Assessing long-term trends in PM_{10} concentrations in Blenheim

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Executive Summary

The objectives of this study are to identify meteorological conditions in Blenheim that are likely to lead to high pollution events, assess the long term trend in PM_{10} air quality monitoring data for Blenheim and produce a tool (excel spreadsheet) that will allow MDC staff to assess trends in PM_{10} concentrations while taking account of the impact of variable meteorology. While the method developed here is generally applicable to any location the tool developed for Blenheim in this project is location specific.

This information can be used in evaluating compliance with the Straight Line Path (SLiP) and in evaluating progress towards National Environmental Standard (NES) for PM_{10}.

The years considered for this study run from 2005 to 2009. A total of 495 days of PM_{10} monitoring data was analysed for the months May to August over this five year period. The data shows no obvious trends in either the annual average PM_{10} concentrations or median concentration per year prior to the evaluation of the impact of meteorology.

A boosted regression tree (BRT) model was used to determine the meteorological variables that best identify high pollution events in Blenheim. Using the meteorological variables selected by BRT analysis, normal regression tree analysis was used to group the PM_{10} values according to meteorological conditions. The groups of days with the highest air pollution potential were then subjected to a trend analysis. The trend analysis of 24-hour average PM_{10} concentrations is inconclusive with respect to changes from 2005 to 2009.

A method has been developed to normalise (adjust up or down) PM_{10} data recorded in future years based on the meteorological conditions which resulted in high pollution events from 2005 to 2009. The PM_{10} normalising process will allow the evaluation of the trends in PM_{10} data recorded in 2010 (and beyond) without having to repeat the BRT modelling exercise. A spreadsheet tool has been developed to allow MDC staff to undertake evaluation of trends in PM_{10} data monitored from 2010 onward.

The greatest number of days when PM_{10} concentrations exceeded 50 $\mu g\ m^{-3}$ occurred when the 24-hour average temperature was less than 7 degrees Celsius (ºC), the average wind speed between 5pm and midnight was less than 1.5 ms^{-1}, and the difference between the maximum temperature on the sample day and the minimum temperature the following day was greater than 9.95 ºC. Two other high pollution nodes were also identified. One of these included days which met the same wind speed and 24-hour average temperature requirement but which showed a temperature difference of less than 2.6 degrees. The third high pollution category occurred under the same wind speed criteria but an average temperature (24-hour) of between 7 and 9.4 degrees and a wind direction of between 313 and 347 degrees.

Over the study period 113 days met these three criteria and the average PM_{10} concentration on these days was 38 $\mu g\ m^{-3}$.

1. Introduction

In Blenheim concentrations of PM_{10} breach the National Environmental Standards (NES) for PM_{10} of 50 µgm^{-3} on several occasions on most years during the winter months. The PM_{10} standard, which allows for one breach per year, must be met by 2013 or Councils are unable to grant resource consents for discharges to air in the airshed. In the interim concentrations are required to meet a straight line path (SLiP) to compliance with the NES by 2013 or resource consents for significant PM_{10} discharges are unable to be granted[1].

Marlborough District Council is currently considering policy options to reduce concentrations of PM_{10} in Blenheim. These include a ban on outdoor burning, a prohibition on the use of open fires, phase out of old woodburners and a prohibition on new multi fuel burners from being installed.

Based on a starting point for the SLiP of 62 µg m^{-3}, the reduction required in PM_{10} concentrations in Blenheim is 25% (Wilton, 2009). The starting point was revised in 2009 and is based on PM_{10} concentrations measured during 2007. Ongoing monitoring of PM_{10} concentrations is necessary to track compliance with the straight line path and to assess the impact of management measures adopted by the Council.

Since the introduction of the NES for PM_{10}, management of emissions in Blenheim has been minimal as the Council has been investing resources in establishing the causes and evaluating the most effective options for management. Notwithstanding this, PM_{10} emissions are likely to have reduced slightly as a result of households replacing older burners with lower emission NES compliant burners at the end of their useful life and as a result of the consenting process for industrial emissions (Wilton, 2009).

Tracking PM_{10} emissions and PM_{10} concentrations are two methods of assessing trends in PM_{10} with time and evaluating compliance with the SLiP. Methods for tracking changes in PM_{10} emissions include conducting air emission inventories and using building consents data to evaluate changes in home heating methods with time. Methods used for tracking trends in PM_{10} concentrations include identification of meteorological conditions most conducive to elevated concentrations and then tracking concentrations of PM_{10} within these groups (Bluett, et. al., 2009).

The objectives of this study are to:

- identify the meteorological conditions in Blenheim that are likely to lead to high pollution events,

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[1] Or may be granted if the new discharge is offset by reductions in other sources.

