Environet ltd
Air Quality & IT Specialists

Assessing trends in PM_{10} concentrations in Gore

Prepared for Environment Southland Regional Council
by Emily Wilton[1], Iman Soltanzadeh[2] and Peyman Zawar-Reza[2]

[1] Environet Ltd
[2] Department of Geography, University of Canterbury

June 2011

This project was funded by Envirolink 978-ESRC239

Executive Summary

Concentrations of PM_{10} measured in Gore have exceeded the National Environmental Standard of 50 μg m^{-3} (24-hour average) in Gore up to seven days per year since continuous monitoring commenced in 2006. Exceedences occur during the winter months and the main source is solid fuel burning for domestic home heating.

Trends in PM_{10} concentrations are difficult to evaluate based on monitoring data alone because the impact of meteorological conditions varies from year to year. The objective of this study is to characterise meteorological conditions in terms of impact on PM_{10} concentrations and to evaluate trends in PM_{10} within subgroups of meteorological conditions. This provides an indication of potential changes in emissions by evaluating concentrations, whilst minimising the impact of meteorological conditions.

Meteorological conditions with the potential for the highest PM_{10} concentrations in Gore were:

- 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of less than or equal to 1.4 degrees C.
- 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of greater than 1.4 degrees C and relative humidity greater than 78%.
- 24-hour average wind speed greater than 1.1 ms^{-1} but less than or equal to 1.7 ms^{-1}, minimum temperature on the day following the high pollution day of less than or equal to 1.9 degrees C and relative humidity less than 71.5 degrees.

Combined, these meteorological conditions account for around 77% of the days when PM_{10} concentrations exceeded 50 μg m^{-3} between 2006 and 2010.

An evaluation of PM_{10} concentrations on days when the above meteorological conditions occurred shows no real trends in concentrations from 2006 to 2010. A further re-evaluation of trends in PM_{10} concentrations with 2011 and 2012 data using tools prepared in this study is recommended.

Contents

List of Tables

List of Figures

1 Introduction

Concentrations of PM_{10} in Gore have breached the National Environmental Standards (NES) for PM_{10} up to seven times per year from 2006 to 2010 during the winter months (Wilton, 2011). The NES specifies a limit of 50 μgm^{-3} (24-hour average) with one allowable exceedence per year (MfE, 2004). In Gore the NES for PM_{10} is required to be met by 2016.

Environment Southland has undertaken scientific research to establish sources of PM_{10} and causes of breaches of the NES. In 2004 an emissions inventory was completed. The results indicate that domestic heating is the main source of PM_{10} emissions in Gore with 94% of PM_{10} emissions coming from this source (Wilton, 2005). Further work is proposed for 2011 to update the inventory and to assess the effectiveness of different strategies to reduce PM_{10} concentrations to meet the NES by 2016.

The Regional Air Quality Plan for Southland has been operative since 1999 and does not contain regulations to control discharges to air from domestic home heating. Review of the plan will be required to reduce PM_{10} concentrations to meet the NES.

In 2009 an evaluation of trends in PM_{10} concentrations in Invercargill found improvements had occurred from 2004 to 2009 in the absence of regulations (Wilton, et. al., 2009).

The objectives of this study are to:

- characterise meteorological conditions in terms of impact on PM_{10} concentrations
- assess trends in PM_{10} concentrations when the impact of meteorological conditions are minimised
- evaluate the likelihood of changes in emissions having occurred from 2006 to 2010.

2 Methodology

2.1 Monitoring data

Continuous monitoring of PM_{10} in Gore commenced in May 2006 with the use of beta attenuation monitor (BAM). Daily PM_{10} concentrations were provided by Environment Southland for the period 2006-2010 for the trends evaluation.

The data to be included in the study was limited to the months May to August. This assists in the characterisation of meteorological conditions most conducive to elevated winter time PM_{10} concentrations and is more relevant in terms of breaches of the NES. A total of 607 days were included in the study.

2.2 Meteorological data

Meteorological data for the period 2006 to 2010 were collated from the Gore air quality monitoring site for the variables shown in Table 3.1. The range of averaging periods were included to determine which variables most significantly explained variations in 24-hour average PM_{10} concentrations and which were the greatest indicators of elevated PM_{10}.

