Assessing trends in PM_{10} concentrations in Hastings

Prepared for Hawke's Bay Regional Council
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Executive Summary

Concentrations of PM_{10} exceed the National Environmental Standard of 50 µg m^{-3} (24-hour average) in Hastings typically between 10 and 30 days per year during the winter months. The main source of PM_{10} when these breaches occur is solid fuel burning for domestic home heating.

Assessing trends in PM_{10} concentrations based on monitoring data alone is difficult 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 were 24-hour average wind speeds of less than 1.6 ms^{-1} and 24 hour average temperature less than 5.95 degrees C. There were 16 days when these conditions occurred and all of them resulted in a breach of the NES. The average PM_{10} concentration on these days was 82 µg m^{-3}. A further 20 days met the first criteria of 1.6 ms^{-1} 24-hour average wind speed and had 24-hour average temperatures between 5.95 and 7.81 degrees C. The average PM_{10} concentration on these days was 63 µg m^{-3}. Breaches of the NES occurred on 80% of the days when these meteorological conditions were met. Other meteorological conditions conducive to elevated PM_{10} concentrations included days when the 24-hour average wind speed was less than 2.46 ms^{-1} but more then 1.6 ms^{-1} when the 24-hour average temperature was less than 7.81 degrees. Combined, these meteorological conditions account for around 79% 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. However, when days included are limited to those when 24-hour average wind speeds are less than 1.6 ms^{-1} and 24-hour average temperatures are less than 7.81 degrees C a downward trend is observed. The latter result would be consistent with results of a recent air emissions inventory which suggests a decrease in PM_{10} emissions from 2005 to 2010 of around 18% for Hastings (Wilton & Baynes, 2010). However, it is uncertain whether this observation is indicative of a change in concentrations over time because of the smaller number of observations meeting these criteria each year. A further re-evaluation of trends in PM_{10} concentrations after August 2011 and 2012 using tools prepared in this study is recommended.

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1 Introduction

PM_{10} concentrations in Hastings breach the National Environmental Standards (NES) for PM_{10} between 10 and 30 times per year during the winter months. The NES specifies a limit of 50 μgm^{-3} (24-hour average) with one allowable exceedence per year. The main source of PM_{10} on days when the NES is breached is solid fuel burning for domestic home heating.

An emission inventory was undertaken in 2005 and updated in 2010 to establish sources of PM_{10} and changes in emissions with time (Wilton, 2006, Wilton & Baynes 2010). The results of both indicated that domestic heating is the main source of PM_{10} emissions in Hastings during the winter months. Spatial variability in concentrations and the reductions required to meet the NES were also assessed (Gimson, 2006). A source apportionment study for Hasting was carried out in 2007 which confirmed the main source of PM_{10} concentrations and also identified the relative contribution of natural sources (marine aerosol and dusts) to measured PM_{10} (Wilton et. al, 2008). An analysis of the effectiveness of different strategies to reduce PM_{10} concentrations to meet the NES has also been carried out and measures have been included in the Plan Change 2: Hawke's Bay Regional Resource Management Plan - Air Quality.

The reduction in PM_{10} concentrations required to meet the NES was identified as 66% for Hastings (Gimson, 2006). Measures included in Plan Change 2 for Hastings are:

- A ban on the use of open fires.
- A ban on domestic outdoor rubbish burning.
- A phase out of solid fuel burners installed before 1996 by 2013.
- A phase out of solid fuel burners installed from 1996 to 2005 by 2016.
- A phase out of all burners not meeting the NES design criteria for wood burners by 2020.

The 2010 emission inventory estimated that an 18% reduction in PM_{10} emissions had occurred in Hastings between 2005 and 2010 as a result of fewer households using solid fuel burning heating methods (Wilton & Baynes, 2010). The inventory relied on a telephone survey of home heating methods and fuels and coincided with a time when households were sensitive to issues around air quality and in particular home heating methods because of progress with regulations targeting these heating methods. Because of the latter and the potential for bias in respondents or strategic answering of the questionnaire a further study to validate the estimated reduction in emissions was considered appropriate.