- assess the long term trend in PM_{10} air quality monitoring data for Blenheim, and
- produce a tool (excel spreadsheet) that will allow MDC staff to assess trends in PM_{10} concentrations while taking account of the impact of variable meteorology.

2. Method

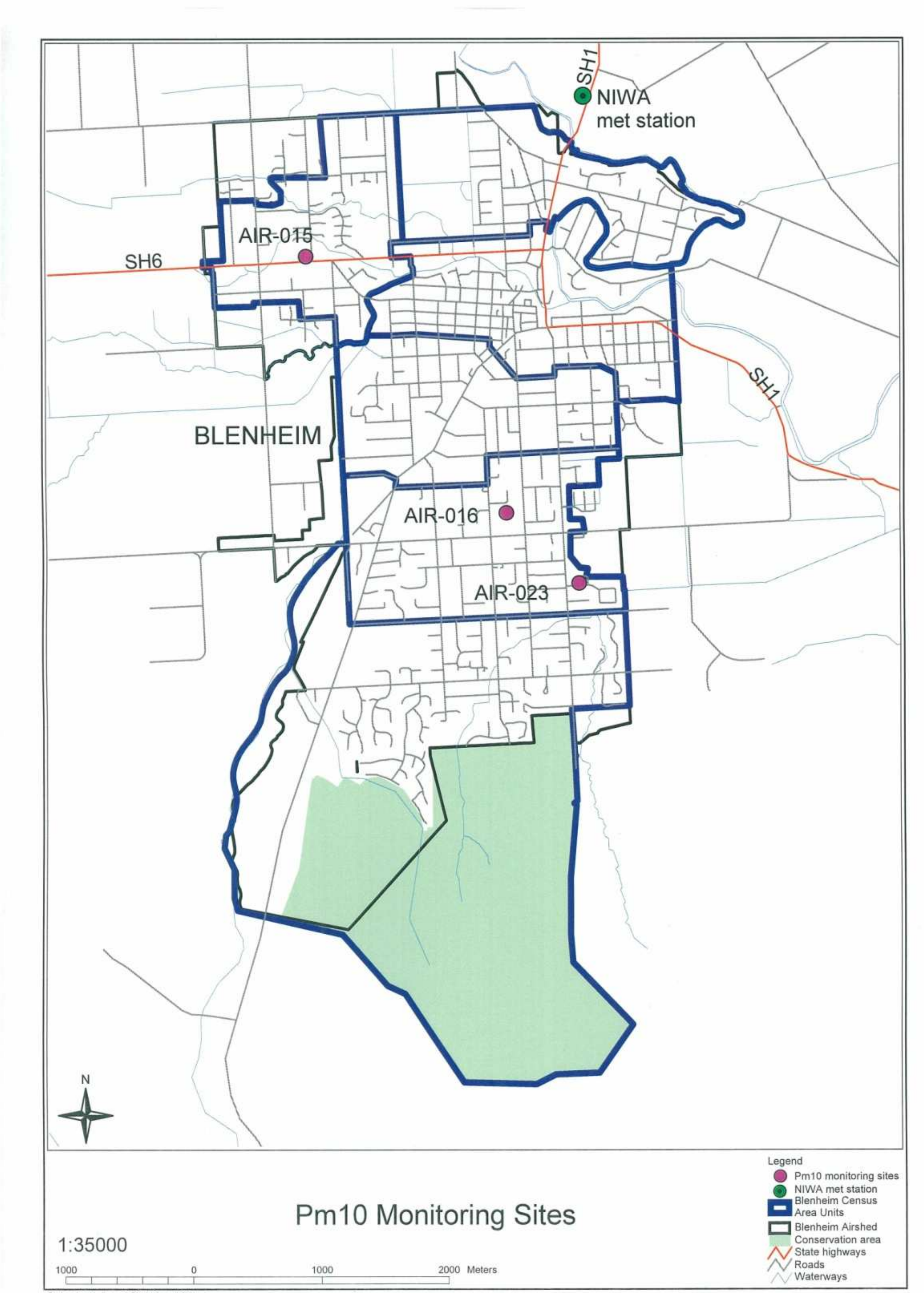
2.1. Monitoring data

Monitoring of PM_{10} in Blenheim commenced in 2000 with gravimetric sampling using a high volume sampler at a monitoring site in Middle Renwick Road (MRR). The sample frequency was one day in six during the summer months and one day in three during the winter. In 2002 a second monitoring site was established in Redwoodtown and was found to measure higher PM_{10} concentrations than MRR. From 2002 to 2005, the monitoring method at Redwoodtown was a high volume gravimetric sampler with a sample frequency similar to MRR. From 24 June 2006 the monitoring method used at the Redwoodtown site was a Met One beta attenuation monitor (BAM). For one year the high volume sampler was operated in conjunction with the BAM to evaluate the relationship between the different methods.

