highest PM<sub>10</sub> levels.
4. Particulate movement is often influenced by nocturnal drainage winds with PM<sub>10</sub> accumulating in a 'downwind' area of an airshed. This was observed in Milton where PM<sub>10</sub> is, on average, highest at the southern end of town partly a result of gentle nocturnal winds moving southwards.

In Balclutha, the same effect of winds on particulate transport was noticed, but with a different result. Drainage winds following the Clutha-Mata Au River help flush PM<sub>10</sub> levels on the flat, central portion of Balclutha, keeping PM<sub>10</sub> levels relatively low as compared to the hill suburbs to the northeast and southwest of the town centre.

In Alexandra, the unique basin topography and meteorology combine to create a large area of nocturnal wind convergence in town, resulting in little ventilation and relatively high PM<sub>10</sub> through the central part of town.

A NIWA-led spatial study (2009) was performed in Dunedin over two weeks in winter 2009. The results of this larger scale study exhibited several of the elements noted above with Dunedin's complex topography creating multiple paths of nocturnal drainage of winds. Results of the analysis indicated while there is a considerable variation in air quality across Dunedin during winter days, the ORC monitor is fairly well representative of the Central Dunedin area.

These studies have added an additional dimension to the understanding of winter air quality in Otago towns by offering a "snapshot" view of ambient air quality across wider spatial areas.

## **7. Discussion and conclusion**

Air quality monitoring results over the past ten years indicate a wide range of ambient air quality throughout the region, particularly during winter months when conditions are calm and cold. Emissions from solid-fuel burners used for domestic heating are the major contributor of PM<sub>10</sub> in most areas of Otago with industry playing a role in Central Dunedin and Mosgiel.

During winter, emissions from all sources are often trapped near the ground under an inversion layer, causing PM<sub>10</sub> concentrations to rise to high levels. This is particularly true in Central Otago towns and Milton, where high PM<sub>10</sub> leads to numerous exceedances of the NESAQ each winter. The number of days each year that average daily PM<sub>10</sub> levels have

exceeded the NESAQ threshold concentration ( $50 \mu\text{g}/\text{m}^3$ ) is listed in Table 18. A more comprehensive listing of parameters can be found in Appendix 2.

**Table 18. Number of days when average daily  $\text{PM}_{10}$  exceeds the NESAQ.**

| Site       | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|------------|------|------|------|------|------|------|------|------|------|------|
| Alexandra  | 42   | 45   | 33   | 74   | 40   | 51   | 40   | 40   | 47   | 51   |
| Mosgiel    | 11   | 8    | 4    | 9    | 7    | 8    | 8    | n/a  | 5    | 7    |
| Dunedin    | 1    | 6    | 1    | 9    | 6    | 12   | 14   | 1    | 0    | 0    |
| Arrowtown  |      | 18   | 39   | 38   | 31   | 39   | 27   | 24   | 17   | 48   |
| Clyde      |      |      |      | 37   | 23   | 40   | 23   | 9    | 10   | 22   |
| Cromwell   |      |      |      | 31   | 30   | 43   | 20   | 30   | 33   | 49   |
| Milton     |      |      |      | 46   | 33   | 46   | 20   | 38   | 42   | 14   |
| Balclutha  |      |      |      |      | 2    | 2    | 4    | 13   | 4    | 3    |
| Naseby     |      |      | 0    |      |      |      |      |      |      |      |
| Roxburgh   |      |      | 0    |      |      |      |      |      |      |      |
| Ranfurly   |      |      | 0    | 0    |      |      |      |      |      |      |
| Palmerston |      |      |      |      |      |      |      |      | 0    | 0    |
| Oamaru     |      |      |      | 3    | 2    |      |      |      |      |      |
| Lawrence   |      |      |      |      |      |      | 2    | 2    |      |      |

Programmes to improve insulation and upgrade wood burners in these towns have resulted in over 1000 new (MfE-compliant) appliances being installed. While this undoubtedly has led to reductions in emissions, a corresponding reduction in concentrations is not apparent in most towns. Trend analyses do show some slight reductions in  $\text{PM}_{10}$  in Clyde, Arrowtown, and Alexandra but not to the extent that was originally predicted in work done for Otago's original air quality management strategy (ORC, 2007). In order to achieve compliance with the NESAQ, a more extreme reduction in emissions will be required in these areas.

In Air Zone 2 towns such as Balclutha and Mosgiel,  $\text{PM}_{10}$  levels are still exceeding the limits deemed acceptable for human health set in the NESAQ and there is no sign of any downward trend. Relying on the natural rate of burner replacements to improve air quality over time has not proven successful.

Central Dunedin has shown the most significant improvement in air quality over the last 10 years. This is most likely due to the reduction in industrial emissions that have occurred due

to the pro-active approach to upgrades of coal boilers in the city. The Central Dunedin airshed has complied with the NESAQ for the past three years.

Projected emissions reductions from domestic burner upgrades have not yielded the expected reductions in PM<sub>10</sub> concentrations. Key to successful planning for future work will be to understand why that is.