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 Hastings commenced in May 2006 with the use of beta attenuation monitor (BAM). The monitoring site was located at St John's College. Daily PM_{10} concentrations were provided by Hawke's Bay Regional Council for the period 2006-2010 for inclusion in the trends evaluation.

The data to be included in the study was limited to include data for 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 615 days were included in the study.

2.2 Meteorological data

Meteorological data for the period 2006 to 2010 were collated from the Whakatu Climate Station in Hastings for the variables shown in Table 3.1. This data contained a more complete record of variables from 2006 to 2010 than data from the St John's monitoring site. 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 (^oC)	Wind direction (^oN)	Relative Humidity %	Solar Radiation
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 Hastings. 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

Figure 3.1 shows trends in PM_{10} concentrations from 2006 to 2010 unadjusted for variability in meteorological impacts. Data illustrated includes the median (middle ranked 24-hour average PM_{10} concentration) and 25^{th}, 75^{th} and 90^{th} percentile concentrations for the months May to August for each year. Results suggest no significant changes in PM_{10} concentrations from 2006 to 2010.

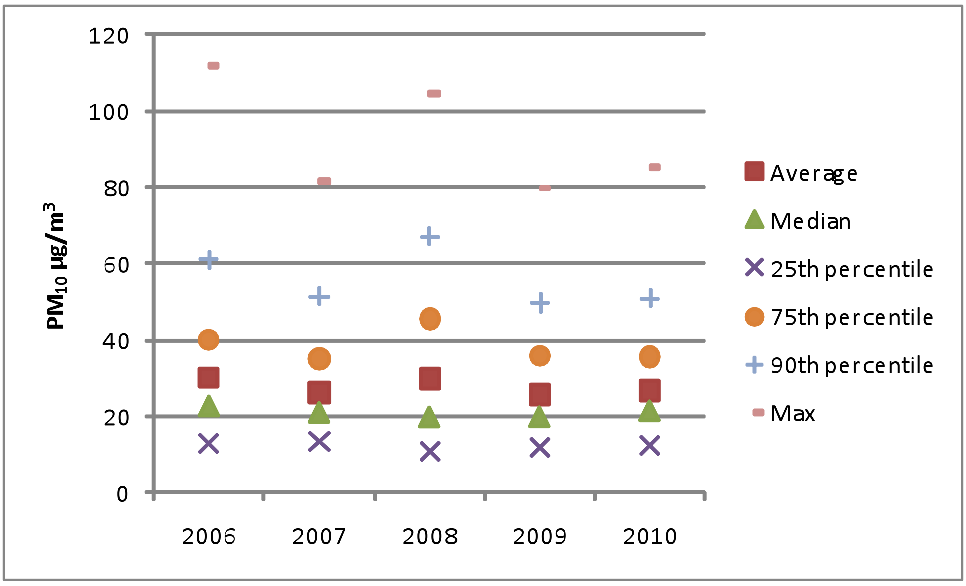

Figure 3.1: 24-hour average PM_{10} concentrations by year for Hastings from 2006 to 2010

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; $p \leq 0.05$).