MDC does not collect meteorological data at itsr monitoring site. The NIWA climate station is the main source of meteorological monitoring data for Blenheim used in air quality studies. The site is located to the north of Blenheim near State Highway 1. The locations of the air quality monitoring sites and NIWA climate station for Blenheim are shown in Figure 2-1. A photograph of the Redwoodtown site is shown in Figure 2-2.

Although monitoring has been carried out at Redwoodtown since 2002, because of limited sampling days in early years and changes to the monitoring site in 2004, the years considered for this study are 2005 to 2009. Only data collected during the months May to August were included in the trends analysis because this is when highest PM_{10} concentrations are measured. A total of 495 days of PM_{10} monitoring data was collected during the months May to August over this five year period.

The PM_{10} data for 2005 and half of 2006 were based on the gravimetric high volume sampling method. Results of the comparison between the BAM and high volume sampler are detailed in Wilton (2008). An upwards adjustment of BAM concentrations of around 7% is required to allow comparison of PM_{10} concentrations to the gravimetric method. As MDC has not opted to adjust BAM concentrations for consistency with the historical high volume sampling method, gravimetric high



Produced on Marlborough District Council GIS-cmi.
O CorpRef EnvIssues AirQuality EmissionsInventory "pm10-emission-densities-nov05.apr"

Figure 2-1: Location of the Middle Renwick Road (AIR-015) and Redwoodtown (AIR-016) PM_{10} monitoring sites and NIWA meteorological monitoring station in Blenheim

Figure 2-2: **Photograph of the Redwoodtown PM_{10} monitoring site with high volume sampler installed (pre-June 2006).**

volume data used in this analysis have been adjusted downwards to allow a more true representation of any trends in PM_{10} concentrations from 2005 to 2009 whilst keeping data consistent with the future reporting method[2].

2.2. Statistical Analysis

To account for year-to-year variation in meteorology and to analyse the long term trend in PM_{10} concentrations a combination of a boosted regression tree (BRT) analysis and normal regression tree analysis was used. BRT (see below) was used to identify the most important meteorological parameters explaining the variation in PM_{10} values. Normal regression tree analysis (see below) was used to group PM_{10} values measured under similar meteorological conditions together.

BRT analysis (Elith et al. 2008) was used to investigate which meteorological variables best explain the variation in PM_{10} values. BRT analysis is a powerful approach for dealing with non-linearities, interactions and modelling of sparse and noisy data. A BRT model fits a large collection of simple regression tree terms using a boosting algorithm whose predictions are then combined to provide estimates of the response. Each term is fitted in a forward stagewise manner by adding a regression tree that is fitted taking into account the deviance of the preceding trees. BRT is stochastic in nature, with each run differing slightly.

Two important parameters contribute to model performance during boosting: tree complexity and learning rate. The number of nodes in an individual tree was

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[2] Note the authors are not advocating a downwards adjustment of gravimetric data to BAM equivalent for PM_{10} reporting purposes.

controlled by tree complexity. A model with a tree complexity of 1 fits a purely additive model, i.e. without interaction terms. In this study, a tree complexity of 3 resulted in an optimal performance of the BRT analysis. The learning rate reduces the influence of each individual tree, e.g., a small learning rate leads to the fitting of an increased number of trees to find the model that best minimizes the residual deviance. Regularization methods are used to constrain the fitting procedure so that it balances model fit and predictive performance. To determine the optimal number of trees for each model and to assess model performance, cross validated predictive deviances were minimized. Cross validation assesses model performance by comparing model predictions to withheld portions of the data; in this case 12 mutually exclusive subsets randomly selected, give cross validated estimates of model performance in terms of cross validation correlation. The cross validated residual deviance gives a measure of the deviance left unexplained by the model and the cross validated correlation describes the correlation between the fitted values and the raw data withheld for cross validation.

BRT analysis was performed using a Gaussian link function. All BRT models were fitted in R (v2.6.0, www.Rproject.org; (R Development Core Team, 2004) using the ‘gbm’ library (Ridgeway, 2004).

The normal regression tree model is fitted using binary recursive partitioning, whereby the data are successively split along coordinate axes of the explanatory variables so that, at any node, the split which maximally distinguishes the response variable in the left and the right branches is selected. Splitting continues until nodes are pure or the data are too sparse (fewer than six cases in this study). Each explanatory variable is assessed in turn, and the variable explaining the greatest amount of the deviance in y is selected.

3. Trends in PM_{10} concentrations

3.1. Trends in existing dataset

Summary statistics of PM_{10} concentrations measured at the Redwoodtown monitoring site are shown in Figure 3.1. Data illustrated includes the median (middle ranked 24-hour average PM_{10} concentration), 25 and 75 percentile concentrations, the concentrations within which 96% of the data lie (two standard deviations) and extreme values.