## References

- Ancelet, T., 2014. Particulate matter sources on an hourly timescale in a rural community during the winter. *Journal of the Air & Waste Management Association*, 64:5, 501-508pp.
- Carslaw, D.C., Ropkins, K., 2012. Openair — an R package for air quality data analysis. *Environmental Modelling & Software*, Volume 27-28, 52-61pp.
- Carslaw, D.C., (2014). The openair manual — open-source tools for analysing air pollution data. Manual for version 1.0, King's College London.
- Carslaw, D.C., Beevers, S.D., Tate J.E., 2007. Modelling and assessing trends in traffic-related emissions using a generalised additive modelling approach. *Atmospheric Environment* 41 (26), 5289-5299pp.
- Davy, P., et.al., 2011. Source apportionment of airborne particles at Dunedin, GNS Science Consultancy Report 2011/131, prepared for the Otago Regional Council.
- Krzyanowski, M., Cohen, A., 2008. Update of WHO air quality guidelines. *Air Qual Atmos Health*. 1:7-13pp.
- Longley, I., Olivares, G., (2008). A Review of Regional and natural Background PM10 in New Zealand. NIWA Client Report: AKL2008-062, Auckland.
- McKendry, I.G., 1996. Photochemical pollution potential in New Zealand. NIWA Report: AK96076, Auckland.
- Ministry for the Environment, 1997. Environmental Performance Indicators: Proposals for Air, Fresh Water and Land, Wellington.
- Ministry for the Environment, 1994. Ambient air quality guidelines, Wellington.
- Ministry for the Environment, 2002. Ambient air quality guidelines – 2002 update. Air Quality Report No. 32, Wellington.
- Ministry for the Environment, 2004. Resource Management (National Environmental Standards for air Quality) Regulations, Wellington.
- Ministry for the Environment, 2011. Resource Management (National Environmental Standards for air Quality) Amendment Regulations 2011, Wellington.
- Ministry for the Environment, 1997. Environmental performance indicators: Proposals for air, fresh water, and land. Wellington.
- Ministry for the Environment, 2011. 2011 Users' Guide to the revised National Environmental Standards for Air Quality. 138 pp.
- Otago Regional Council, 2005. Ambient Air Quality in Otago 1997-2004: Particulate Matter. ISBN 1-877265-20-9.

Otago Regional Council, 2005a. Ambient Air Quality in Otago 1997-2004: Nitrogen dioxide, Sulphur dioxide and Carbon monoxide. ISBN 1-877265-21-7.

Otago Regional Council, 2007. Otago Regional Council Clean Air Strategy: 2007-2013, Report to the Policy and Resource Planning Committee, Report #2007/451.

Otago Regional Council. 2009. Ambient Air Quality in Otago: Particulates 2005-2008. ISBN 1-877265-88-8.

Otago Regional Council, (2009). Regional Plan: Air for Otago. Otago Regional Council, Dunedin.

Otago Regional Council. (2009), Report #2009/162 Report to the Environmental Science Committee, Investigation into the interaction of PM<sub>10</sub> emissions from Clyde and Alexandra.

Parliamentary Commissioner for the Environment, 2015. The state of air quality in New Zealand: Commentary by the Parliamentary Commissioner for the Environment on the 2014 air domain Report, Wellington.

Pope III, C.A, Dockery, D.W. (2006), Health Effects of Fine Particulate Air Pollution: Lines that Connect. Journal of the Air & Waste Management Association, 56:6, 709-742.

Standards New Zealand. (2007). AS/NZS 3580.1.1. Methods for sampling and analysis of ambient air, Part 1.1: Guide to siting air monitoring equipment.

Standards New Zealand. (2008). AS/NZS 3580.9.11. Methods for sampling and analysis of ambient air, Method 9.11: Determination of suspended particulate matter – PM<sub>10</sub> beta attenuation monitors.

Statistics New Zealand. (2014). 2013 Census, Wellington.

Tate, A., Spronken-Smith, R.A., (2008), A Preliminary Investigation of the Air Pollution Meteorology of Alexandra, Central Otago, New Zealand. Clean Air and environmental quality Volume 42, No. 2.

Wilton, E. (2005), *Warm Homes Technical Report: Home Heating Methods and Fuels in New Zealand*, Environet, Ltd., prepared for the Ministry for the Environment, Wellington.

Wilton, E. Environet Ltd. 2006. *Air Emission Inventory – Dunedin, Mosgiel and Alexandra, 2005*, Prepared for Otago Region Council. Christchurch.