Table 2.1: Meteorological classifications used for the analysis

	Period	PM$_{10}$	Wind speed (ms^{-1})	Temperature (^{o}C)	Wind direction (^{o}N)	Relative Humidity %
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			✓		
Minimum sample day less minimum day following 1-hour	Midnight to midnight			✓		
Maximum 1-hour	Midnight to midnight		✓	✓		✓
Hourly average	5 pm		✓	✓	✓	✓
Number of hours	5 pm to midnight		<1ms-1 <2 ms-1 <3ms-1	<1 ºC <5 ºC <10 ºC		

2.3 Statistical Analysis

Regression tree analysis was used to investigate the meteorological conditions with the greatest potential to produce elevated concentrations of PM$_{10}$ in Gore. Classification and Regression Trees (CART) describe a statistical procedure that was introduced by Breiman et al. (1984). Classification and Regression Trees have been applied to a wide variety of environmental studies including air quality problems (e.g., Zheng et al. 2009, Hendrikx et. al., 2005).

Based on a set of predictor variables, this statistical approach repeatedly splits the response into a set of classes (or nodes) with maximum possible class purity at each split stage and arranges the final splits into a decision tree diagram. Analysis was undertaken using the Classification and Regression Tree (CART) analysis in R, which is software environment for statistical computing and graphics (http://www.r-project.org/).

3 Trends in PM_{10} concentrations

3.1 Trends in all PM_{10} data

Concentrations of PM_{10} from 2006 to 2010 unadjusted for variability in meteorological impacts are shown in Figure 3.1. Data illustrated includes the average, median (middle ranked 24-hour average PM_{10} concentration) and 25th, 75th and 90th percentile concentrations for the months May to August for each year. No changes in PM_{10} concentrations from 2006 to 2010 indicative of trends in emissions are evident from these data.

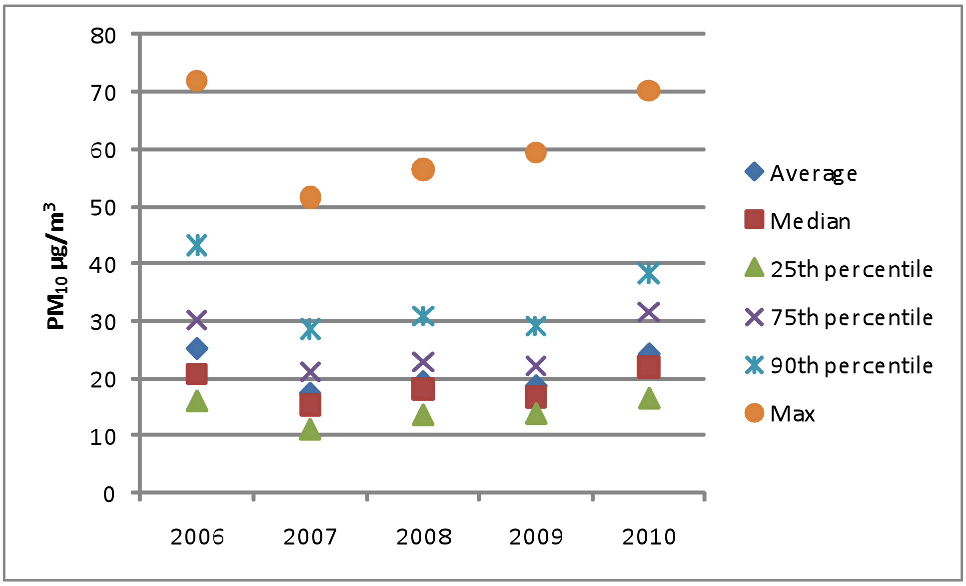

Figure 3.1: 24-hour average PM_{10} concentrations by year for Gore from 2006 to 2010

3.2 Regression tree on PM_{10} data

The relationship between daily average PM_{10} data and meteorological conditions were analysed using a regression tree (Figure 3.2).