The data shows the median 24-hour average PM_{10} concentration has been reasonably consistent over the period 2005 to 2009 at 24 $\mu g\ m^{-3}$. It is important to note, however, that Figure 3-1 does not account for year-to-year variations in meteorology and consequently it is possible that there has been a reduction (or increase) in PM_{10} concentrations that is not apparent in Figure 3-1. The data shows median 24 hour average PM$_{10}$ concentration has been reasonably consistent over the period 2005 to 2009 at 24 µg m^{-3}. It is important to note, however, that Figure 3-1 does not account for year-to-year variations in meteorology and consequently it is possible that there has been a reduction (or increase) in PM$_{1-}$ concentrations that is not apparent in Figure 3-1.

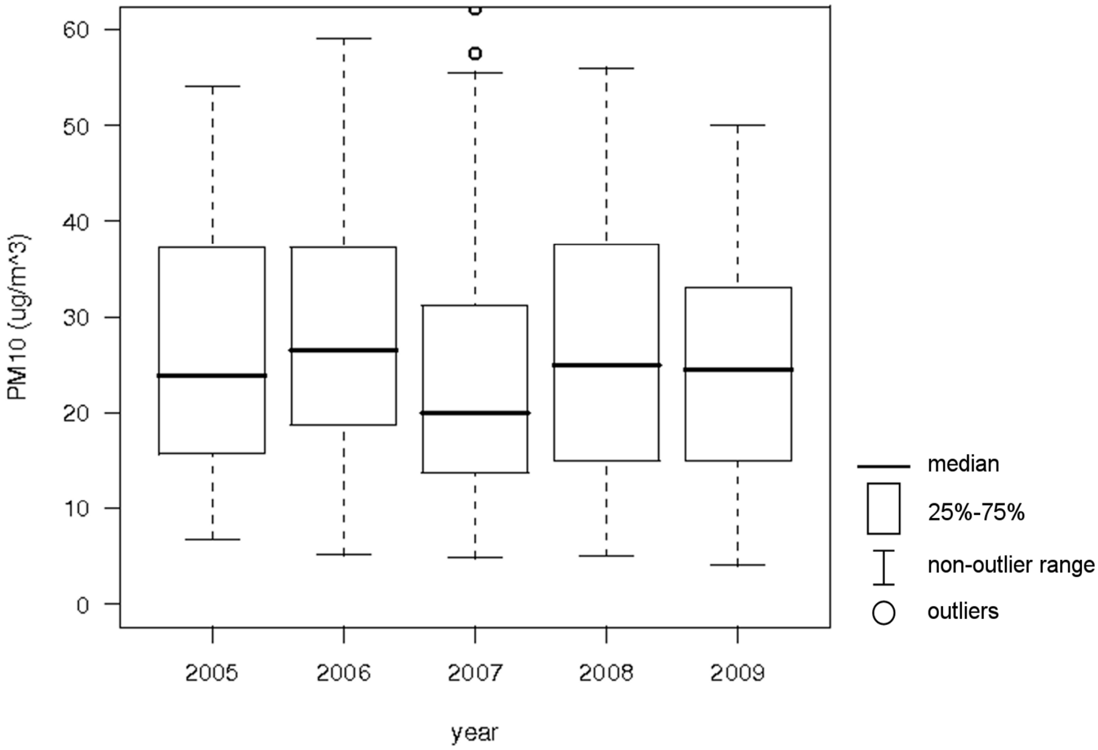

Figure 3-1: **Distribution of 24-hour average PM$_{10}$ concentrations in Blenheim for the months May to August over the years 2005 to 2009**

3.2. Identifying and grouping days with highest PM$_{10}$ concentrations

Meteorological data from 2005 to 2009 were collated based on the variables in Table 3-1. A range of meteorological variables were considered and BRT analysis was used to determine which variables most accurately explained variations in 24-hour average PM$_{10}$ concentrations and which were the greatest indicators of elevated PM$_{10}$.

BRT analysis showed that 24-hour average temperature, average wind speed between 5pm and midnight, wind direction at 5pm and the difference between the maximum temperature on the sample day and the minimum temperature the following day were the meteorological variables that best explained the variation in PM$_{10}$ concentrations. Around 43% of the variability in PM$_{10}$ concentrations was able to be explained by these meteorological variables.