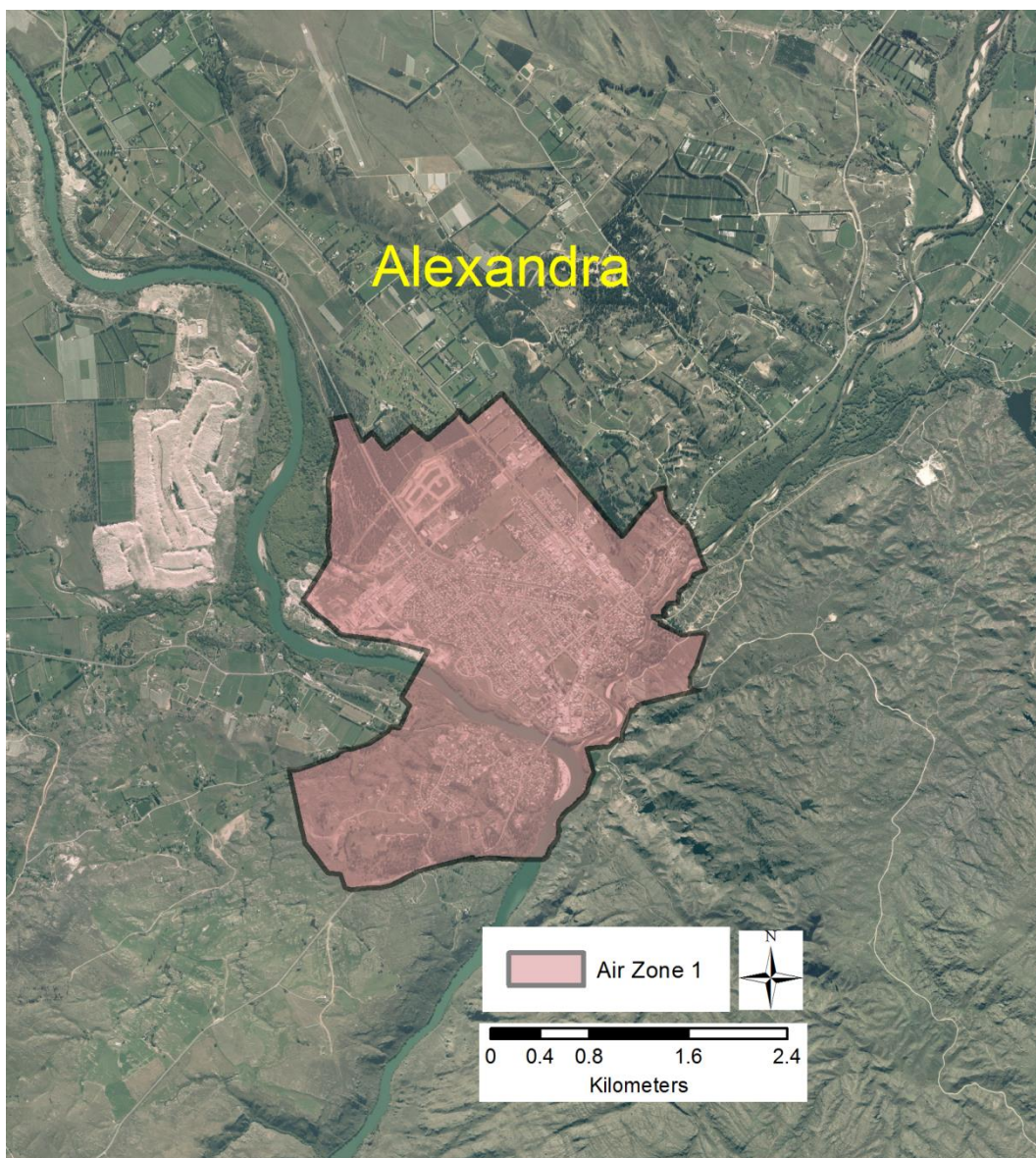
Wilton, E. (2006). *Air Emission Inventory – Dunedin, Mosgiel and Alexandra 2005*, Environet Ltd., Christchurch.

World Health Organisation. 2006. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide – global update 2005.

World Health Organisation. 2013. Review of evidence of health aspects of air pollution – REVIHAAP Project Technical Report, Regional office for Europe.

World Meteorological Organisation. 1983. Guide to Meteorological Instruments and Methods of Observation. No. 8, Ed. 5, Geneva Switzerland.

## Appendix 1 Air Zone boundary maps



And etc. for all the rest of the sites.



## Appendix 2. Hourly air quality summaries by site.

**Table 1. Alexandra – year-round**

|                       | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 52*  | 96   | 98   | 99   | 100  | 98   | 86   | 100  | 89   | 100  |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 29   | 23   | 19   | 28   | 23   | 24   | 24   | 22   | 25   | 24   |
| Max hour              | 309  | 335  | 375  | 386  | 363  | 311  | 326  | 252  | 293  | 496  |
| Max day               | 103  | 149  | 105  | 150  | 136  | 126  | 143  | 93   | 130  | 105  |
| Median                | 14   | 9    | 8    | 12   | 11   | 11   | 12   | 11   | 12   | 12   |
| 95 <sup>th</sup> %ile | 110  | 96   | 80   | 120  | 96   | 99   | 93   | 83   | 96   | 93   |

**Table 1a. Alexandra – winter only**

|                       | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 73*  | 100  | 99   | 100  | 100  | 100  | 100  | 100  | 100  | 100  |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 29   | 47   | 39   | 60   | 46   | 48   | 44   | 44   | 47   | 46   |
| Max hour              | 309  | 335  | 375  | 386  | 363  | 311  | 326  | 252  | 293  | 496  |
| Max day               | 103  | 149  | 105  | 150  | 136  | 126  | 143  | 93   | 130  | 105  |
| Median                | 36   | 32   | 25   | 41   | 29   | 31   | 31   | 33   | 32   | 32   |
| 95 <sup>th</sup> %ile | 138  | 143  | 125  | 173  | 146  | 148  | 126  | 119  | 136  | 130  |

