Balclutha spatial PM_{10} study

Otago Regional Council
Private Bag 1954, 70 Stafford St, Dunedin 9054
Phone 03 474 0827 Fax 03 479 0015
Freephone 0800 474 082
www.orc.govt.nz

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Prepared by Deborah Mills

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Foreword

The Otago region experiences very good air quality most of the year; however, there are times, especially during winter, when residents can suffer from high levels of air pollution from smoke. The majority of smoke comes from solid fuel burners used to heat homes. Industry, vehicles and agricultural activities also contribute to poor air quality at times.

The Ministry for the Environment (MfE) introduced National Environmental Standards for air quality (NES) in 2005, which were then revised in 2011. Otago's main pollutant, PM_{10} (small particles suspended in the atmosphere), is monitored in several towns around the region.

ORC is committed to improving air quality and creating a healthier environment. Our Regional Policy Statement provides for the sustainable management of the air resource, and the Regional Plan: Air sets out the policies, rules and objectives for enhancing its quality.

In addition to the air quality monitoring network, studies to improve our understanding of local air quality issues are routinely carried out. This report examines the air quality of Balclutha, detailing how the patterns change throughout the year, and how it differs between various parts of town.

Executive summary

We have undertaken this investigation into the spatial patterns of PM_{10} in Balclutha to improve the understanding of winter air quality patterns. A permanent air quality monitor was installed in central Balclutha in June 2009 to report on the National Environment Standard for air quality (NES, 2004). The NES set a limit of 50 micrograms per cubic metre of air ($\mu g/m^3$). Results of the ongoing monitoring programme indicate that Balclutha exceeds that level about twice a year.

In this study, data on land-use patterns, fuel-type usage, weather data and PM_{10} levels were collected and analysed to explain differing air quality patterns around Balclutha. Results of this study also provide a spatial context for the permanent monitor's site in relation to the overall pattern of ambient air quality in town.

Balclutha has relatively high PM_{10} emissions due to the extensive use of coal for domestic heating; however, ambient particulate levels in the central, flat area are relatively low. High emissions do not necessarily equate to high ambient concentrations of PM_{10} because meteorology and topography play a major role in how emissions are distributed in the atmosphere.

The current monitoring site represents the downtown area of Balclutha well, but it may not accurately reflect ambient PM_{10} levels in the hill suburbs. Clearly, there are some areas of high emissions. We do not know whether the higher suburban emissions stagnate or disperse throughout the night, as it would require continuous monitoring to establish that. However, plans are in place to relocate the monitor to an area of higher emissions for winter 2011 to verify ambient conditions in the hill suburbs.

The new location will also enable compliance with NES that monitoring takes place in the 'worst' air quality site.

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1 Introduction

To develop an appropriate air resource strategy, PM_{10} monitoring should be performed in an area where the ambient concentrations are expected to be their highest. This is reflected in the NES's requirement to monitor in what is considered to be the 'worst' area of town (MfE, 2004). However, until we have done some spatial monitoring, we do not know which area is the worst. Balclutha's continuous monitor was originally sited in the central part of town, based on comparisons to other towns, where PM_{10} accumulates on the valley floor overnight. Results of 18 months of monitoring have revealed that PM_{10} levels are low to moderate in that area.

However, it is unrealistic to expect that results from a single monitoring site will represent an entire town's exposure to various air pollutants. Different areas in a town will experience different levels of air quality, depending on the specific microclimate, topography and emission rates. To meet the NES requirement of monitoring in the worst place, it is necessary to examine the variation of PM_{10} concentrations across the built-up portion of Balclutha. Taking real-time measurements of PM_{10} at multiple sites across town is one means by which we can get an indication of the values experienced spatially. Results will assist in managing the air resource, as well as providing a context for the values measured at the current continuous monitoring site.

The goal of this project was to define the spatial distribution of PM_{10} in Balclutha. Section 2 discusses the patterns of the PM_{10} data collected at the existing monitoring site in the centre of town. Section 3 describes the spatial patterns of PM_{10} emissions within and around the airshed. It also provides some background on the topography and climatology of the area, two important factors affecting the air quality in Balclutha. Section 4 outlines the methods used in the study; Section 5 discusses the results of the winter 2010 spatial monitoring programme; and Section 6 provides discussion of the results. Conclusions are presented in Section 7.

2 Description of PM_{10} patterns at the current monitoring site

Particulate matter pollution is an issue in many Otago towns during winter when smoke from domestic heating appliances and industry combine with settled weather to produce elevated levels of PM_{10}. Continuous, daily monitoring began in Balclutha in early June 2009, because Balclutha, like other towns in the region, relies heavily on wood and coal as solid fuel for home heating.

Preliminary monitoring done during the winters of 1997 and 2000 indicated that downtown Balclutha had the potential to experience poor air quality. Based on these results, the continuous monitor was located in central, downtown Balclutha, an area of mixed land use. Results from this monitor show that the town centre of Balclutha can expect to exceed the NES standard of 50 micrograms per cubic metre (µg/m^3) of air about twice a year. The Otago Regional Plan: Air has a target goal level of 35µg/m^3; the site has exceeded this target 15 times since the beginning of June 2009. Figure 1 illustrates the daily PM_{10} levels, and the table below details some summary statistics.

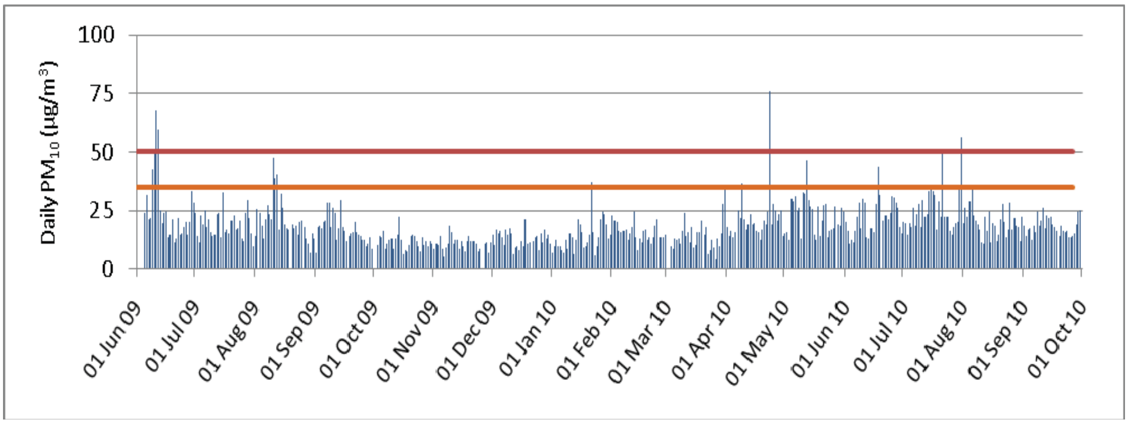

Figure 1: Daily PM_{10} in Balclutha from June 2009 through September 2010. The red line represents the NES limit of 50µg/m^3, and the orange line represents the ORC's goal level of 35µg/m^3

Table 1: Summary of PM_{10} values. Units for maximum and average values are µg/m^3. Data for 2009 include June – December; data for 2010 include January – September

Year	Maximum value	Jun – Aug average	# Days > 50µg/m^3	# Days > 35µg/m^3
2009	68	22	2	7
2010	76	22	2	8

Average daily winter PM_{10} levels are approximately 22µg/m^3, while in summer they are 14µg/m^3, revealing a relatively small, but noticeable, seasonal difference (Table 2).

Table 2: Seasonal PM_{10} averages

Average seasonal PM_{10} levels ($\mu g/m^3$)			
Winter	Spring	Summer	Autumn
22	**15**	**14**	**20**

On a daily basis in winter, PM_{10} levels start to increase between 4-5pm, which is typical in towns where home heating emissions are the primary source of particulates. They peak about 6pm before lowering through the morning hours until about 7am. The 6pm peak is earlier than in most other towns, a point that will be discussed in more detail later.

A secondary peak occurs at 8-9am in winter, presumably from fires being re-lit. This is similar to most other towns in New Zealand. While on average, hourly values are between 10-30$\mu g/m^3$, maximum hourly values can range to around 200$\mu g/m^3$. During one extreme event on 23 April, the hours from 9-11pm were exceptionally high at 389, 474 and 445$\mu g/m^3$, respectively. The reason for this is unknown, but it appears to have been a localised event. Winds were light to moderate from the south-east that day.

During warmer months, hourly values are lower most of the day. They peak at about 9pm, decreasing throughout the evening and into the early morning hours. The timing of the evening peaks is strongly correlated to the drop in wind speed at the end of the day.

Typical diurnal trends, for both winter and the rest of the year, are shown in Figure 2.

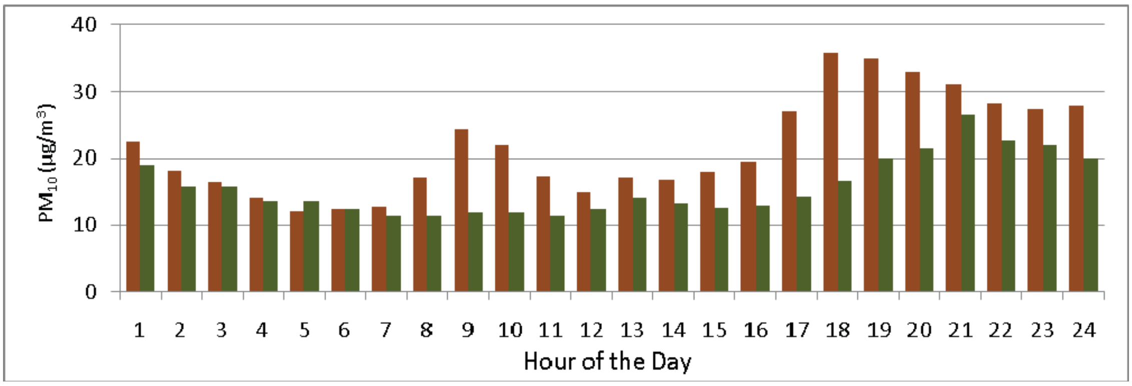

Figure 2: Typical diurnal trends of PM_{10}. The winter pattern (June-August) is shown in brown and the pattern for the rest of the year is shown in green

3 Factors affecting the concentration of PM_{10} in the atmosphere

Two main factors govern the concentration of PM_{10} in the atmosphere: the rate of emissions from various sources and the atmospheric processes that influence the accumulation, transport and dispersal of particulates. This section discusses emission sources in Balclutha, their relative contribution to the PM_{10} patterns, and provides information about Balclutha's climate.