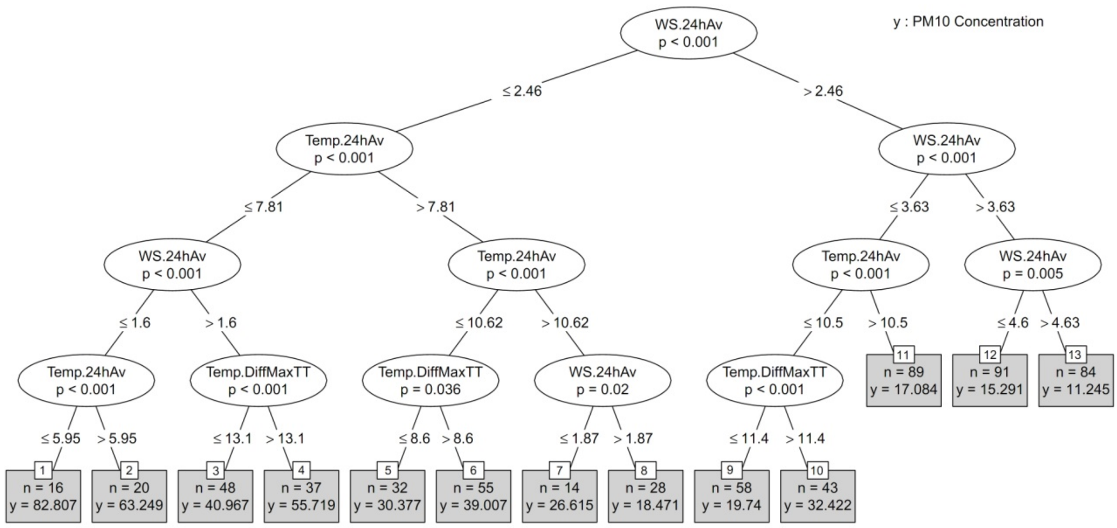

Figure 3.2: Regression tree on PM_{10} data.

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

- 24-hour average wind speed (WS.24hAv)
- 24-hour average temperature (Temp.24hAv)
- Difference between the maximum hourly average temperature on this day and the minimum hourly average temperature on the following day (Temp.DiffMaxTT)

The last variable provides an indication of the rate with which the temperature changes over night and can be an indication of the stability of the atmosphere.

The highest pollution dataset was characterised by 24-hour average wind speeds of less than 1.6 ms^{-1} and 24 hour average temperature less than 5.95 degrees C. There were 16 days when these conditions occurred and the average PM_{10} concentration on these days was 82 µg m^{-3}. The NES was breached on all days when these meteorological conditions occurred. A further 20 days met the first criteria of 24-hour average wind speed less than 1.6 ms^{-1} and had 24-hour average temperatures between 5.95 and 7.81 degrees C. The average PM_{10} concentration on these days was 63 µg m^{-3} and NES breaches occurred on 80% of these days.

Other meteorological conditions conducive to elevated PM_{10} concentrations included days when the 24-hour average wind speed was less than 2.46 ms^{-1} but more then 1.6 ms^{-1} when the 24-hour average temperature was less than 7.81 degrees.

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 1-4. A total of 119 days when meteorological conditions met the criteria of nodes 1-4 were separated by year. Trends in 24-hour average PM_{10} concentrations within this dataset are displayed in Figure 3.3.