The strong correlation between PM_{10} and meteorological parameters such as ambient temperature, relative humidity, solar radiation, wind speed is well known (e.g. Grivas et al., 2004). The relationship between daily average PM_{10} data and meteorological conditions were analysed using a regression tree, which is described below.

Classification and Regression Tree (CART; Breiman et al., 1984) estimates a regression relationship by binary recursive partitioning in a conditional inference framework. Roughly, the algorithm works as follows: 1) Test the global null hypothesis of independence between any of the input variables and the response (which may be multivariate as well). Stop if this hypothesis cannot be rejected. Otherwise select the input variable with strongest association to the response. This association is measured by a p-value corresponding to a test for the partial null hypothesis of a single input variable and the response. 2) Implement a binary split in the selected input variable. 3) Recursively repeat steps 1) and 2).

The implementation utilizes a unified framework for conditional inference, or permutation tests, developed by Strasser and Weber (1999). The stop criterion in step 1) is either based on multiplicity adjusted p-values like Monte-Carlo method or on the univariate p-values called Univariate method. Multiplicity-adjusted Monte-Carlo p-values are computed following a "min-p" approach (here; $p \leq 0.001$). The univariate p-values based on the limiting distribution are computed for each of the random permutations of the data (here; $p \leq 0.05$).

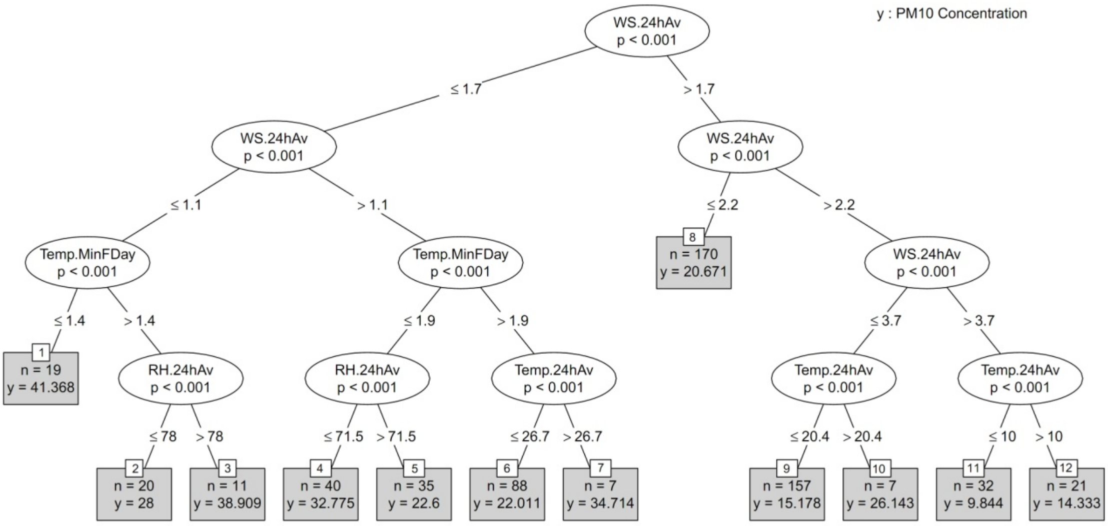

Figure 3.2: Regression tree on PM_{10} data.

The meteorological variables found to have the greatest impact on PM_{10} concentrations were:

- 24-hour average wind speed (WS.24hAv)
- 24-hour average relative humidity (RH.24hAv)
- Minimum hourly average temperature on the following day (Temp.MinFDay)

The last variable is relevant as the severity of a frost the following morning can provide an indication of the stability of the atmosphere during the evening period.

The highest pollution dataset was characterised by 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of less than or equal to 1.4 degrees C (node 1 from Figure 3.2). There were only 19 days when these meteorological conditions occurred from 2006 to 2010 and five of them (26%) resulted in breaches of the NES. The average PM_{10} concentration was 41 $\mu g\ m^{-3}$.