3.1 Emission sources and patterns

3.1.1 Domestic emissions

Balclutha, with an approximate population of 4,000, is the seventh largest town in Otago. It is an agricultural service centre, supporting the surrounding rural area. As shown on the map (Figure 3), most of the town is zoned as urban (consisting of residential and commercial), with some small industrial blocks.

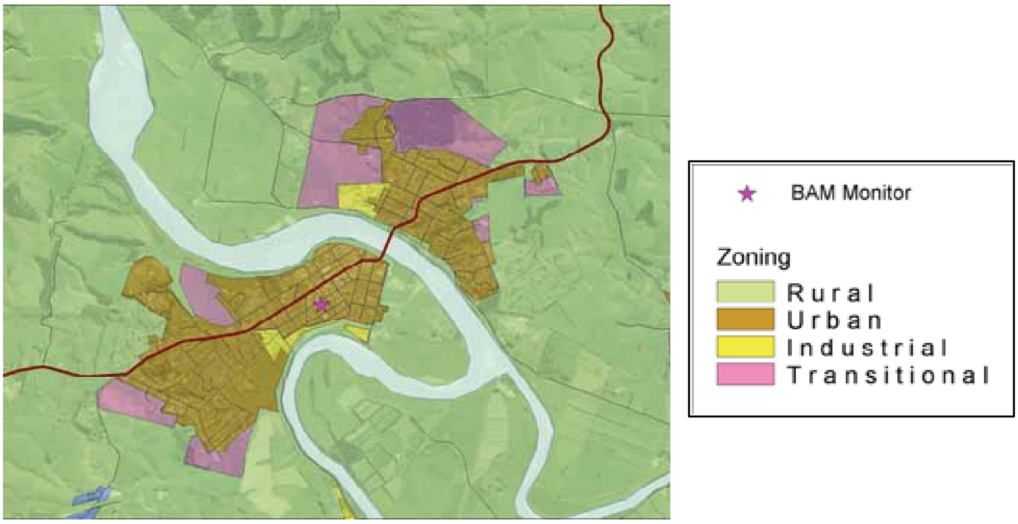

Figure 3: Balclutha zoning map. Urban zones encompass commercial and residential areas. The location of the continuous monitor is shown with a purple star

In most towns in Otago, emissions inventories have shown that domestic heating appliances are the main contributor of PM_{10} on an average winter's day. While no specific inventory has been compiled for Balclutha, the latest census data offer information about the numbers and percentages of different types of fuel use for domestic heating.

According to the most recent census data (Statistics NZ, 2006), there are approximately 1650 family dwellings in Balclutha. Of fuel types used to heat private houses, 75% of total households use electricity for heating at some time. Slightly more households use wood than coal (57 to 49%), and about 20% of homes use bottled gas.[1] Balclutha has one of the highest proportions of households (40%) using coal in multi-fuel burners of all New Zealand towns. Residents burn more coal per day than wood during winter (MfE, 2005a). Balclutha has, therefore, one of the highest emission rates in Otago.

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[1] Some households will use more than one fuel type which is why the percentages add up to over 100%.

Using figures from the Warm Homes Technical Report (2005a), domestic winter fuel use is about 42 tonnes per day. On an average winter's day, this equates to approximately 640kgs of PM_{10} emitted into the atmosphere, almost 70% of which comes from coal used in multi-fuel burners[2]. The pie chart in Figure 4 depicts the various percentages of emissions from each domestic source.

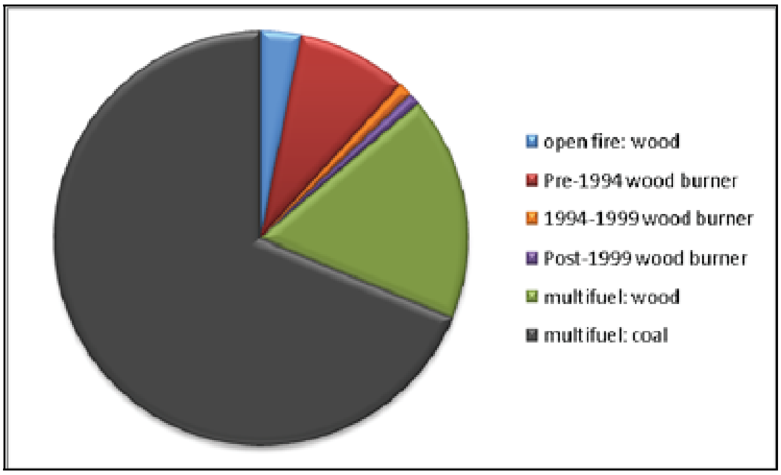

Figure 4: **Relative contributions of various heating sources to total daily emissions. Relative percentages are shown for a typical day in July. Emissions from coal dominate the daily PM_{10} at 69%**

Specific contributions from transport, outdoor burning and other natural sources such as pollen, soil dust and sea salt are largely unknown but are thought to be less significant, and certainly less regular, than domestic and industrial emissions.

According to census figures from 1996-2006, electric, wood, and coal usage declined slightly during that ten year period, while the use of bottled gas grew (Figure 5).

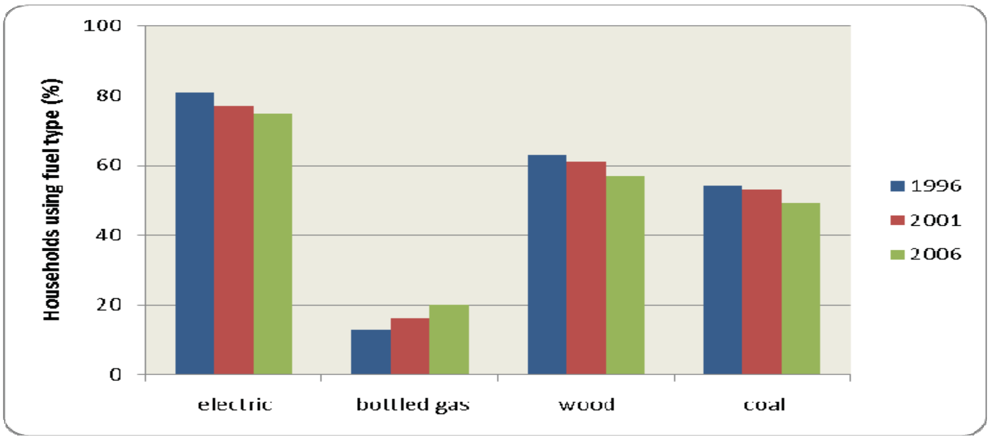

Figure 5: **Change in common fuel use from 1996 to 2006. Use of bottled gas increased and use of other fuels decreased**

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[2] Emission rates can vary greatly depending on the age and specific use of burners. Average rates for this study were based on MfE's Warm Homes Technical Phase 1 Report (MfE, 2005b).

Figure 6 maps the density of burners at the census meshblock[3] unit level to give an indication of where emission levels are highest. The map shows the number of burners per square kilometre, broken down by meshblock; the highest densities are found in the north-east and south-west hill suburbs. Meshblocks shown in grey do not have data provided; they are generally commercial or other sensitive areas.

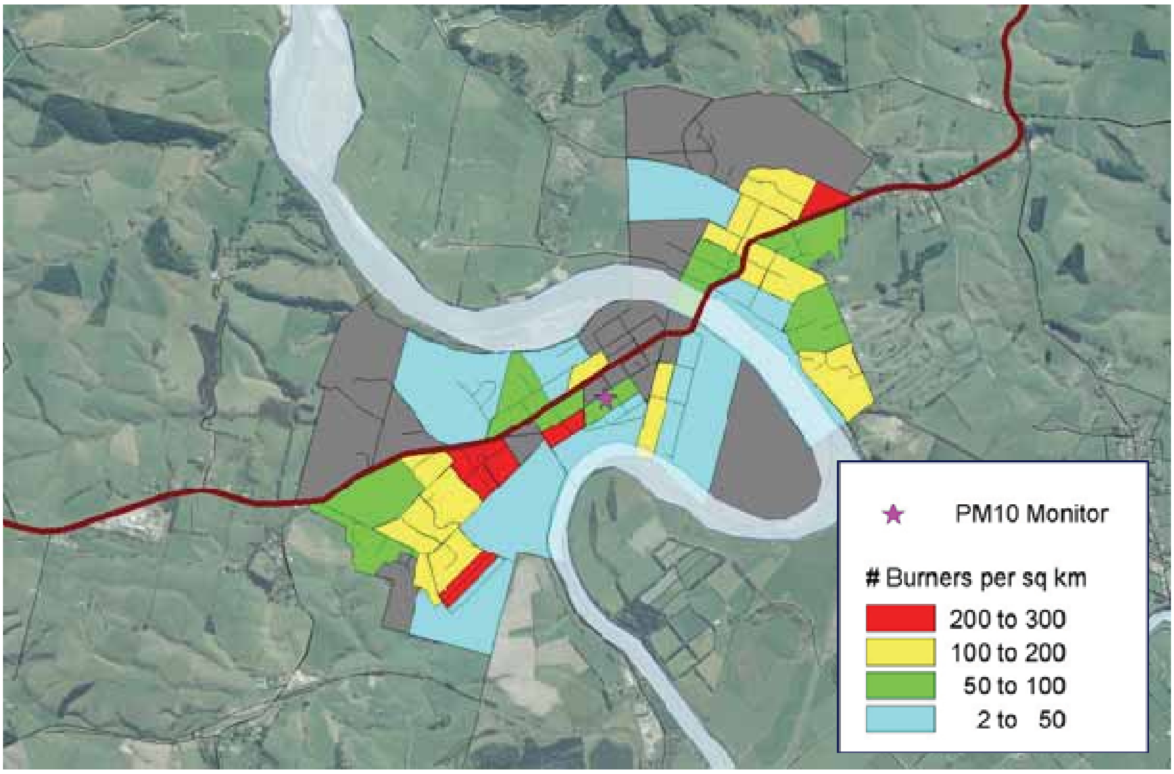

Figure 6: Densities of burners shown by meshblock unit. Data are unavailable for those areas are shown in grey

3.1.2 Industrial and commercial emissions

Industrial and commercial emissions also contribute to the daily load of PM_{10}. Figure 7 shows the locations of consented air discharges in and around the Balclutha air zone during winter 2010. For the most part, these discharges are from coal-fired boilers, and dust from quarries and landfills. Generally, discharges outside the airshed do not affect Balclutha air quality.