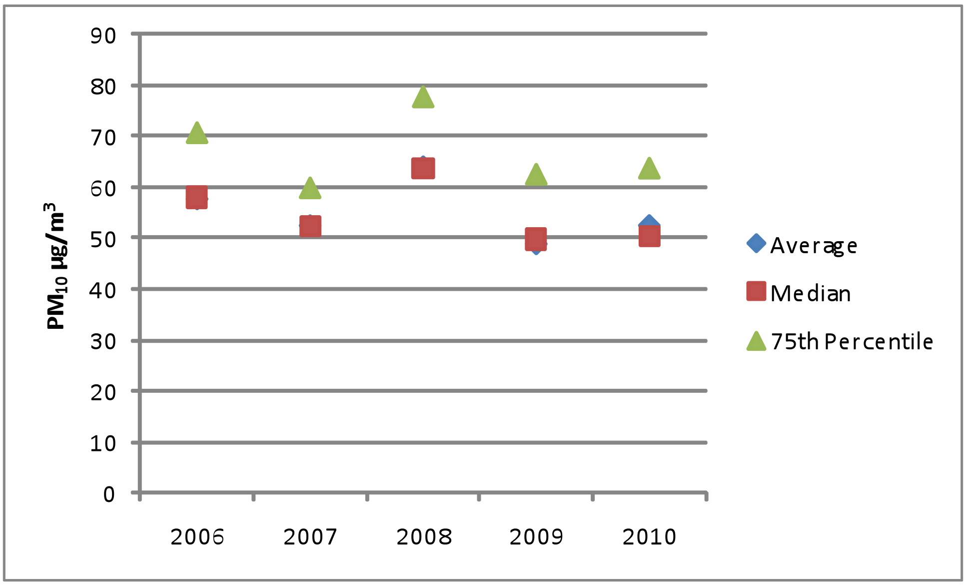

Figure 3.3: Average, 75th percentile and median PM_{10} concentrations for the 174 days when the 24-hour average wind speed was less than 2.46 ms^{-1} and the 24-hour average temperature was less than 7.81 degrees C.

Results suggest no real change in PM_{10} concentrations on days when meteorological conditions are conducive to elevated PM_{10}.

3.4 Trends in exceedences of the PM_{10} NES

Table 3.1 shows the distribution of the 82 days when PM_{10} concentrations exceeded 50 µg m^{-3} (24-hour average) between the high pollution nodes 1-4 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 1-4 was 16 (20%). The majority of these (63%) met the conditions of node 6 (wind speed less than 2.46 ms^{-1}, temperature between 7.81 and 10.62 degrees C and a temperature difference between the maximum hourly temperature this day and the minimum the following day of more than 8.6 degrees).

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). This suggests that during 2008 PM_{10} concentrations exceeded 50 µg m^{-3} on a greater proportion of the days when meteorological conditions were conducive to elevated PM_{10}. This may be indicative of higher emissions during 2008.

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

	Meteorological conditions for high pollution (nodes 1-4)			Other meteorological conditions	
	Number of exceedences	Number of days	Proportion of exceedences	Number of exceedences	Meteorological conditions
2006	15	28	54%	3	Nodes 6 & 10
2007	8	15	53%	5	Nodes 6, 10, 12
2008	20	25	80%	6	Nodes 6, 9 , 10
2009	10	24	42%	1	Node 6
2010	12	27	44%	1	Node 6

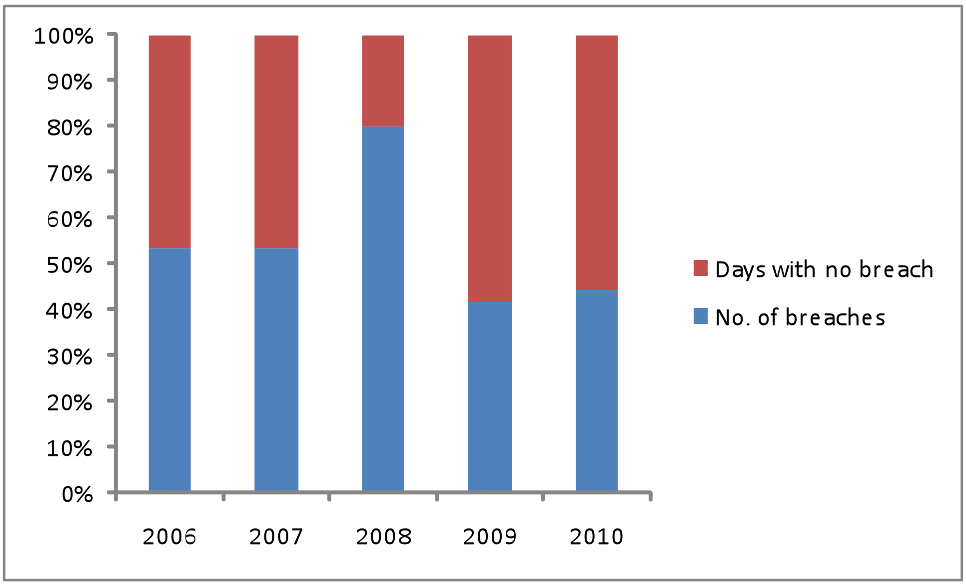

Figure 3.4: Year-to-year variation of the proportion of high potential pollution days (nodes 1-4) that resulted in breaches of 50 µg m^{-3} (24-hour average).