**Table 2. Dunedin (Central)**

|                       | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 61*  | 77   | 97   | 80   | 98   | 93   | 90   | 97   | 95   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 21   | 20   | 24   | 20   | 25   | 25   | 18   | 18   | 18   |
| Max hour              | 309  | 135  | 319  | 197  | 211  | 504  | 338  | 192  | 189  |
| Max day               | 87   | 59   | 70   | 72   | 62   | 70   | 71   | 56   | 40   |
| Median                | 15   | 16   | 19   | 15   | 20   | 20   | 15   | 15   | 15   |
| 95 <sup>th</sup> %ile | 59   | 51   | 55   | 56   | 63   | 63   | 41   | 40   | 39   |

**Table 2a. Dunedin (Central) – winter only**

|                       | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 74*  | 100  | 100  | 100  | 100  | 98   | 89   | 98   | 100  |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 27   | 22   | 25   | 20   | 27   | 27   | 20   | 17   | 18   |
| Max hour              | 309  | 135  | 319  | 197  | 211  | 504  | 338  | 192  | 189  |
| Max day               | 87   | 59   | 70   | 72   | 62   | 70   | 71   | 56   | 40   |
| Median                | 18   | 15   | 19   | 13   | 20   | 21   | 17   | 13   | 14   |
| 95 <sup>th</sup> %ile | 75   | 61   | 66   | 60   | 70   | 72   | 49   | 44   | 45   |

**Table 3. Mosgiel**

|                       | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 58*  | 72*  | 64*  | 93   | 90   | 68*  | 47*  | 15*  | 95   | 99   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 20   | 17   | 16   | 18   | 19   | 24   | 26   | 14   | 20   | 21   |
| Max hour              | 458  | 217  | 229  | 717  | 289  | 329  | 289  | 88   | 167  | 217  |
| Max day               | 92   | 80   | 60   | 108  | 98   | 105  | 95   | 27   | 62   | 107  |
| Median                | 12   | 9    | 10   | 10   | 12   | 17   | 20   | 12   | 16   | 17   |
| 95 <sup>th</sup> %ile | 67   | 59   | 53   | 55   | 55   | 66   | 66   | 29   | 50   | 52   |

**Table 3a. Mosgiel – winter only**

|                       | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 75   | 100  | 100  | 100  | 99   | 98   | 94   | 0*   | 93   | 98   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    |      | 0    | 0    |
| Mean                  | 28   | 24   | 19   | 25   | 25   | 30   | 32   |      | 27   | 27   |
| Max hour              | 458  | 217  | 229  | 717  | 289  | 329  | 289  |      | 167  | 217  |
| Max day               | 92   | 80   | 60   | 108  | 98   | 105  | 95   |      | 62   | 107  |
| Median                | 17   | 15   | 11   | 15   | 16   | 21   | 21   |      | 20   | 20   |
| 95 <sup>th</sup> %ile | 90   | 77   | 64   | 78   | 77   | 84   | 75   |      | 71   | 73   |

**Table 4. Arrowtown – winter only**

|                       | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|------|------|
| % valid daily data    | 45*  | 81   | 97   | 96   | 100  | 100  | 100  | 100  | 98   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 38   | 52   | 44   | 40   | 42   | 34   | 36   | 30   | 45   |
| Max hour              | 278  | 762  | 455  | 288  | 318  | 280  | 725  | 241  | 392  |
| Max day               | 96   | 168  | 126  | 118  | 101  | 116  | 147  | 77   | 148  |
| Median                | 21   | 27   | 27   | 22   | 24   | 19   | 21   | 17   | 25   |
| 95 <sup>th</sup> %ile | 133  | 174  | 131  | 140  | 143  | 123  | 118  | 101  | 158  |

**Table 5. Clyde – winter only**

|                       | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|
| % valid daily data    | 98   | 95   | 100  | 72*  | 100  | 98   | 99   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 40   | 31   | 44   | 36   | 28   | 28   | 32   |
| Max hour              | 288  | 283  | 261  | 249  | 167  | 161  | 224  |
| Max day               | 104  | 103  | 109  | 107  | 64   | 66   | 84   |
| Median                | 26   | 16   | 28   | 23   | 19   | 19   | 23   |
| 95 <sup>th</sup> %ile | 130  | 111  | 148  | 116  | 85   | 81   | 100  |

**Table 6. Cromwell – winter only**

|                       | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|
| % valid daily data    | 95   | 94   | 100  | 56*  | 99   | 95   | 99   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 28   | 34   | 48   | 35   | 34   | 38   | 40   |
| Max hour              | 397  | 364  | 393  | 322  | 560  | 533  | 378  |
| Max day               | 109  | 115  | 133  | 92   | 91   | 107  | 112  |
| Median                | 16   | 15   | 25   | 20   | 19   | 20   | 23   |
| 95 <sup>th</sup> %ile | 161  | 154  | 191  | 124  | 125  | 142  | 140  |

**Table 7. Milton – winter only**

|                       | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|------|
| % valid daily data    | 98   | 98   | 98   | 56*  | 81   | 100  | 81   |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 47   | 42   | 49   | 43   | 50   | 44   | 31   |
| Max hour              | 396  | 476  | 300  | 347  | 290  | 306  | 324  |
| Max day               | 141  | 144  | 119  | 114  | 144  | 139  | 133  |
| Median                | 30   | 25   | 35   | 29   | 33   | 31   | 20   |
| 95 <sup>th</sup> %ile | 149  | 149  | 141  | 125  | 150  | 125  | 100  |