Table 3-1: Predictor variables used for the BRT analysis

	Period	PM$_{10}$	Wind speed (ms^{-1})	Temperature (^{o}C)	Wind direction (^{o}N)
24-hour average	Midnight to midnight	✓	✓	✓	
7-hour average	5 pm to midnight		✓	✓	
4-hour average	8 pm to midnight		✓	✓	
6-hour average	6am to midday		✓		
6-hour average preceding day	6pm to midnight		✓		
Minimum 1-hour	Midnight to midnight		✓	✓	
Minimum following day 1-hour	Midnight to midnight			✓	
Max sample day less min day following 1-hour	Midnight to midnight			✓	
Maximum 1-hour	Midnight to midnight		✓	✓	
Hourly average	Hour ending 5 pm		✓	✓	✓
Hourly average	Hour ending 8 pm		✓	✓	✓
Number of hours	5 pm to midnight		<1ms-1 <2 ms-1 <3ms-1	<1 ºC <5 ºC <10 ºC	

Using the meteorological variables as determined by BRT, a normal regression tree analysis was performed to group the PM$_{10}$ data according to the meteorological conditions, Figure 3-2. The boxes at the end of each branch of the tree are referred to as terminal nodes. Summary statistics are provided for PM$_{10}$ data within each node. These include:

- Mean = mean value of PM$_{10}$ concentrations of the days within that particular group
- N= number of days within that particular group.

The tree grouped the data into twelve terminal nodes, three of which were designated as containing the days with the highest pollution potential (circled in red in Figure 3-2). Around 23% of the dataset are contained within these three highest pollution nodes. The mean values of PM$_{10}$ within these nodes are 43, 43 and 37 µgm^{-3} and the average of data within the three nodes is 38 µg m^{-3}. The high pollution nodes are defined by the following predictor variables:

High pollution node 8 (mean 43.47 µg m^{-3}, n = 10)

- 24-hour average temperature was between 7 and 9.4 degrees Celsius (ºC)
- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- wind direction at 5pm between 312 and 347.5 degrees

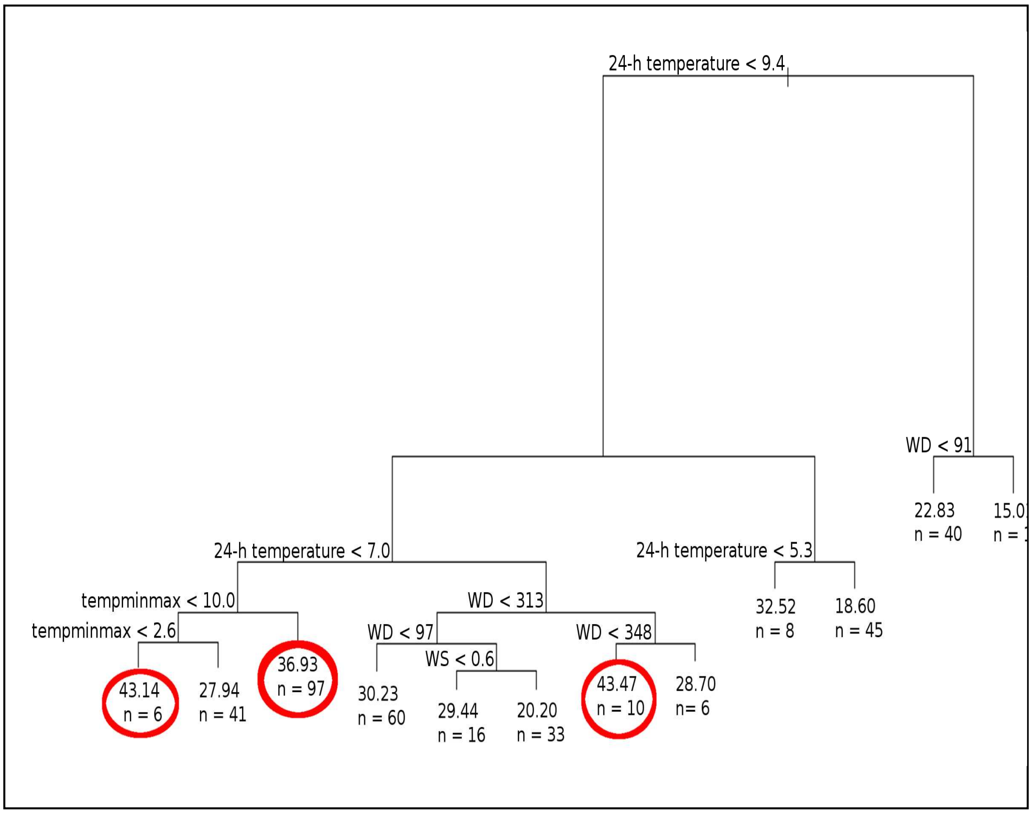

Figure 3-2: **Regression tree to fit full 24-hour average PM_{10} data set, where 24-h temperature is the average 24 h temperature (°C), tempminmax is the difference between the maximum temperature this day and the minimum temperature the following day (°C), WD is the wind direction (°) and WS is the minimum wind speed between 17:00 and 24:00 (ms^{-1})**