Other meteorological conditions which gave rise to higher PM_{10} concentrations included:

- 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of greater than 1.4 degrees C and relative humidity greater than 78% (node 3).
- 24-hour average wind speed greater than 1.1 ms^{-1} but less than or equal to 1.7 ms^{-1}, minimum temperature on the day following the high pollution day of less than or equal to 1.9 degrees C and relative humidity less than 71.5 degrees (node 4).

Combined these meteorological conditions accounted for 10 of the 13 NES breaches (77%) that occurred from 2006 to 2010. The remaining three occurred under node 8 meteorological conditions (24-hour average wind speeds between 1.7 and 2.2 ms^{-1}).

3.3 Trend analysis of days with high pollution potential

An evaluation of PM_{10} concentrations by year for days when meteorological conditions met the high pollution criteria can be used to determine trends in PM_{10} when some of the impact of meteorological conditions is accounted for.

The high pollution subsets used for the preliminary trends analysis were nodes 1, 3 and 4. A total of 70 days when meteorological conditions met the criteria of nodes 1, 3 and 4 were separated by year. Trends in 24-hour average PM_{10} concentrations within this dataset are displayed in Figure 3.3.

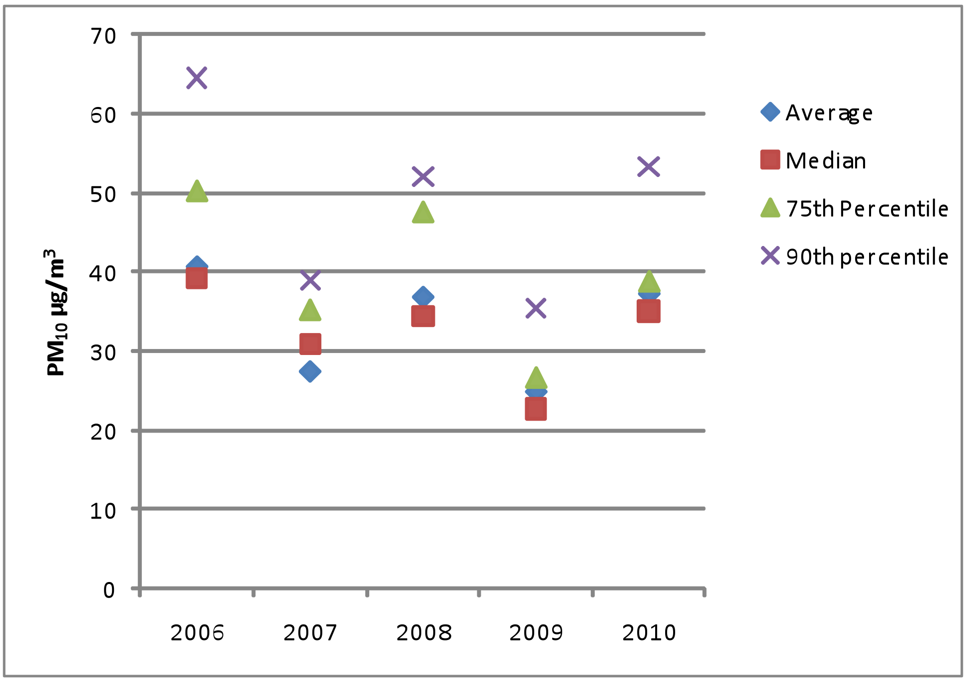

Figure 3.3: Average, 75th percentile and median PM_{10} concentrations for the 70 days when meteorological conditions met the criteria of nodes 1, 3 and 4.

No change in median or average PM_{10} concentrations is evident in the trends assessment. However, a slight decrease in the 75th percentile concentrations may have occurred from 2006 to 2010.

3.4 Trends in exceedences of the PM_{10} NES

Table 3.1 shows the distribution of the 13 days when PM_{10} concentrations exceeded 50 µg m^{-3} (24-hour average) between the high pollution nodes 1, 3 and 4 and other meteorological conditions for each year from 2006 to 2010. The number of days when meteorological conditions conducive to high pollution occurred each year is also shown. The number of breaches occurring on days when meteorological conditions were not consistent with nodes 1, 3 and 4 was three (23%).