Industrial emissions within the town are estimated to constitute approximately 6% (about 40kgs) of all emissions in Balclutha on a winter's day.

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[3] Meshblocks are geographical areas typically containing about 110 people.

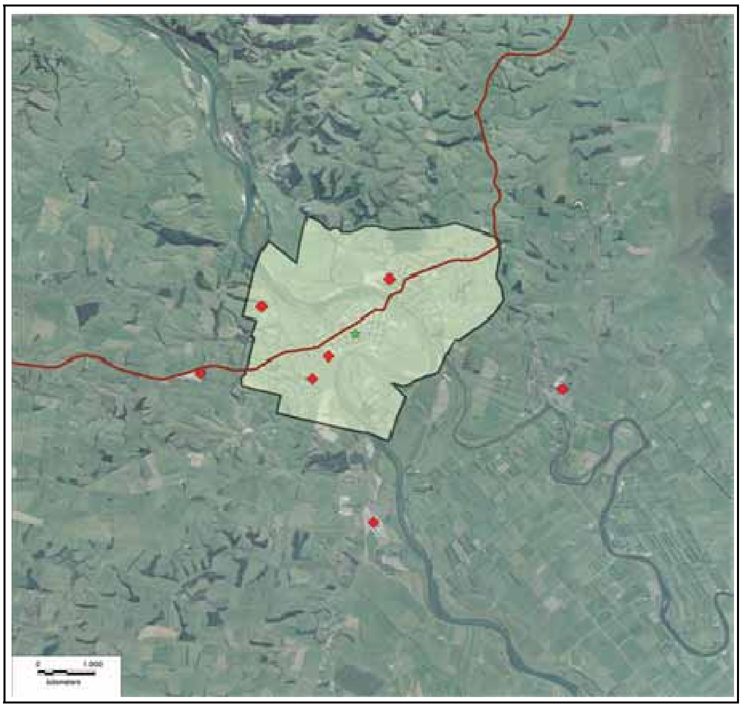

Figure 7: Map of the Balclutha airshed, showing relevant discharge to air consents during winter 2010. Most of these discharges are emissions from coal burners

3.2 Topography and climate of Balclutha

In addition to emissions, another major influence on air quality is the nature of the atmosphere's stability, which dictates how and when particulates disperse. The topography and climate of an area combine to influence the daily weather patterns that affect stability conditions. As is seen in towns with poor winter air quality (most Central Otago towns), one of the most common contributors to stagnant particulates is the formation of a temperature inversion. An inversion typically occurs during very cold, cloudless, calm nights during winter, and its presence serves to trap a cold, polluted layer of air underneath another warmer layer. A second contributor to poor air quality is the presence of cold-air drainage. This is the result of cold night-time air sliding down adjacent slopes, which forms a dense, stable layer on the surface.

Due to its location, Balclutha does not experience either of these features to any great extent, thereby reducing the amount of particulates stagnating near the surface. The town is located along both banks of the Clutha River/Mata-Au, on a broad northwest-southeast sloping plain (Figure 8). It is approximately 35 kilometres from the sea, across the wide Inch Clutha plain. The town is framed by the southern syncline to the south and gently rolling hills to the north. This topographic layout provides an opportunity for regular ventilation through the town, and assists in the dispersal of particulates.

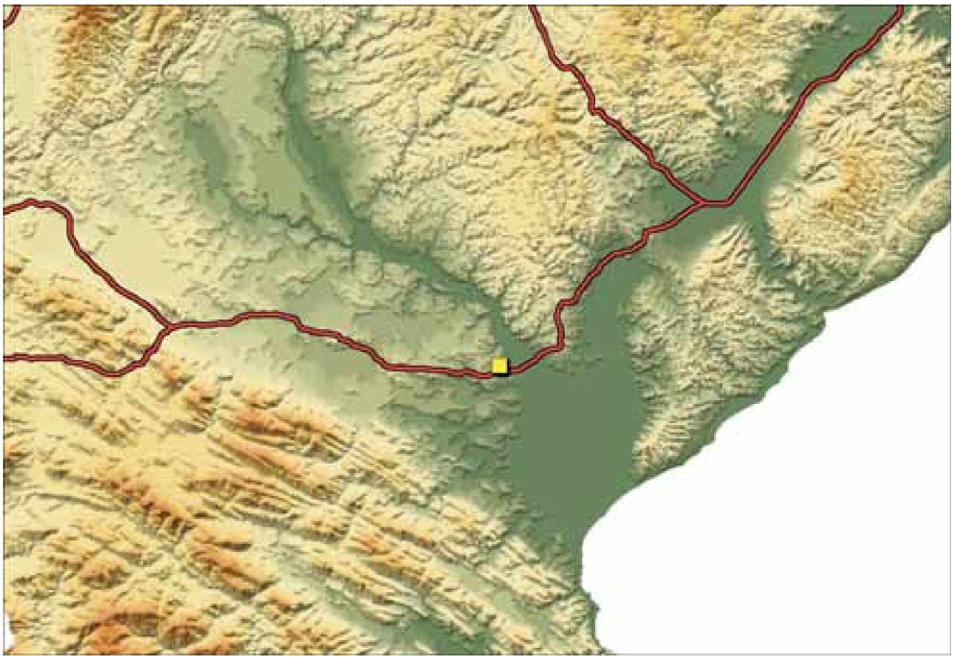

Figure 8: General topography of the Balclutha area. The town centre is shown by the yellow square

Balclutha has more of a maritime climate than the Central Otago towns, as it experiences smaller temperature ranges, higher minimum temperatures in winter, increased precipitation events and fewer calm conditions. These climatological features indicate that, compared to Central Otago towns, the formation of strong temperature inversions is probably a less frequent occurrence. Table 3 summarises these features, using data from the temperature record at Balclutha's nearby Telford weather station, which are then contrasted with those collected from the NIWA weather station at Clyde.

Table 3: Comparison of climate statistics between Balclutha (Telford station) and Clyde. The timeframe is June-August 2010. Temperatures are in degrees Celsius

	# Rain days	% Calm	Ave temp range	Ave min temp
Telford	39 (42%)	4	3.5	1.8
Clyde	28 (28%)	49	10.4	-0.8

From wind speed and direction data collected at the Telford weather station during winter 2010 (Figure 9), it can be seen that the most common wind directions were west and north-west (generally downriver). Wind speeds greater than two metres per second (m/s) are common, and the area rarely experiences completely calm conditions. These features aid particulate dispersal. With no steep, high hills nearby, the likelihood of cold-air drainage is significantly reduced as well.

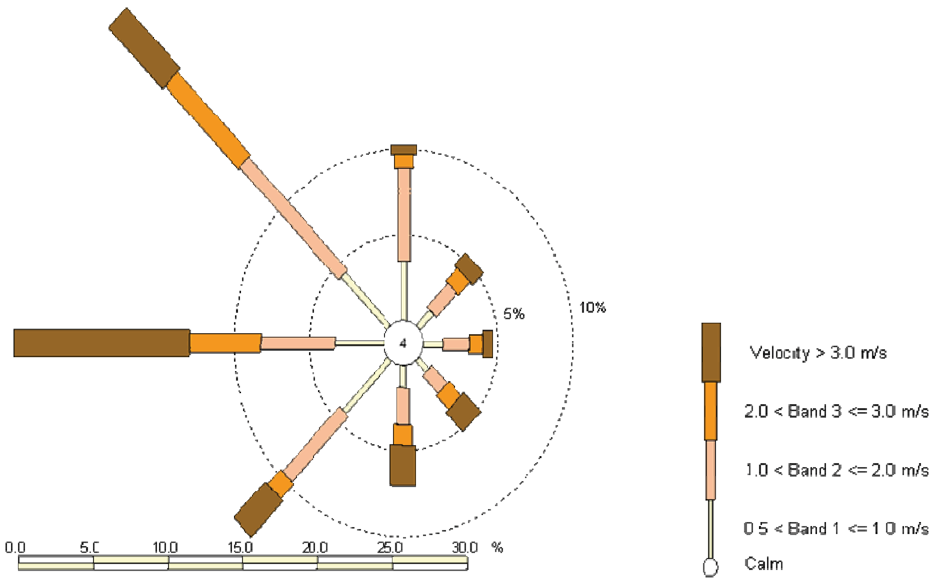

Figure 9: Wind rose for Telford weather station shows that the most frequent wind directions are west and north-west. Wind speeds are frequently greater than 2m/s, and only 2% of winter days had calm conditions

This is not to say that particulates cannot, and do not, accumulate in Balclutha. Rather, there are mechanisms available in the area to assist in dispersing particulates into the atmosphere

4 Methods

The objective of this study was to produce a snapshot of PM_{10} concentrations across Balclutha, in order to augment the point measurements being taken in the town by the continuous monitor. Measurements were taken on four nights during hours of peak emissions. These short-term, real-time measurements do not necessarily equate to an average ambient condition because of the influential effects of changing weather conditions. Ideally, a comprehensive network of permanent, continuous monitors throughout the town would provide the best information on ambient air quality across a large area. However, since such an operation is cost-prohibitive, a small-scale mobile monitoring programme such as this can provide an idea of where, potentially, the highest PM_{10} values might be found, and what the spatial distribution of particulates might be on an average winter's evening.

A brief overview of the methods used to collect and process the data provides a framework for understanding the results of the sampling work.

4.1 Data Collection

A route of 27 sites was established to include Balclutha's central, flat area, and the two hill suburbs, north-east and south-west of the centre of the town (Figure 10). On each of the four evenings chosen to sample, PM_{10} measurements were taken, following the route first forwards and then backwards. This was done to make the evening's sampling results more robust and to eliminate some of the fluctuations in emissions due to the change in time.

The sites, shown below, were located in a variety of land-use areas, including residential, industrial and commercial. Further detail on the sites can be found in Appendix 1.