High pollution node 2 (mean 43.14 µg m-3, n = 6)

- 24-hour average temperature was less than 7 degrees Celsius (ºC)
- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- the difference between the maximum temperature on the sample day and the minimum temperature the following day was less than 2.6 ºC

High pollution node 3 (mean 36.93 µg m-3, n = 97)

- 24-hour average temperature was less than 7 degrees Celsius (ºC)
- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- the difference between the maximum hourly average temperature on the sample day and the minimum hourly average temperature the following day was greater than 9.95 ºC

The PM_{10} dataset for 2005 to 2009 includes 16 days when concentrations exceeded 50 μgm^{-3}. The three highest pollution nodes from Figure 3-2 contain 73% of the high pollution days (12 in total) as well as 101 days when PM_{10} concentrations were less than 50 $\mu g\ m^{-3}$. The greatest proportion (50%) of high pollution days occurred within node 3, which was represented by low 24-hour average temperature (less than 7 degrees), low evening wind speed (less than 1.5 ms^{-1}) and very stable atmospheric connditions (temperature difference between hourly maximum on sample day and minimum the following day of more than 9.95 degrees)[3].

Similar meteorological conditions occurred within node 2 except that the stability of the atmosphere was less extreme. Of the six days that met the meteorological conditions of node 2, only one exceeded 50 $\mu g\ m^{-3}$. This occurred on 29 June 2007 and represents the highest measured PM_{10} concentrations during the study period of 62 $\mu g\ m^{-3}$.

Node 8 contained three days (19%) when PM_{10} concentrations exceeded 50 $\mu g\ m^{-3}$ and the highest average PM_{10} concentrations, but only 10 data points in total. The meteorological conditions were warmer than for node 3 with an average 24-hour temperature between 7 and 9.4 degrees, similar in terms of low evening wind speed but specific in terms of wind direction at 5pm with a wind direction of between 312 and 347 degrees. The stability indicator was not a criteria used to split these data. However examination of the stability indicator on days meeting the above criteria shows high stability on days within Node 8. The dates of the exceedences that fell into this meteorological classification were: 20 May 2008, 18 July 2006 and 13 May 2008.

3.3. Trend analysis of days with high pollution potential

The 113 days identified as having meteorological conditions most conducive to elevated pollution were separated by year of monitoring. This data set included:

- 2005 - 7 days (6% of winter days)
- 2006 - 22 days (18% of winter days)
- 2007 - 20 days (16% of winter days)
- 2008 - 27 days (22% of winter days)
- 2009 - 37 days (30% of winter days)

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[3] The difference in the maximum temperature on the sample day and the minimum temperature the following day is generally an indicator of the temperature gradient during the evening period and therefore an indicator of atmospheric stability over this period.

This suggests a greater prevalence of meteorological conditions conducive to elevated PM_{10} concentrations during 2009 (i.e. 2009 was a colder less windy winter). Trends in 24-hour average PM_{10} concentrations within this dataset are displayed in Figure 3-3.

Figure 3-3 shows no firm long trend in PM_{10} concentrations on days with similar high pollution potential. The trend analysis of 24-hour average PM_{10} concentrations is inconclusive with respect to any long term changes in PM_{10} concentrations since 2005.