3.5 Evaluation of PM_{10} concentrations within nodes 1 an 2 only

An evaluation of PM_{10} concentrations within the highest two nodes by year is shown in Figure 3.5. This suggests that a slight decrease in concentrations may have occurred from 2006 to 2010. The difference between the average PM_{10} concentration for 2006 and 2010 within this dataset is 21% and reduces to 17% for the 75th percentile.

From 2006 to 2010 there were 36 days when these meteorological conditions occurred and breaches of the NES were measured on 89% of these days. Figure 3.6 shows that three of the four days when these conditions did not result in NES breaches happened in 2010 with the other event happening in 2007. A higher frequency no NES breaches on days when meteorological conditions comply with nodes 1 and 2 is indicative of a reduction in emissions.

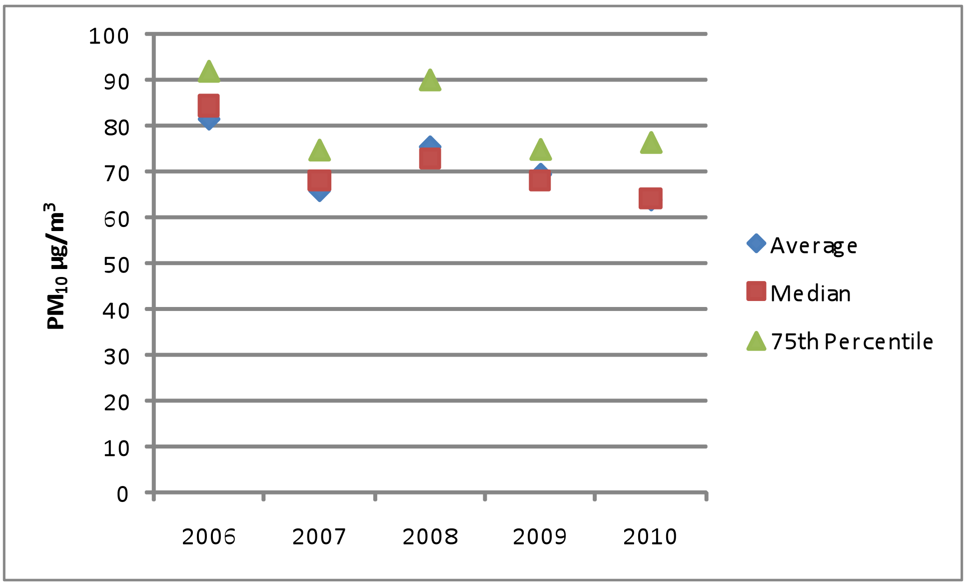

Figure 3.5: Average, 75th percentile and median PM_{10} concentrations for days when the 24-hour average wind speed was less than 1.6 ms^{-1} and the 24-hour average temperature was less than 7.81 degrees C.