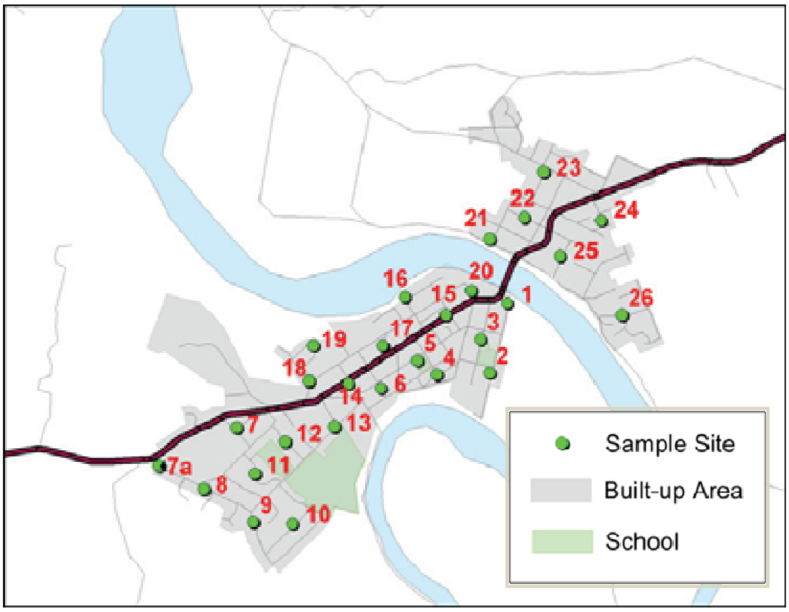

Figure 10: **Location of sampling sites. The continuous monitor is located at Site 5 in the centre of town. Site 7a, located at the far western end of Balclutha, was added from the second night as a boundary site**

The four sample nights occurred during winter 2010. On all four nights, MetService predicted clear skies, lights winds and mostly stable high-pressure systems. (Refer to Appendix 2 for the situation maps for the sampling days). These synoptic conditions are usually related to elevated levels of wintertime PM_{10}. They often lead to the formation of temperature inversions that serve to trap particulates near the surface. Sampling took place between 4-8pm, hours when peak emissions were expected.

A real-time optical PM_{10} sensor unit, the DustTrak 8532, was mounted on a vehicle with the intake on the roof at approximately 1.5m above the ground. The vehicle was driven to each site, the engine turned off and the sampler started.

Samples were taken continuously with measurements logged at two-second intervals for approximately 30-40 seconds (once the measurement had stabilised), providing about 15-20 readings for each of the 27 sites. Additional visual observations such as wind speed and direction were noted at each site, as was any other relevant information. After an evening's two runs were completed (forward run traversing sites 1-27, backward run from sites 27-1), the data were uploaded, quality assured and then processed.

4.2 Data processing

The data were graphed and examined for stability. For residential sites, any outliers related directly to car exhaust from a passing vehicle were eliminated. Once the dataset was finalised, a calibration procedure was undertaken.

To make direct comparisons to the continuous BAM monitor's readings, the DustTrak values must be adjusted. For two weeks during the early part of winter 2010, the two monitors were run alongside each other, taking hourly samples, in order to develop a correlation between the two instruments. Using these results, calibration factors were developed to define the relationship between the two instruments' values, and the DustTrak values were adjusted accordingly. Further information on why this procedure is necessary and the details of the data adjustment can be found in Appendix 3.

Once adjusted, the values for the two runs were then averaged, resulting in one PM_{10} value per site, per night. To provide a generalised picture of the ambient air quality condition on a typical winter's night, an overall average was generated, encompassing all four nights' data.

Results for the individual nights and the overall average condition are presented in the next section.

5 Results

To understand the distribution of PM_{10} emissions in different areas of Balclutha, sampling of the concentrations during times of peak emissions was undertaken. Four evenings were chosen for sampling during winter 2010: 16 June, 24 June, 7 July and 24 August. Each night exhibited its own specific PM_{10} characteristics, but, taken together, they provide a representative view of PM_{10} concentrations during early evening in Balclutha. In the following sections, each evening's results are presented, along with the average of the four nights.

5.1 Results from individual nights

5.1.1 Night 1: 16 June 2010 (4-8pm)

Following several days of pronounced southerlies, which served to flush out any particulates, the first night of sampling was relatively calm, as a ridge of high pressure had moved over the South Island.

From about 4pm onward, chimney smoke was visible at numerous houses in the town. Smoke drifted south-east due to a light, but steady north-west breeze. There was no large smoke cloud visible over Balclutha, as is often the case in Central Otago towns during the early evening. The sun was still hitting the ground through most areas of town until nearly 5pm, providing for vertical convection in the atmosphere during peak emission hours.

The highest values were recorded in the north-eastern hill suburbs, where the smell of coal smoke was strong (Figure 11). PM_{10} levels were also elevated in the south-western suburbs. Levels were relatively low in the centre of town, although emissions tended to accumulate towards eastern areas, due to the north-west breeze.

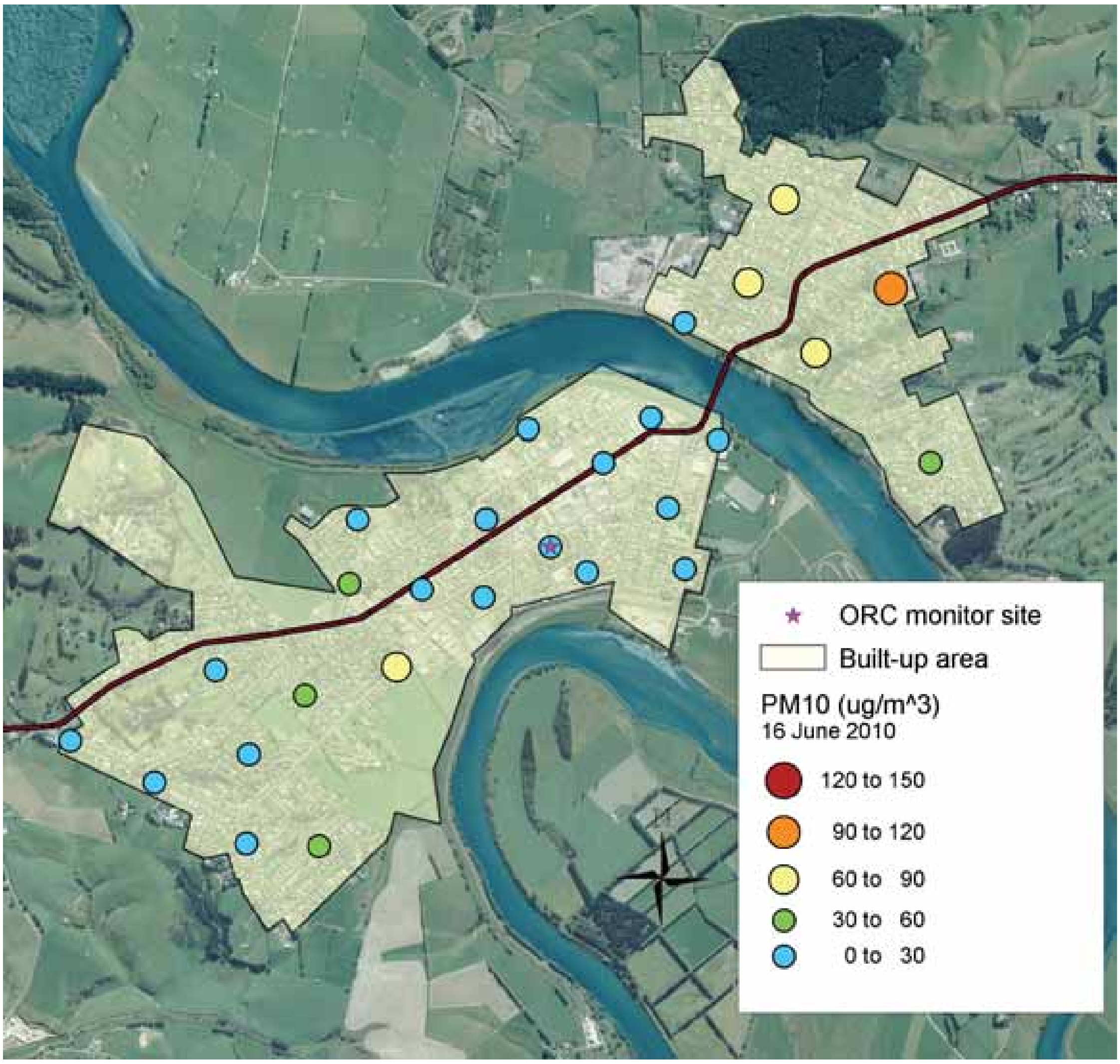

Figure 11: Concentrations of PM_{10} on 16 June 2010 from 4-8pm (Night 1)

5.1.2 Night 2: 24 June 2010 (4-8pm)

Similar synoptic conditions were present during the second night of sampling (i.e. clear, relatively calm, with a ridge of high pressure over the South Island). On this night, though, the breeze was from the south-east, basically upriver. There was a high altitude haze over the town, perhaps due to the plume from the plant at Finnegand which was tending towards town. The ground-level PM_{10} samples taken on the eastern side of town, however, did not seem to reflect any influence from the plant.

There was still a fair amount of convection during the early evening, due to the sun hitting and warming the surface during burner start-up times. This prevented accumulation of particulates near the surface. Averages do show, however, that due to the south-east breeze, particulates accumulated at the north-western side of town. PM_{10} values were generally higher this night than the previous evening (Figure 12).