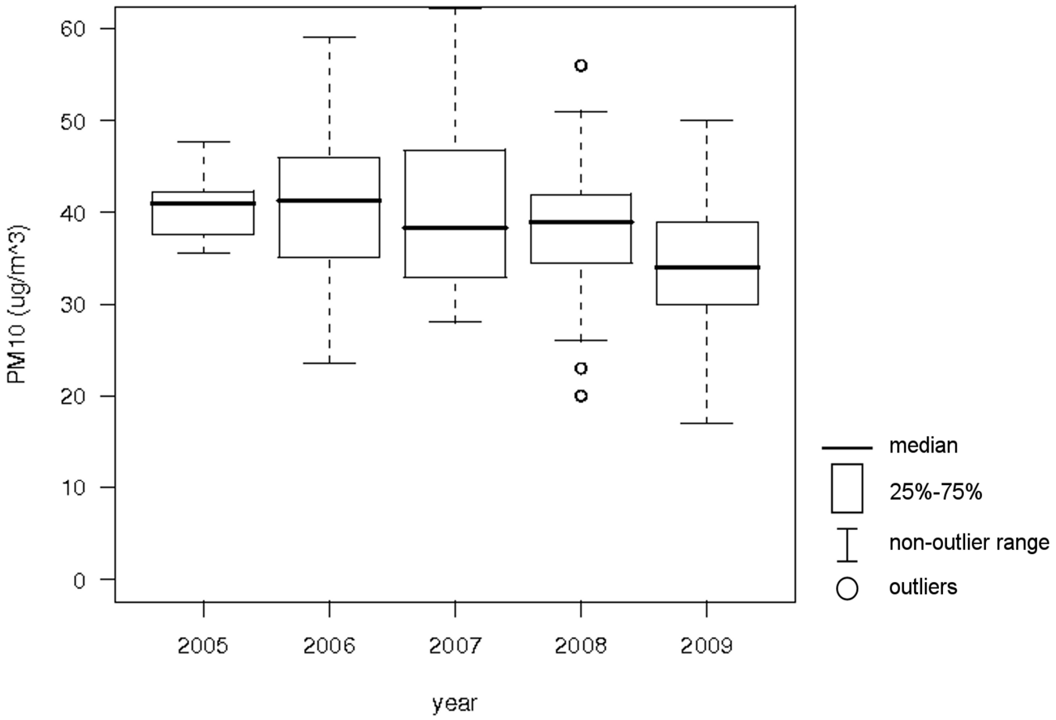

Figure 3-3: Variations in 24-hour average PM_{10} concentration for the 113 days when meteorological conditions were most conducive to elevated PM_{10} (nodes 2, 3 and 8).

3.4. Trends in exceedences of the PM_{10} NES

Within the 113 high potential pollution days, the NES for PM_{10} (50 μgm^{-3}, 24-hour average) was exceeded at total of 12 times. Figure 3-4 shows the year-to-year variation in the percentage of high pollution days when the NES was breached.

Figure 3-4 shows that the prevalence of NES breaches on high potential pollution days was:

- Zero in 2005,
- Around 20% in 2006 and 2007
- Less than 10% in 2008
- Less than 5% in 2009

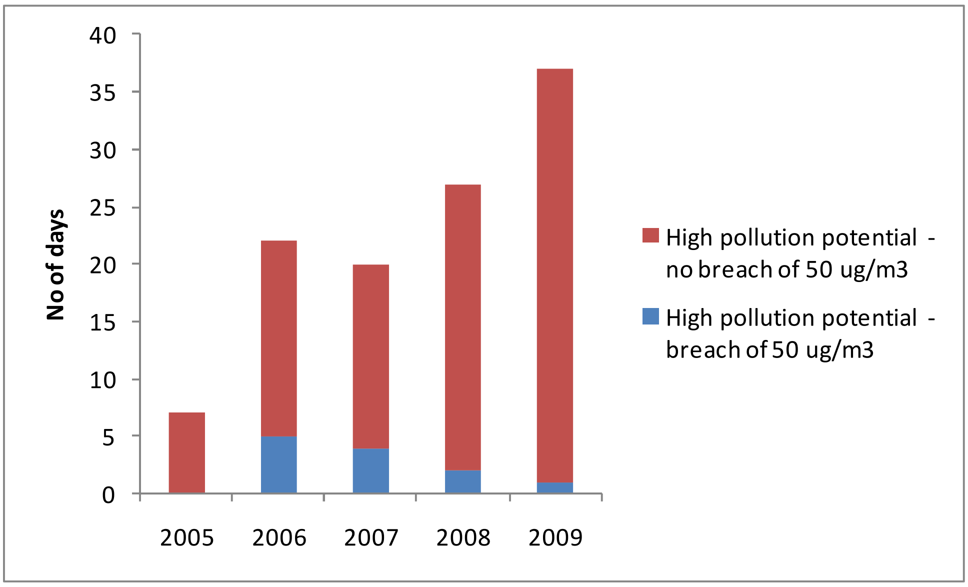

Figure 3-4: **Year-to-year variation of the percentage of high potential pollution days with PM_{10} concentrations of greater than 50 µgm^{-3} (24-hour average).**

Figure 3-4 suggests that over the years 2006 to 2009 there may have been a downward trend in the number high pollution potential days that actually result in a high pollution event occurring. However the 2005 data is not consistent with this trend and it is difficult to form conclusions based on the four year period from 2006-2009. It is worth noting that 2009 had the highest number of high pollution potential days, but only one resulted in a high pollution event. While there are some indicators of a reduction in emissions, trends are not well enough defined to be considered conclusive.

4. Normalising PM_{10} concentrations

Trends in PM_{10} data recorded in the years 2010 and beyond can be evaluated based on the results of the BRT and normal regression tree analysis described in Section 3.2. This involves normalising PM_{10} data from 2010 onwards based on meteorological conditions associated with high pollution over the years 2005 to 2009. As all meteorology has some impact, one of the biggest issues in establishing a methodology for normalising data was determining what constitutes “no impact”, that is, what concentrations should be normalised to.