Figure 3.4 shows the year-to-year variation in the percentage of high pollution potential days when PM_{10} concentrations exceeded 50 µgm^{-3} (24-hour average). A consistent decrease in the proportion that results in a breach of the NES can be indicative of a reduction in PM_{10} emissions. While a reduction in the proportion of days resulting in a breach is observed for 2010 more years of similar data would be required to be indicative of a decrease in emissions.

Table 3.1: Summary of exceedence days for 2006 to 2010 days by meteorological classifications.

	Meteorological conditions for high pollution (nodes 1, 3 and 4)			Other meteorological conditions	
	Number of exceedences	Number of days	Proportion of exceedences	Number of exceedences	Meteorological conditions
2006	6	29	21%	1	Node 8
2007	0	7	0%		
2008	2	10	20%		
2009	0	9	0%	2	Node 8
2010	2	15	13%		

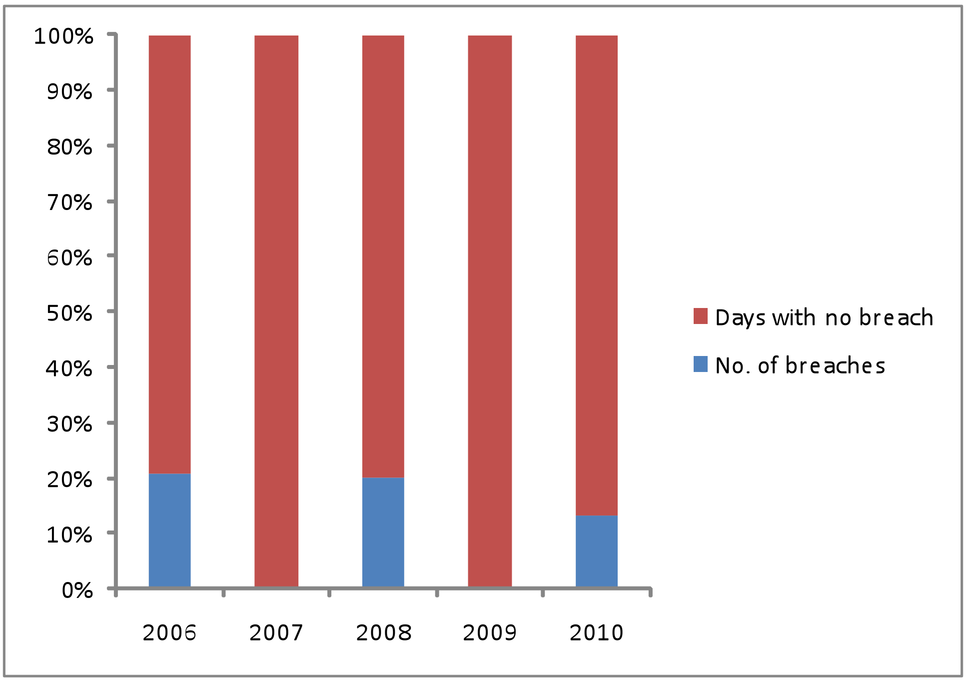

Figure 3.4: Year-to-year variation of the proportion of high potential pollution days (nodes 1, 3 and 4) that resulted in breaches of 50 µg m^{-3} (24-hour average).

4 Normalising PM_{10} concentrations

One of the objectives of this work is to enable an assessment of trends in PM_{10} concentrations in future years. 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 used aims to minimise the impact of varying meteorology for high pollution events. To include the majority of the days when 50 $\mu g\ m^{-3}$ is exceeded the method for minimising the impact of meteorology on concentrations has been based on days when meteorological conditions were consistent with nodes 1, 3 and 4 Figure 3.1.

It should be noted that the following method provides only an indication of trends in high PM_{10} concentrations and 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.

Select days which meet the meteorological criteria of 24-hour average wind speed less than or equal to 1.1 ms^{-1}, and days when the 24-hour average wind speed was greater than 1.1 ms^{-1} and less than 1.7 ms^{-1} and the minimum temperature the following day is less than 1.9 degrees and the 24-hour average relative humidity is less than 71.5%.