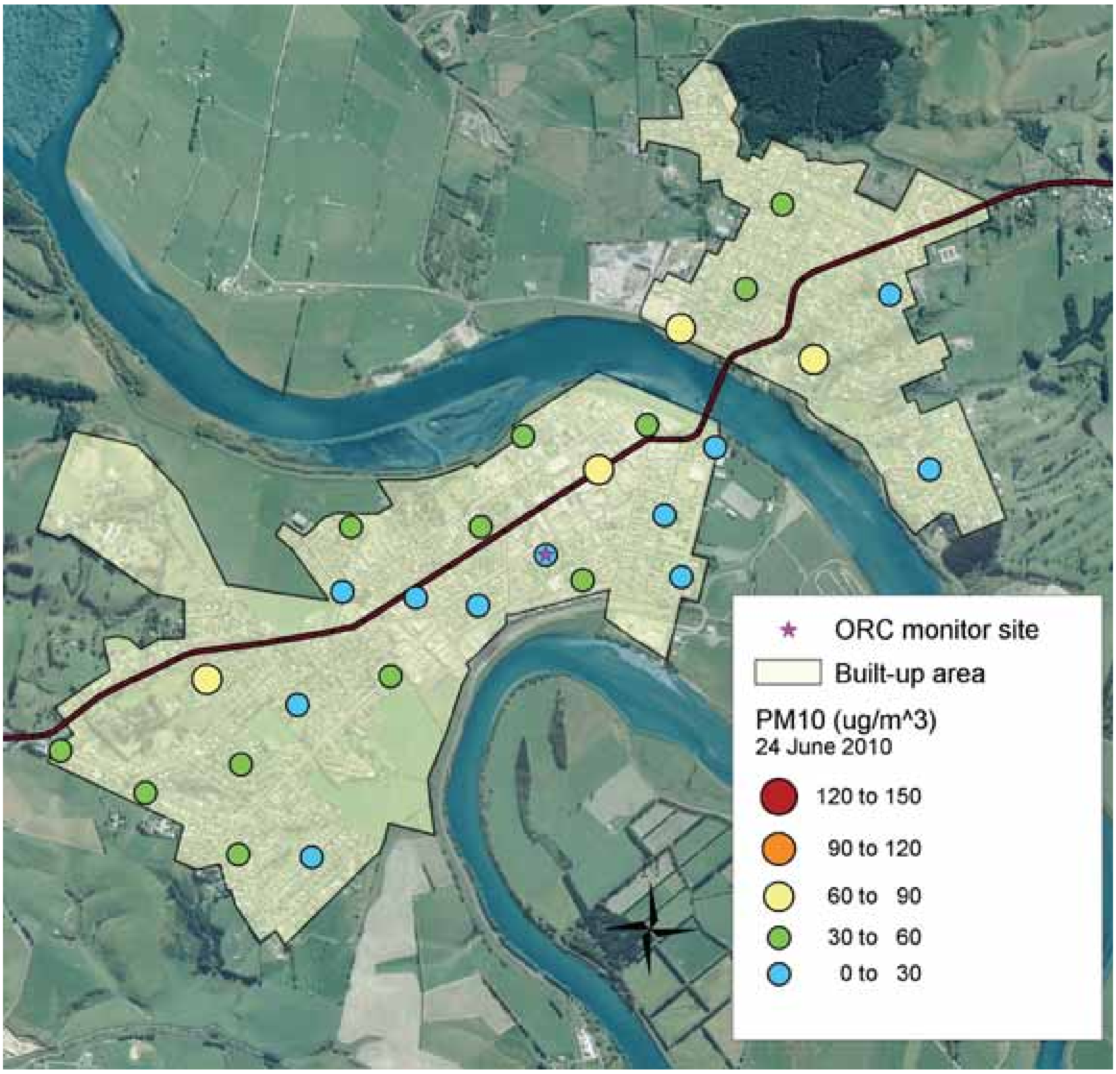

Figure 12: Concentrations of PM_{10} for 24 June 2010, 4-8pm (Night 2)

5.1.3 Night 3: 7 July 2010 (4-8pm)

During the third night of sampling, a gentle west-northwest breeze was present, which appeared to push particulates to the south-east (Figure 13). This localised effect was particularly evident in the south-west hill suburbs, where site 7A (at the western edge of the map (blue dot) had the lowest concentrations, and the eastern areas had the highest.

Certain 'hotspots'[4] appeared, illustrating the potential for high emissions through various sectors of town. Again, it was the north-eastern and south-western suburbs that produced the highest results on this night. A strong smell of coal smoke was evident throughout most of town.

PM_{10} levels on this evening were comparable overall to those taken on the previous sampling night.

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[4] A "hotspot" is a location with a temporarily high reading. Averaging results from two runs on a night smooths out some of this artificial effect.

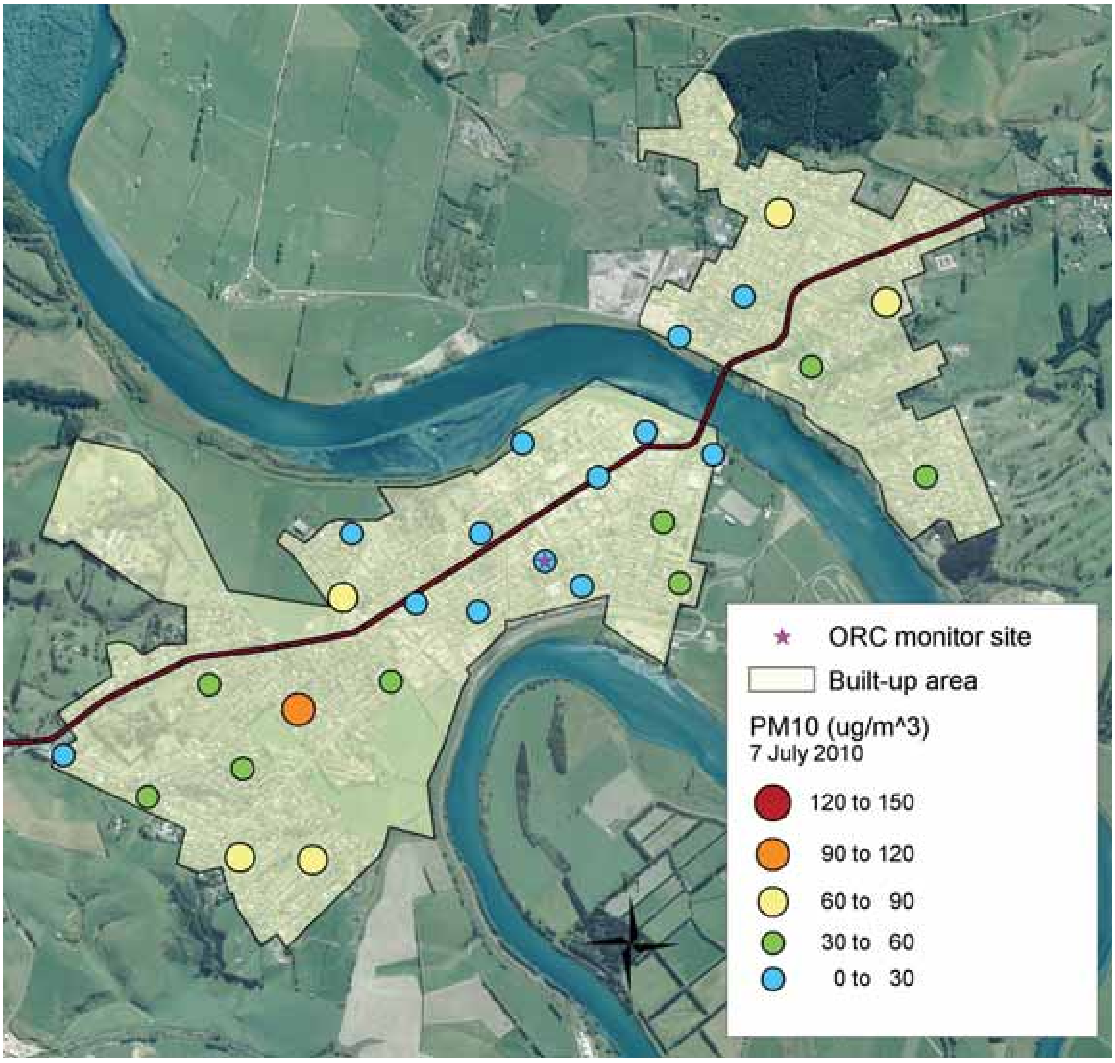

Figure 13: **Concentrations of PM_{10} on July 7, 2010 from 4-8pm**

5.1.4 Night 4: 24 August 2010 (4-8pm)

A steady, light north-east breeze was evident early in the evening, and the sky was clear on this fourth night of sampling. By the end of winter, the sun remains on the valley floor until about 5.30, providing ample convection for most emissions.

PM_{10} levels were low to moderate, except for one obvious hotspot in the north-east sector (Figure 14). Visual observations noted that one chimney provided most of the particulates for the readings at this particular site on the forward run. The hotspot stands out in red.