The method proposed here is identical to that used in Wilton (2007) and Bluett et al (2009) and aims to minimise the impact of varying meteorology for high pollution events. Results are not expected to give an indication of day to day variability in PM_{10} emissions but may provide some indication of annual trends in emissions. To include the majority of the days when 50 µg m^{-3} is exceeded, the method for minimising the impact of meteorology on concentrations proposed here has been based on days when the 24-hour average temperature is less than 9.44 degrees and the evening average wind speed is less than 1.5 ms^{-1} (Figure 3.2). It is proposed that this group alone is used to track changes with time. The following adjustments to data are recommended:

Select days which meet the meteorological criteria (wind speed (average 5pm to midnight) <1.5 ms^{-1} and 24-hour average temperature <9.44 degrees).

- If daily average temperature is >7 °C, wind direction at 5pm is between 97 and 313 degrees and wind speed is > 0.6 ms^{-1} do not adjust data.
- If daily average temperature is >7 °C, wind direction at 5pm is between 97 and 313 degrees and wind speed is < 0.6 ms^{-1} subtract 9.2 from PM_{10} value.
- If daily average temperature is >7 °C, wind direction at 5pm is less than 97 subtract 10.0 from PM_{10} value.
- If daily average temperature is >7 °C, wind direction at 5pm is greater than 347.5 subtract 8.5 from PM_{10} value.
- If daily average temperature is >7 °C, wind direction at 5pm is between 313 and 347.5 degrees subtract 23.3.
- If daily average temperature is <7 °C and the temperature difference is greater than 9.95 subtract 16.7 from PM_{10} value.
- If daily average temperature is <7 °C and the temperature difference is less than 2.6 subtract 22.9 from PM_{10} value.
- If daily average temperature is <7 °C and the temperature difference is between 2.6 and 9.95 degrees subtract 7.7 from PM_{10} value.

Note the following:

- Wind speed refers to the average wind speed between 5pm and midnight.
- Temperature difference refers to the difference between the maximum hourly temperature on the sample day and the minimum hourly temperature the following day.

The PM_{10} normalising process has been coded into a spreadsheet tool which has been provided to Marlborough District Council. This will allow council staff to evaluate trends in PM_{10} from 2010.

5. Conclusions

The objectives of this study were to identify meteorological conditions in Blenheim that are likely to lead to high pollution events, assess the long term trend in PM_{10} air quality monitoring data for Blenheim and produce a tool (excel spreadsheet) that will allow MDC staff to assess trends in PM_{10} emissions while taking account of the impact of variable meteorology.

The dataset used in this study was PM_{10} concentrations measured at Redwoodtown from 2005 to 2009. A total of 495 days of PM_{10} monitoring data was collected over this five year period. An evaluation of summary statistics for the whole data set for each year shows there is no obvious trend in the annual median. Trends in higher concentrations were examined further in this study by attempting to minimise the impact of meteorological conditions on high PM_{10} concentrations.

To account for year-to-year variation in meteorology and to analyse the long term trend in PM_{10} concentrations a combination of a boosted regression tree (BRT) analysis and normal regression tree analysis was used. BRT was used to identify the most important meteorological parameters explaining the variation in PM_{10} values. The identified important meteorological parameters were used in normal regression tree analysis to group PM_{10} values measured under similar meteorological conditions together. Meteorological conditions most conducive to elevated PM_{10} concentrations were identified as:

High pollution node 8 (mean 43.47 $\mu g\ m^{-3}$, n = 10)

- 24-hour average temperature was between 7 and 9.4 degrees Celsius (ºC)
- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- wind direction at 5pm between 312 and 347.5 degrees

High pollution node 2 (mean 43.14 $\mu g\ m^{-3}$, n = 6)

- 24-hour average temperature was less than 7 degrees Celsius (ºC)
- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- the difference between the maximum temperature on the sample day and the minimum temperature the following day was less than 2.6 ºC

High pollution node 3 (mean 36.93 $\mu g\ m^{-3}$, n = 97)

- 24-hour average temperature was less than 7 degrees Celsius (ºC)

- average wind speed between 5pm and midnight was less than 1.5 ms^{-1}
- the difference between the maximum hourly average temperature on the sample day and the minimum hourly average temperature the following day was greater than 9.95 ºC

The group of 113 days when these meteorological conditions were met were then subjected to a trend analysis. The trend analysis of 24-hour average PM_{10} concentrations is inconclusive with respect to any long term changes in PM_{10} concentrations since 2005.

A method has been developed to normalise (adjust up or down) future PM_{10} data to allow MDC staff to evaluate the effectiveness of future air plan measures on PM_{10} concentrations. The PM_{10} normalising process will allow the evaluation of the trends in PM_{10} data recorded from 2010 without having to repeat the BRT modelling exercise.

The overall results of this study suggest that there are no significant changes in PM_{10} concentrations measured in Blenheim from 2005 to 2009. However, trends may become apparent with the addition of a few more years of monitoring data.

6. Acknowledgements

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