**Table 8. Balclutha – winter only**

|                       | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-----------------------|------|------|------|------|------|------|
| % valid daily data    | 72*  | 100  | 50*  | 89   | 100  | 64*  |
| Minimum               | 0    | 0    | 0    | 0    | 0    | 0    |
| Mean                  | 22   | 22   | 30   | 34   | 28   | 27   |
| Max hour              | 168  | 474  | 223  | 231  | 211  | 318  |
| Max day               | 67   | 76   | 94   | 75   | 88   | 55   |
| Median                | 16   | 17   | 22   | 24   | 22   | 22   |
| 95 <sup>th</sup> %ile | 63   | 62   | 84   | 96   | 77   | 71   |

**Table 9. Lawrence – winter only**

|                       | 2010 | 2011 | 2012 |
|-----------------------|------|------|------|
| Minimum               | 0    | 0    | 0    |
| Mean                  | 29   | 21   | 23   |
| Max hour              | 145  | 420  | 244  |
| Max day               | 54   | 57   | 68   |
| Median                | 22   | 16   | 18   |
| 95 <sup>th</sup> %ile | 74   | 57   | 62   |

**Table 10. Naseby – winter only**

|                       | 2007 |
|-----------------------|------|
| Minimum               | 0    |
| Mean                  | 14   |
| Max hour              | 179  |
| Max day               | 33   |
| Median                | 10   |
| 95 <sup>th</sup> %ile | 41   |

**Table 11. Roxburgh – winter only**

|                       | 2007 |
|-----------------------|------|
| Minimum               | 0    |
| Mean                  | 16   |
| Max hour              | 90   |
| Max day               | 36   |
| Median                | 12   |
| 95 <sup>th</sup> %ile | 44   |



**Table 12. Ranfurly – winter only**

|                       | 2007 | 2008 |
|-----------------------|------|------|
| Minimum               | 0    | 0    |
| Mean                  | 21   | 22   |
| Max hour              | 125  | 150  |
| Max day               | 43   | 46   |
| Median                | 13   | 15   |
| 95 <sup>th</sup> %ile | 64   | 67   |

**Table 13. Palmerston – winter only**

|                       | 2013 | 2014 |
|-----------------------|------|------|
| Minimum               | 0    | 0    |
| Mean                  | 26   | 21   |
| Max hour              | 112  | 141  |
| Max day               | 50   | 50   |
| Median                | 21   | 17   |
| 95 <sup>th</sup> %ile | 62   | 52   |

**Table 14. Oamaru – winter only**

|                       | 2008 | 2009 |
|-----------------------|------|------|
| Minimum               | 0    | 0    |
| Mean                  | 22   | 19   |
| Max hour              | 189  | 182  |
| Max day               | 54   | 62   |
| Median                | 15   | 12   |
| 95 <sup>th</sup> %ile | 67   | 63   |

### Appendix 3. Spatial study results.

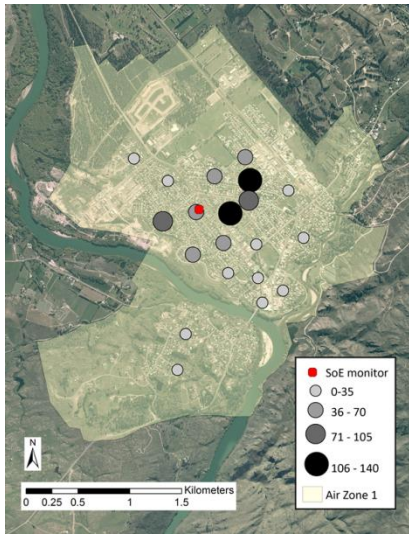


Figure 33. Alexandra

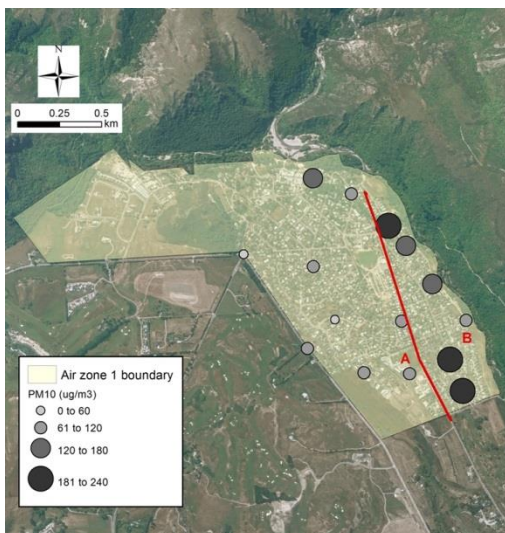
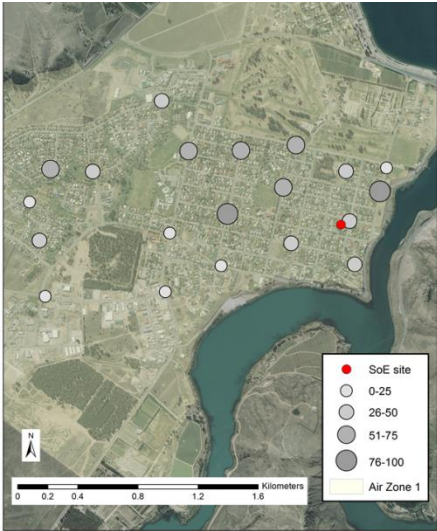