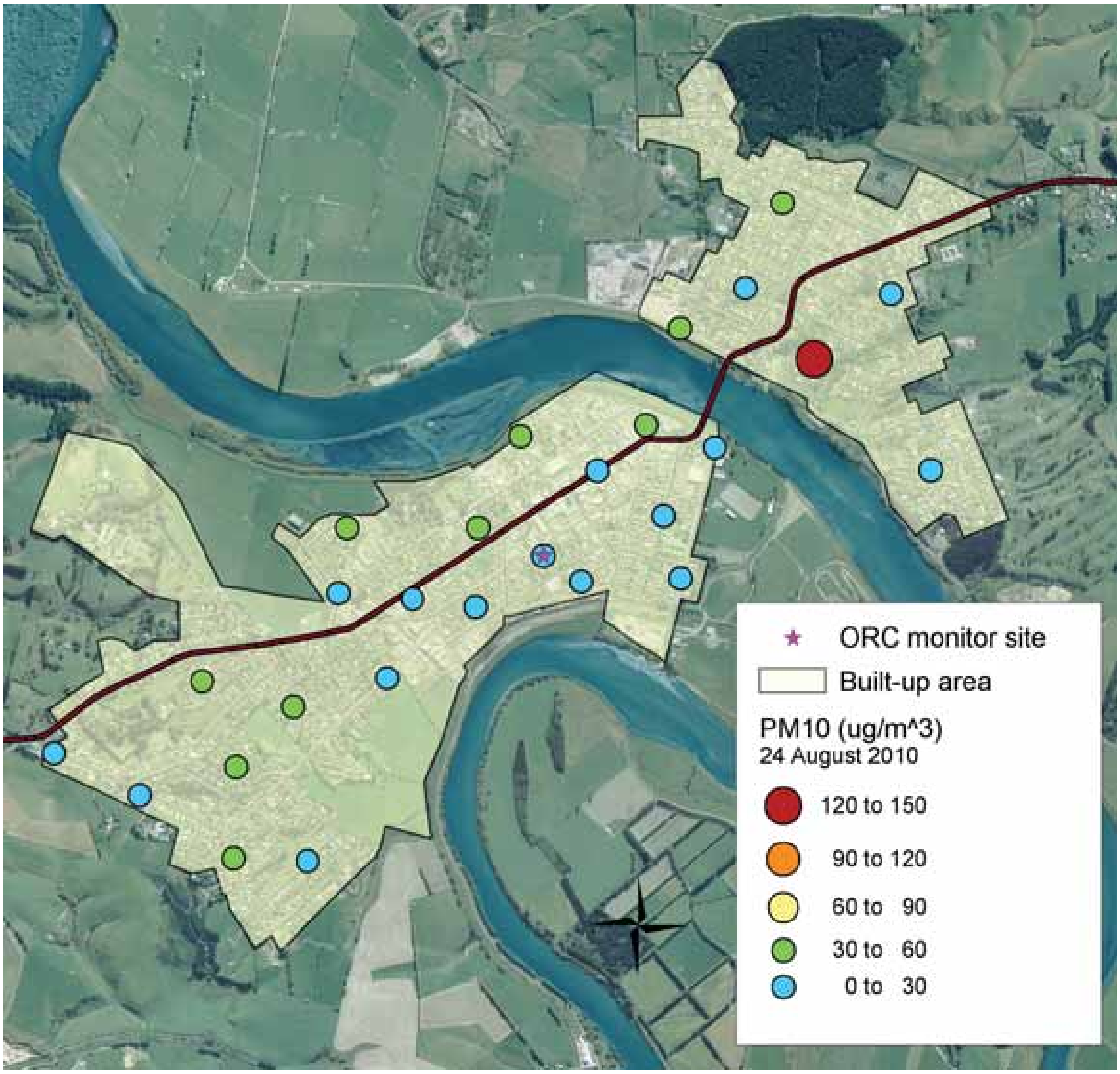

Figure 14: Concentrations of PM_{10} on 24 August 2010 from 4-8pm

5.2 Overall average PM_{10}

When results of the four nights are averaged, a pattern begins to emerge showing the relative levels of PM_{10} throughout Balclutha. The highest values are found in the north-eastern hill suburbs, where densely located coal burners are the main source of emissions. The south-western hill suburbs also experience elevated levels of PM_{10} during the early evening; this area is similarly residential. Some of the lower values are found on the flat, central area of Balclutha. The lowest values were found along the outer edges of town and in the industrial quarters during non-working hours.

Figure 15 gives a good indication of general PM_{10} concentrations over the time-period sampled (4-8pm).

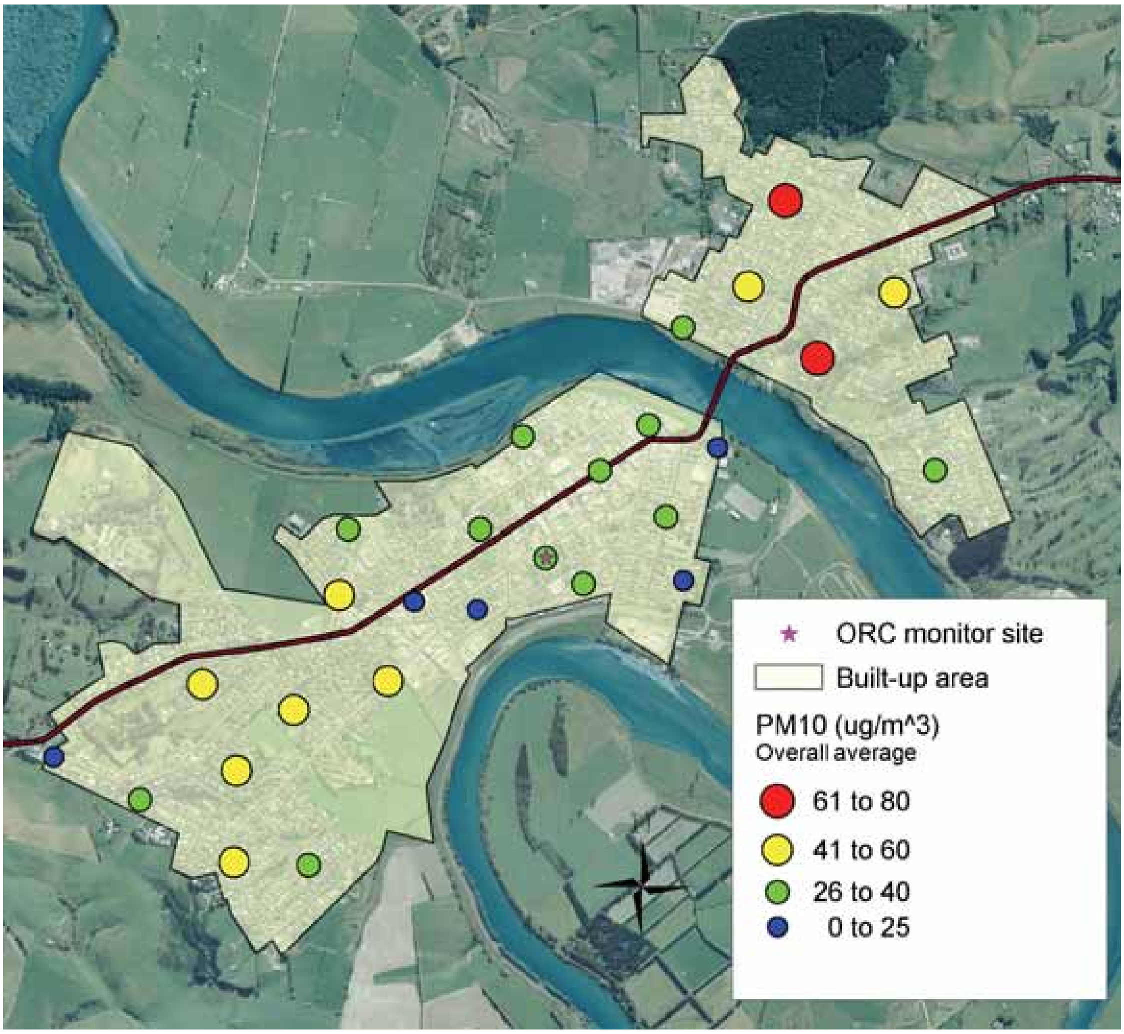

Figure 15: **Overall average PM_{10} concentrations over four nights (8 runs) during winter 2010**

The graph in Figure 16 shows that highest overall values (60 to 80µg/m^3) are found at a few sites in the north-eastern suburbs, with most of the south-western suburbs consistently averaging about 40µg/m^3. The sites are colour-coded according to which area of town they represent: green bars are those sites in the flat, central area of Balclutha, yellow bars are sites located in the south-western hill suburbs, and red bars are sites located in the north-east hill suburbs across the river.

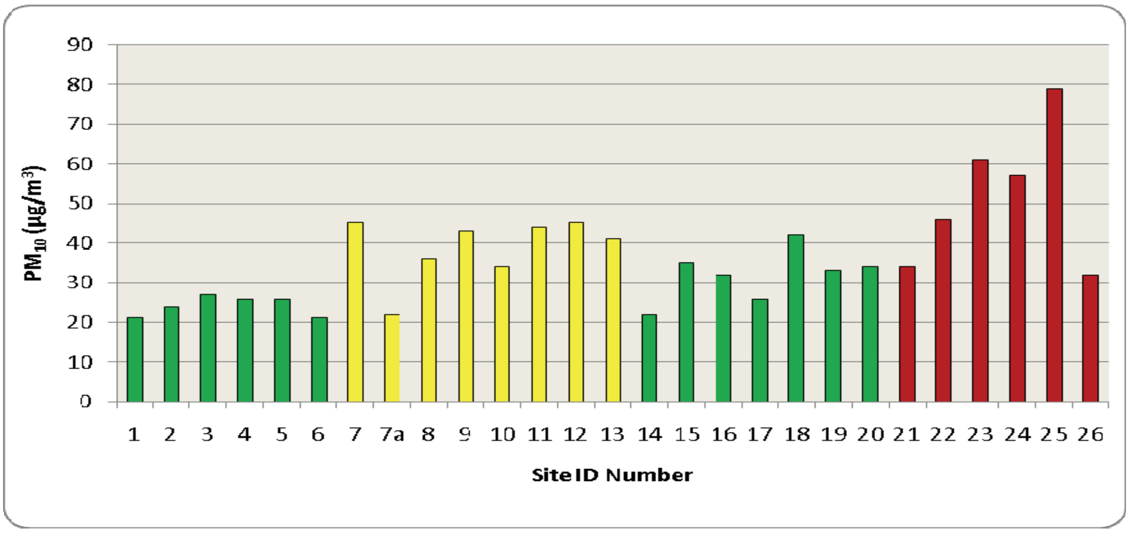

Figure 16: Overall average PM_{10} values for each site. Site ID numbers are shown across the bottom and the colour of the bar represents the area of Balclutha in which the sites are located (green = central, yellow = southwest, red = northeast)

6 Discussion

6.1 Spatial patterns of PM_{10} in Balclutha

The results of sampling with a mobile real-time monitor indicate that PM_{10} concentrations can vary by a factor of ten in Balclutha on a typical winter's evening. This result is similar to that found in spatial monitoring studies in both Dunedin (NIWA, 2009) and Mosgiel (ORC, 2009).

On average, the highest concentrations are recorded in areas of town with the densest use of coal burners; these areas include the north-eastern and south-western hill suburbs. Results presented in this report show the average of two runs taken per night, which tends to smooth out the evening's PM_{10} activity. A closer examination of the individual sampling reveals that readings taken at the same site, approximately an hour apart, can be quite different. For example, at Site #23 on 16 June, the first pass recorded $110\mu g/m^3$, and the level recorded 45 minutes later on the second pass was $34\mu g/m^3$. This shows that 'ambient' air quality is a dynamic situation, constantly adjusting to atmospheric conditions and that only through repeated measurements can a true average scenario be approached.

The results of this study, based on eight individual runs over four nights, do present a consistent pattern of PM_{10} distribution. It is unknown at this time, however, whether the higher levels in the hill suburbs persist throughout the night.

6.2 Effect of climate and topography on PM_{10}

Sampling for this spatial study was undertaken on nights when synoptic conditions were predicted to include clear skies, cold night-time temperatures and calm winds. These conditions were chosen because they typically lead to poor winter air quality in towns where residents rely on solid fuel burning for domestic heat. However, on the sampled days, the average daily PM_{10} values ranged from 16 to $25\mu g/m^3$. This seems to indicate that either this relationship does not hold in Balclutha and/or that the town has a microclimate that does not conform to the predicted larger-scale synoptic conditions.