- If the 24-hour average wind speed is less than or equal to 1.1 ms^{-1} and the minimum hourly temperature the following day is greater than 1.4 degrees and the 24-hour average relative humidity is less than 78 degrees do not adjust data.
- If the 24-hour average wind speed is less than or equal to 1.1 ms^{-1}, the minimum hourly temperature the following day is greater than 1.4 degrees and the 24-hour average relative humidity is greater than 78 degrees – subtract 10 $\mu g\ m^{-3}$.
- If the 24-hour average wind speed is less than or equal to 1.1 ms^{-1} and the minimum hourly temperature the following day is less than 1.4 degrees – subtract 13 $\mu g\ m^{-3}$.
- If the 24-hour average wind speed is greater than 1.1 ms^{-1} and the minimum hourly temperature the following day is less than or equal to 1.9 degrees and the 24-hour average relative humidity is less than or equal to 71.5 degrees – subtract 5 $\mu g\ m^{-3}$.

The PM_{10} normalising process has been coded into a spreadsheet tool that is provided to Environment Southland. This will allow council staff to evaluate trends in PM_{10} in future data without having to redo the trends analysis. Alternatively trends could be tracked using the method of selecting only days with high pollution potential as per this report.

5 Conclusions

The objectives of this study were to:

- Characterise meteorological conditions in terms of impact on PM_{10} concentrations.
- Assess trends in PM_{10} concentrations when the impact of meteorological conditions are minimised.
- Evaluate the likelihood of changes in emissions having occurred from 2006 to 2010.

Meteorological conditions with the potential for the highest PM_{10} concentrations in Gore were:

- 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of less than or equal to 1.4 degrees C.
- 24-hour average wind speed less than or equal to 1.1 ms^{-1} and minimum temperature on the day following the high pollution day of greater than 1.4 degrees C and relative humidity greater than 78%.
- 24-hour average wind speed greater than 1.1 ms^{-1} but less than or equal to 1.7 ms^{-1}, minimum temperature on the day following the high pollution day of less than or equal to 1.9 degrees C and relative humidity less than 71.5 degrees.

These meteorological conditions resulted in 77% of the NES breaches measured in Gore from 2006 to 2010.

An evaluation of trends in PM_{10} concentrations on days meeting the above criteria suggests no changes in PM_{10} concentrations between 2006 and 2010. It is recommended that 2011 and 2012 concentrations be examined using either the normalising tool or by allocating concentrations to nodes to allow ongoing assessment of trends.

References

Breiman L., Friedman J.H., Ohlsen R. and Stone C.J. 1984, 'Classification and regression trees', Wadsworth, Belmont, CA.

Grivas G, Chaloulakou A, Samara C, and N. Spyrellis. 2004. Spatial and Temporal Variation of PM10 Mass Concentrations within the Greater Area of Athens, Greece. Water, Air, & Soil Pollution; 158: 357-371.

Hendrikx J., Owens I., Carran W. and Carran A. 2005, 'Avalanche activity in an extreme maritime climate: The application of classification trees for forecasting', *Cold Regions Science and Technology*, 43, 104 – 116.

Ministry for the Environment, 2004, *National Environmental Standards for Air Quality,* Ministry for the Environment.

Strasser, H., and C. Weber. 1999. On the asymptotic theory of permutation statistics. Mathematical Methods of Statistics, 8, 220–250.

Wilton, E., 2005*, Invercargill and Gore, Air Emission Inventory – 2004*. Unpublished report prepared for Environment Southland.

Wilton, E., 2011, *Annual air quality monitoring report – 2011.* Unpublished report prepared for Environment Southland.

Wilton, E., Baynes, M, Appelhans, T., Zawar Reza P, 2009, *Management of PM_{10} in Invercargill An assessment of management options to achieve National Environmental Standards,* Unpublished report prepared for Environment Southland.

Zheng H., Chen L., Han X., Zhao X. and Ma Y. 2009, 'Classification and regression tree (CART) for analysis of soybean yield variability among fields in Northeast China: The importance of phosphorus application rates under drought conditions', *Agriculture*, Ecosystems & Environment, 132, 98 – 105.