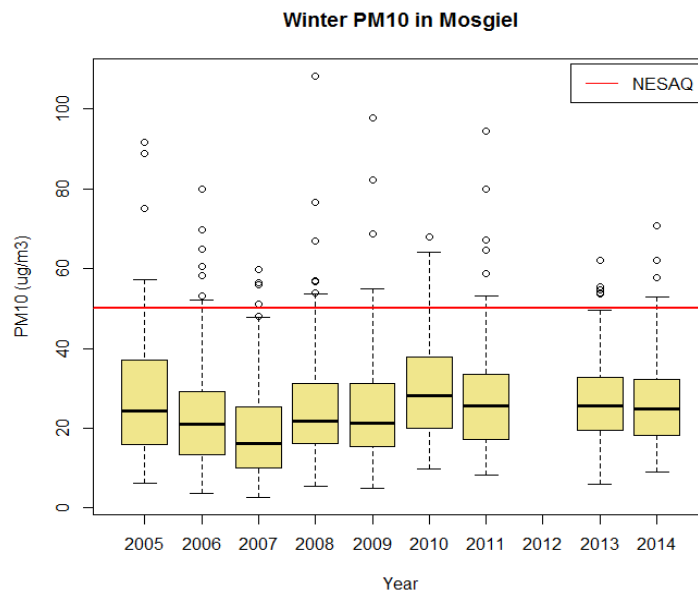
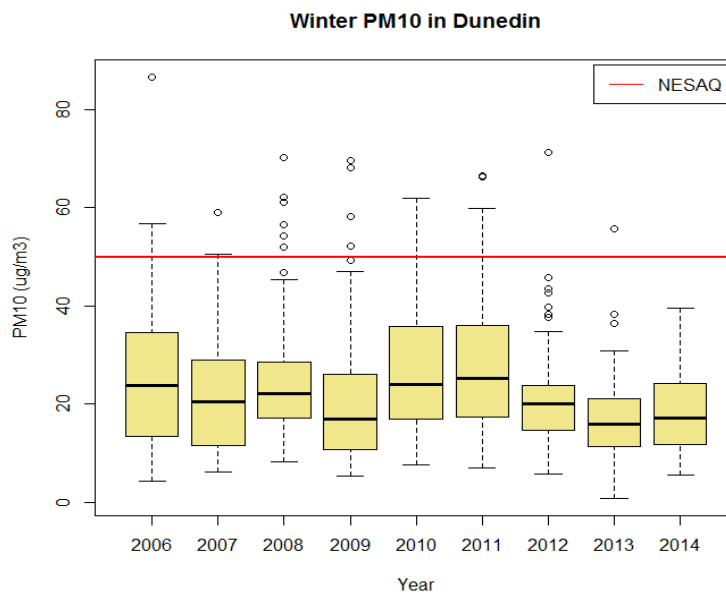
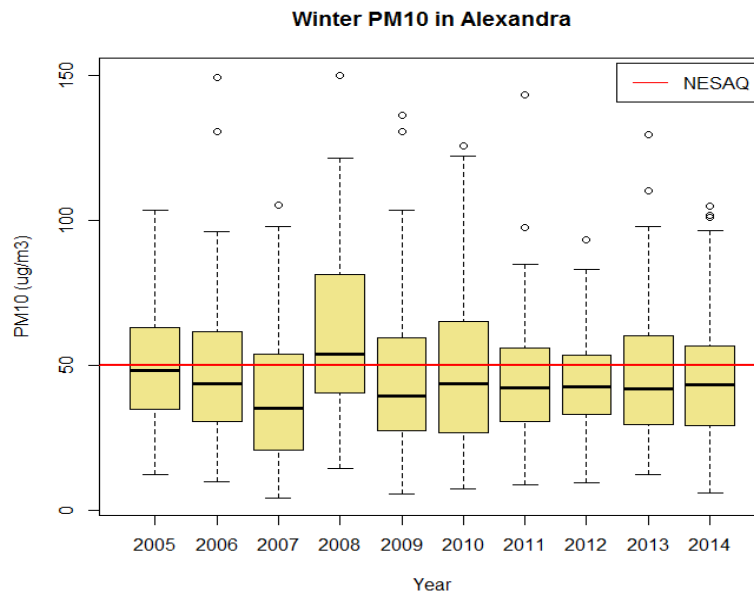
Figure 34. Arrowtown