Looking at the continuous BAM data for the 15 days when the daily average PM_{10} was greater than $35\mu g/m^3$ yields some insights. Of those 15 days, 11 occurred in winter (June-August), one in summer and three in autumn. Of the 11 wintertime days, ten exhibited typical home heating patterns of PM_{10} levels, and one had higher levels during the daytime hours. The one summer day and one of the autumn days also had high daytime levels. High daytime levels may come from nearby industry when winds are favourable or from solid fuel burners. According to MfE's Warm Homes Technical Report, Balclutha is one of the only towns where coal burners are used throughout the year, not just on colder winter days. This burning behaviour will confound the expected patterns of PM_{10} levels.

Furthermore, on those days with elevated PM_{10} readings, winds were mostly from the south and south-west, possibly pushing particulates over the monitor from densely populated suburbs. The high emissions in the north-eastern hill suburbs do not appear to cross the river and influence the monitor.

Balclutha’s climate is also different from other towns in Otago, and this may account for some of the variation from the normal pattern seen. Based on observations made on several days and evenings (including the sampling nights), even when a ridge of high pressure may be present, Balclutha does not exhibit calm conditions often. The wide and constantly-moving Clutha River/Mata-Au will be causing steady air movement to flow through the town. Furthermore, Balclutha is far enough south to be affected by fronts that flick the South Island, bringing cloudy and breezy weather. With its maritime climate, overnight temperatures are moderated, rarely going down below freezing, a critical point in the creation of temperature inversions.

All these conditions make it very difficult to predict PM_{10} levels in Balclutha because they lead to a very dynamic atmospheric situation.

6.3 Implications of using the current monitoring site for NESAQ

The overall map (Figure 16) indicates a typical air quality scenario during the early evening in winter under certain synoptic conditions. What this map does not provide is information on whether the conditions found in the two hill suburbs persist throughout the night and into the next morning.

The results do support the measurements made at the continuous monitoring site which, at the time of this study, is located at St Joseph’s School. This monitor is well placed to represent the conditions along the flat in Balclutha.

7 Conclusions

This study illustrates the usefulness of using a mobile monitoring programme in developing a picture of PM$_{10}$ emissions in a town. Each town, or airshed, will have its own, unique PM$_{10}$ 'signature' which is only nominally represented by a single monitor.

Results of this spatial PM$_{10}$ study indicate several key features regarding air quality in Balclutha:

1. The Balclutha airshed can be thought of as having three distinct sub-airsheds: the flat, central part of town, the north-eastern hill suburbs and the south-western hill suburbs as they all have different emission regimes. Both hill suburbs appear to have higher emissions than the centre of town.

2. Even within these sub-airsheds, PM$_{10}$ concentrations may vary considerably from street to street.

3. The prevailing wind speeds and directions influence PM$_{10}$ concentrations at any given time.

4. Balclutha seems to have greater ventilation than other towns in Otago, as it has steady breezes through the early evening that reduce the build-up of emissions. There is also vertical movement of the atmosphere relatively late in the day during winter as the sun continues to warm the valley floor until 5pm on sunny days.

5. The continuous monitor located in downtown Balclutha, at St. Joseph's School, is representative of the flat, central area of town where ambient PM$_{10}$ levels are generally low to moderate.

6. There does not appear to be an accumulation of emissions over 3-4 day periods, as is often found in Central Otago towns. There is generally a flushing of particulates on a daily basis, due to the town's climate and topography.

7. To verify whether the high PM$_{10}$ values sampled during peak emissions persist throughout the night, measurements need to be taken in a hill suburb.

8 References

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Appendix 1

Table 4: Locations and descriptions of sampling sites

Site ID	Area*	Location	Land Use**	Average PM_{10}***
1	C	Glasgow St at the squash club	C	21
2	C	Glasgow St at Drumclog St	R	24
3	C	Lanark St between Paisley St and Drumclog St	R	27
4	C	Douglas St at Gordon St	R	26
5	C	James St at St. Joseph's School Carpark	R, C, I	26
6	C	Barr St between James St and Stewart St	R	21
7	SW	Oxford St at Ross St	R	45
7a	SW	Wilson Rd at Clyde St	C	22
8	SW	Wilson Rd at Lewin St	R	36
9	SW	Wilson Rd at Francis St	R	43
10	SW	Christie St between Wilson Rd and Armstrong St	R	34
11	SW	Malcolm Tce between Lewin St and Francis St	R	44
12	SW	Naish St between Lewin St and Francis St	R	45
13	SW	Francis St at Ann St	R, C, I	41
14	C	High St at Clyde St	C, I	22
15	C	Clyde St at Elizabeth St	C	35
16	C	Crown St at George St	R, C, I	32
17	C	Caldervan St between Clyde St and Charlotte St	R	26
18	C	Charlotte St at Centennial Ave	R	42
19	C	Crossleigh Crescent—midway	R	33
20	C	Charles St at iSite location	C	34
21	NE	Pakefield St at Barnego Rd	R, I	34
22	NE	Lowestoft St between Pakefield and Cromer Sts	R	46
23	NE	Springfield St at Gormack St	R	61
24	NE	Smith St at Athol St	R	57
25	NE	Newarp St between Lowestoft St & Hasborough Pl.	R	79
26	NE	Ipswich St at St Andrew Pl.	R	32

* General locations of sites: C = central, SW = south-west, NE = north-east

** Surrounding land use at each site: R = residential, C = commercial, I = industrial

*** PM_{10} levels are colour coded as either green (<35μg/m^3), yellow (between 35-50μg/m^3) or red (>50μg/m^3).

Appendix 2

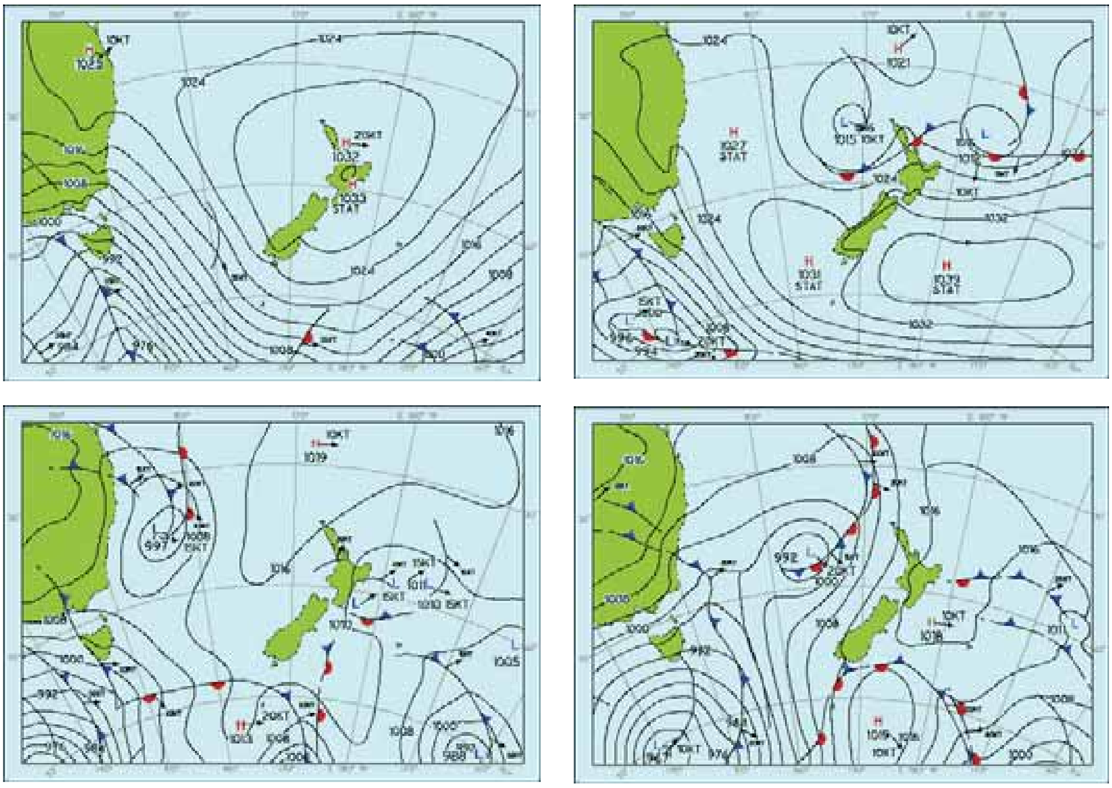

Figure 17: MetService situation maps for sampling nights (from upper left going clockwise: 16 June, 24 June, 7 July and 24 August 2010)

Appendix 3

Calibration procedure

The DustTrak and BAM monitors calculate PM_{10} concentrations using two different technologies, although both report in micrograms per cubic metre of air. The BAM pumps in air, depositing any PM_{10} on a filter tape. It then measures the difference in the number of electrons that can pass through a clean filter with the number that can pass through an 'exposed' filter; that difference, or attenuation, is then translated into a mass. The DustTrak also pumps in air, but circulates it in a chamber where a light is reflected off any PM_{10}; the amount of reflectance is then translated into a mass. The reflectance depends, to some degree, on particle size. To be able to make direct comparisons between the two monitors, a calibration equation must be developed for the DustTrak results. This is done by running the samplers together for several days, evaluating the relationship between the two resultant datasets and developing a coefficient or equation to apply to the DustTrak values.

Co-location of the samplers took place from 19 May to 2 June 2010. The DustTrak was configured to record 10-minute averages, from which 50-minute averages (to match the BAM sampling regime) and 24-hour daily values were generated. A scatter plot (Figure 17) comparing the daily average PM_{10} between the two instruments reveals a good relationship between the two, with the DustTrak tending to overestimate by a factor of approximately two at higher values. (Note that all units are $\mu g/m^3$.)