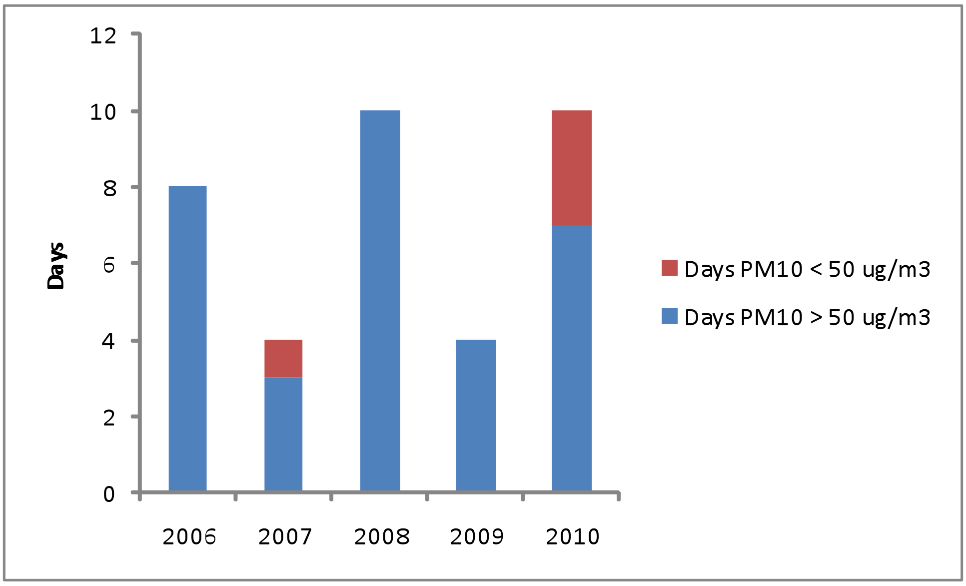

Figure 3.6: Year-to-year variation of the proportion of high potential pollution days (node 6 and 7) that resulted in breaches of 50 µg m^{-3} (24-hour average).

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 μg m^{-3} is exceeded the method for minimising the impact of meteorology on concentrations has been based on days meeting the meteorological criteria in nodes 1-4 of the regression tree shown in 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 1.6 ms^{-1} and 24-hour average temperature of less than 7.81 degrees C.

- If the 24-hour average wind speed is greater than 1.6 ms^{-1} and the difference in temperature between the maximum hourly average temperature today and the minimum hourly temperature tomorrow is less than or equal to 13.1 degrees C do not adjust data.
- If the 24-hour average wind speed is greater than 1.6 ms^{-1} and the difference in temperature between the maximum hourly average temperature today and the minimum hourly temperature tomorrow is greater than 13.1 degrees C subtract 14.7 μg m^{-3}.
- If the 24-hour average wind speed is less than or equal to 1.6 ms^{-1} and the 24-hour average temperature is greater than 5.95 degrees C subtract 22.2 μg m^{-3}.
- If the 24-hour average wind speed is less than or equal to 1.6 ms^{-1} and the 24-hour average temperature is less than 5.95 degrees C subtract 41.8 μg m^{-3}.

The PM_{10} normalising process has been coded into a spreadsheet tool that is provided to Hawkes Bay Regional Council. This will allow council staff to evaluate trends in PM_{10} in future data without having to conduct a thorough trends analysis.

Alternatively trends could be tracked using the method of selecting only days with high pollution potential as per this report. A two tiered approach of tracking only the very high pollution events based on 24-hour average wind speeds of less than 1.6 ms^{-1} and 24-

hour average temperature of less than 7.81 degrees C (nodes 1 and 2) and separately evaluate trends in the larger higher pollution group of 24-hour average wind speeds of less than 2.46 ms^{-1} and 24-hour average temperature of less than 7.81 degrees C (nodes 1-4).

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.

The meteorological conditions which result in the highest PM_{10} concentrations are 24 hour average wind speed of less than 1.6 ms^{-1} and 24-hour average temperature of less than 5.95 degrees C (node 1). These conditions occurred on 16 occasions between 2006 and 2010 and always resulted in an NES breach. Other days when the wind speed was less than 1.6 ms^{-1} and the 24 hour average temperature was between 5.95 and 7.81 degrees C (node 2) also occurred on 20 days and resulted in NES breaches on 16 (80%) of these. Other meteorological conditions conducive to elevated PM_{10} concentrations included days when the 24-hour average wind speed was less than 2.46 ms^{-1} but more then 1.6 ms^{-1} when the 24-hour average temperature was less than 7.81 degrees (nodes 3 and 4).

An evaluation of trends in PM_{10} concentrations on days meeting the above criteria suggested no changes in PM_{10} concentrations between 2006 and 2010. However, evaluation of concentrations within the top two high pollution nodes suggests a slight decrease since 2006 may have occurred. It is uncertain based on this result whether the reductions in PM_{10} emissions of around 18% estimated in the inventory has occurred or whether some issues such as bias in non respondents has influenced the survey. It is recommended that 2011 and 2012 concentrations be examined using either the normalising tool or by allocating concentrations to nodes assessing further trends to determine the validity or otherwise of this result.

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