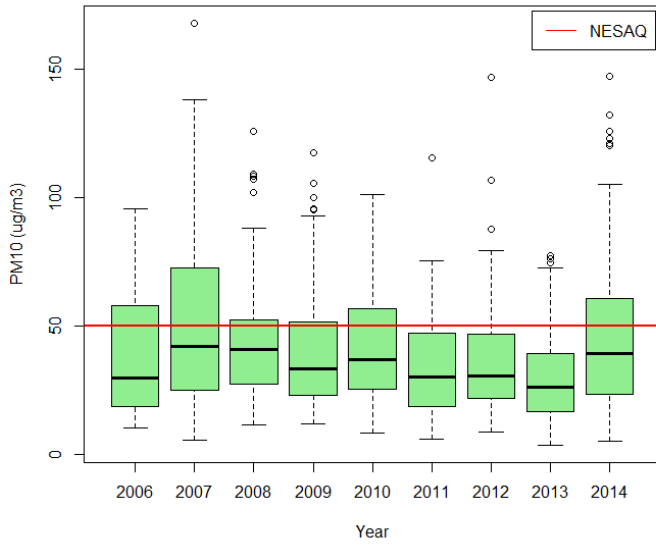
**Figure 35. Cromwell**

Etc. for the rest

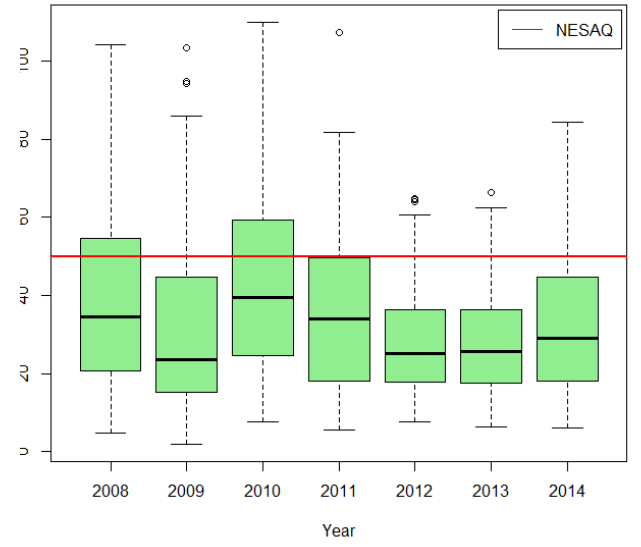
## Appendix 5. Annual box plots of wintertime PM<sub>10</sub> distribution.