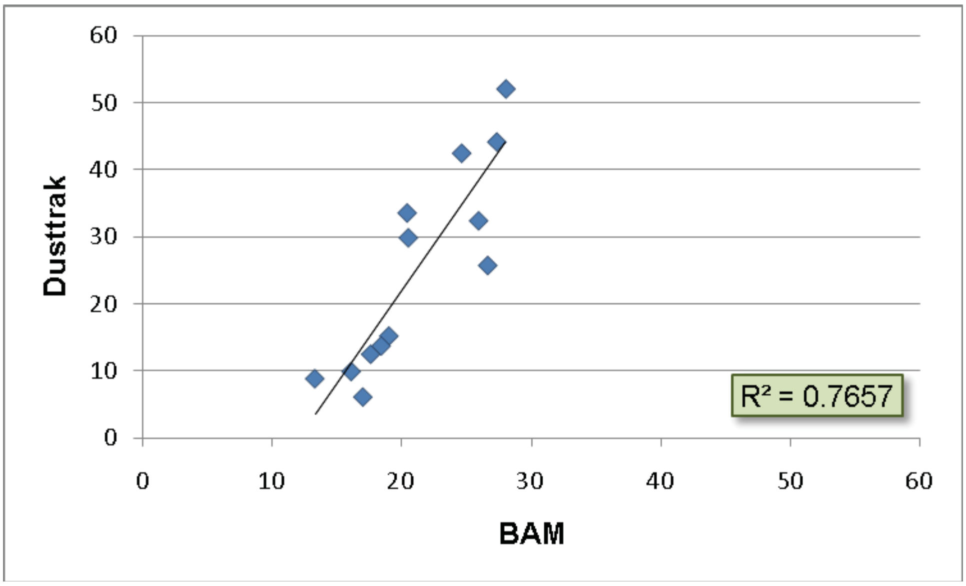

Figure 17: **Scatter plot of average daily PM_{10} values comparing the DustTrak and the BAM during the period 19 May to 2 June 2010**

This is similar to other New Zealand studies, where particulate properties have caused the DustTrak to overestimate by a factor of about two (Reese, 2008) to five (Conway et al., 2007). Plotting all of the hourly pairs in the graph below (Figure 18) reveals a more complex relationship, perhaps due to the reliance on the use of coal in Balclutha, which has a higher usage rate than any other New Zealand town.

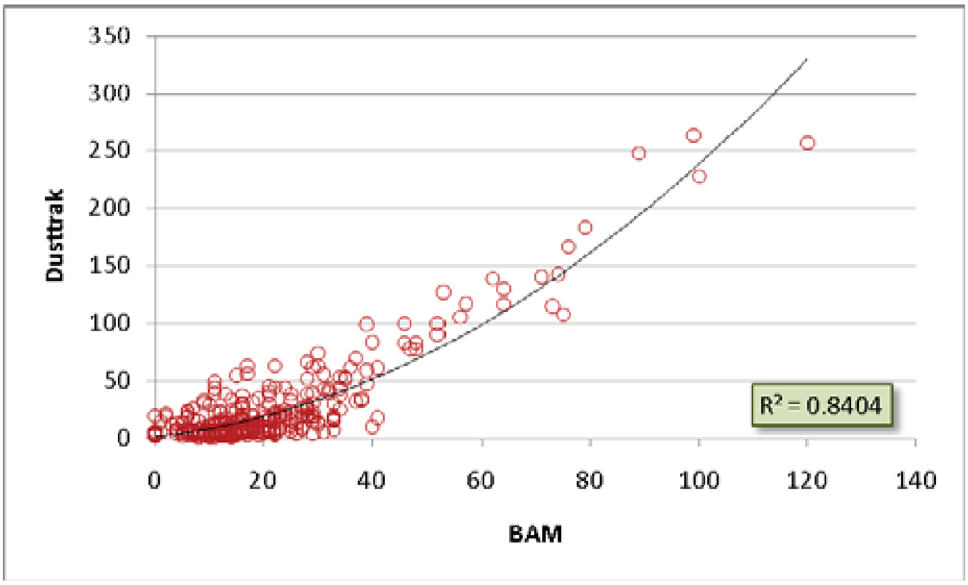

Figure 18: Scatter plot of all pairs of DustTrak and BAM hourly data

A second-order polynomial has the best fit, indicating that the relationship is not strictly linear. There is a great deal of variability in the area where DustTrak values are less than 40µg/m^3, as the R^2 value of 0.1633 in Figure indicates.

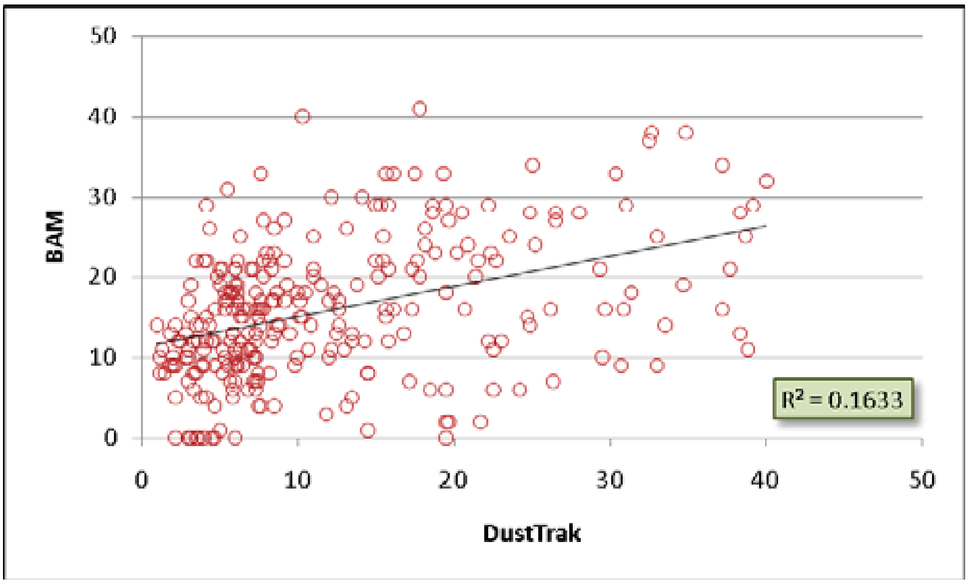

Figure 20: Scatter plot of all hourly values when the DustTrak results are less than 40µg/m^3

Above the 40µg/m^3 threshold, though, the relationship improves significantly, with an R^2 value of 0.8601 (Figure 21).

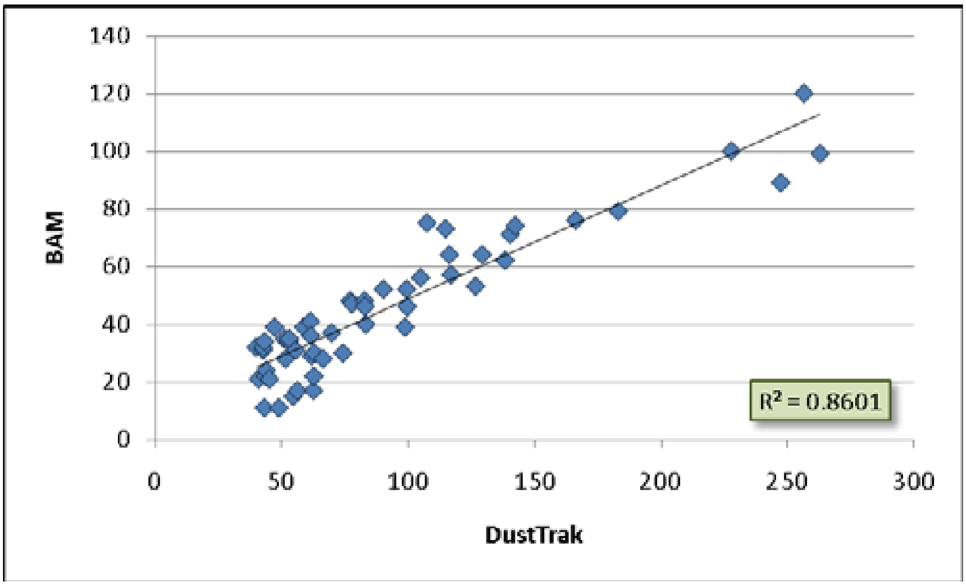

Figure 21: **Scatter plot of hourly values for pairs when the DustTrak results are greater than 40µg/m^3**

These higher values are of more concern in terms of the NES and for general public health. As such, we decided to apply two separate linear calibration equations to the DustTrak data, as shown in Table 5.

Table 5: **Calibration equations applied to the DustTrak data to obtain BAM-equivalent PM_{10} concentrations**

	For values < 40µg/m^3	For values >=40µg/m^3
DustTrak hourly PM_{10} (x)	$y = 0.3735x + 11.389$	$y = 0.3941x + 9.2653$

Appendix 4

For each night, values are shown for the average value (A), the forward (F) and the backward (B) run values. PM_{10} values are colour-coded as green (<35), yellow (35-50) and red (>50). The geographic locations of the sites are colour-coded as central Balclutha (green), south-west (yellow) and north-east (red).

Table 6: PM_{10} results for all sampling runs

	16 June			24 June			7 July			24 August		
SITE	A	F	B	A	F	B	A	F	B	A	F	B
1	16	16	15	26	30	22	14	14	14	29	13	45
2	22	23	20	23	20	25	34	31	37	16	15	17
3	29	40	18	16	15	16	35	22	48	27	17	36
4	18	20	15	41	51	31	20	16	23	24	30	17
5	25	25	25	27	37	17	24	26	21	26	21	31
6	17	20	14	24	21	26	19	18	20	22	21	23
7	26	28	23	76	93	58	46	63	29	33	33	33
7a	n/a	n/a	n/a	43	51	35	17	19	14	26	28	24
8	26	26	25	49	66	31	39	26	51	28	31	25
9	24	27	20	37	45	29	69	21	116	42	51	33
10	31	31	30	21	22	20	67	71	63	18	15	21
11	27	25	28	51	55	47	57	49	64	39	42	36
12	33	33	32	20	18	21	91	143	38	35	26	44
13	72	69	75	30	14	45	39	41	37	21	18	23
14	20	18	22	21	21	21	18	20	16	28	33	22
15	15	17	13	81	35	126	18	19	16	27	28	26
16	13	12	13	57	80	33	15	15	15	41	28	54
17	22	28	16	32	30	33	18	16	20	33	22	44
18	30	23	37	29	27	31	81	35	126	29	16	42
19	22	12	32	51	29	73	16	14	18	42	40	43
20	22	16	27	54	73	34	14	13	15	46	45	47
21	15	14	15	60	57	62	17	17	17	43	45	40
22	72	110	34	56	69	42	27	32	22	29	33	25
23	83	92	73	46	36	55	60	75	44	54	85	23
24	10	101	114	16	16	15	89	107	71	15	12	18
25	69	48	90	60	73	47	44	57	31	142	268	16
26	32	31	32	23	26	20	45	47	43	21	21	21