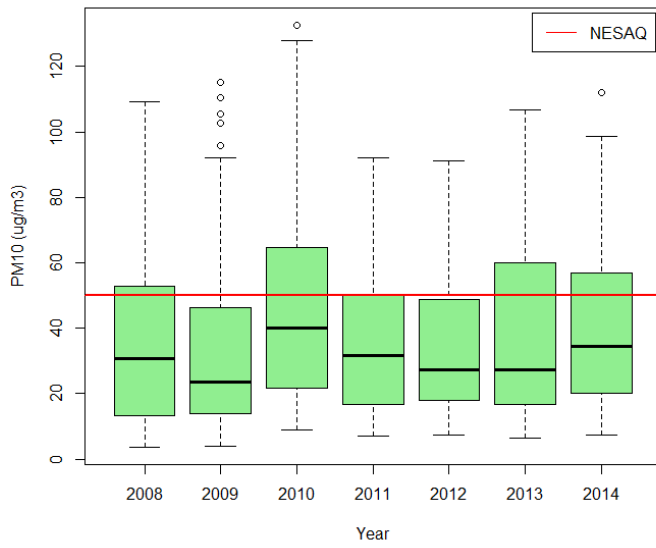
Winter PM10 in Arrowtown



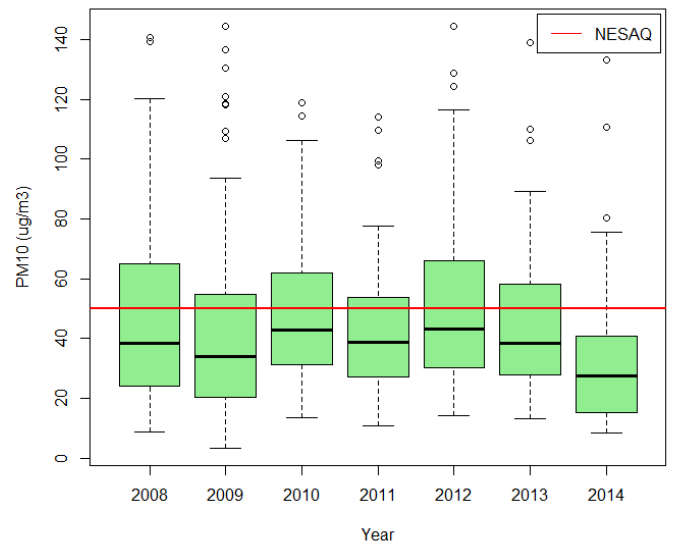
Winter PM10 in Clyde



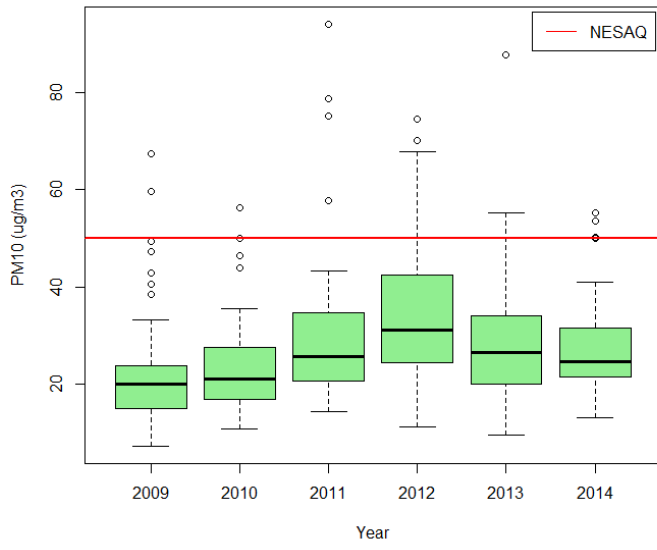
Winter PM10 in Cromwell



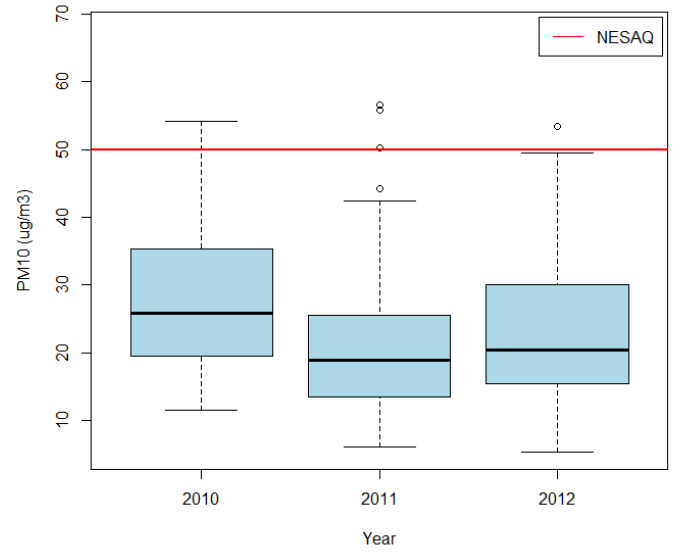
Winter PM10 in Milton



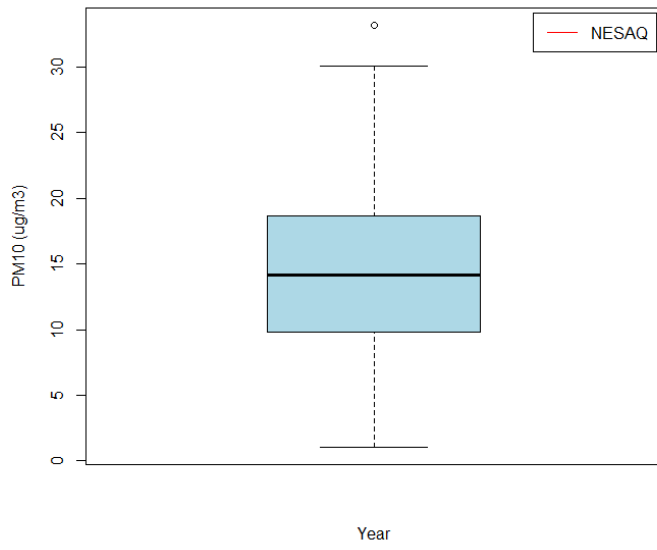
Winter PM10 in Balclutha



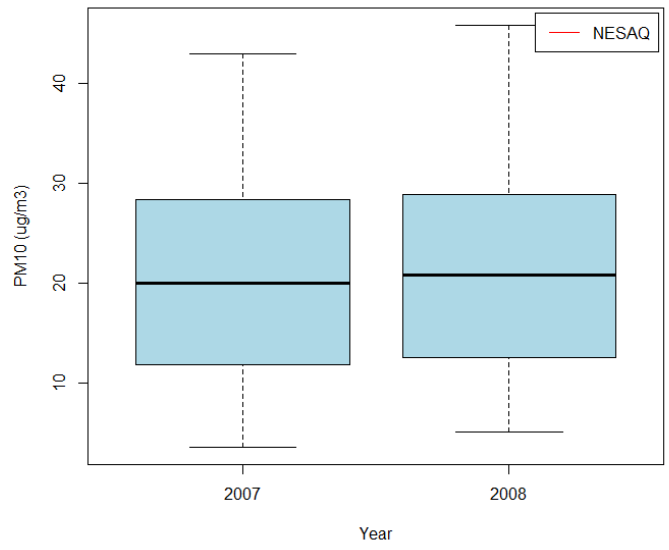
Winter PM10 in Lawrence



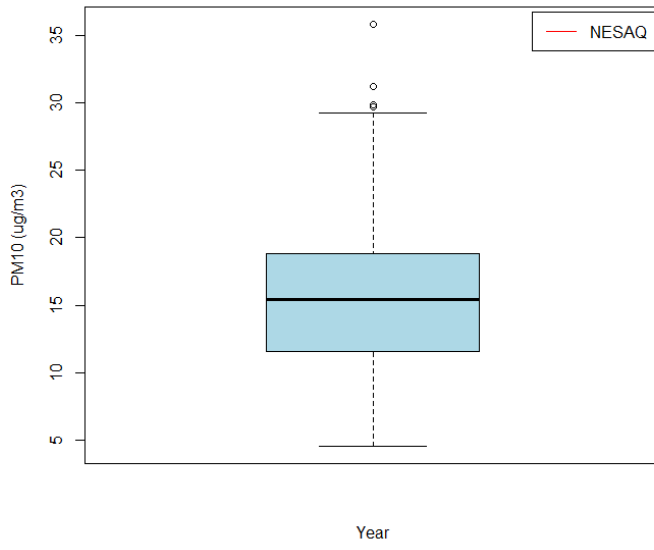
Winter PM10 in Naseby



Winter PM10 in Ranfurly



Winter PM10 in Roxburgh



Winter PM10 in Oamaru

