Assessing long-term trends in PM_{10} emissions and concentrations in Richmond

NIWA Client Report: CHC2010-015
February 2010

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Assessing long-term trends in PM_{10} emissions and concentrations in Richmond

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Prepared for

Tasman District Council

Cover Photograph. – View from the southern end of the Port Hills in Tahunanui, Nelson, looking south towards Richmond. 28 June, 2007. Trevor James Tasman District Council

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Executive Summary

In Richmond, concentrations of PM_{10} breach the National Environmental Standards (NES) for PM_{10} of 50 µgm^{-3} (24-hour average) regularly each year during the months May to August. The PM_{10} standard, which allows for one breach per year, must be met by 2013.

The objectives of this study are to:

- assess the long term trend in PM_{10} air quality monitoring data for Richmond
- identify the meteorological conditions in Richmond that are likely to lead to high pollution events and
- provide a tool (excel spreadsheet) that will allow TDC staff to assess future trends in PM_{10} emissions while taking account of the impact of variable meteorology.

This information can then compared with the Straight Line Path (SLiP) and the reductions required to meet the National Environmental Standard (NES) for PM_{10}. The comparison is indicative only as trends are examined here in a "high pollution subset", whereas changes in the second highest concentrations are most relevant for SLiP and NES compliance because the standard allows for one exceedance per year.

Nine years of PM_{10} data were included in the study which was limited to the months May to August, being the only months when exceedences of the NES have been recorded. These data were collected between 2000 and 2009 and a total of 718 days of PM_{10} monitoring data were included. No data were available for 2001, and 2002 data were limited to August because monitoring only occurred during this period.

A boosted regression tree (BRT) model was used to determine the meteorological variables that best identified high pollution events in Richmond. 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 group of days with the highest air pollution potential were then subjected to a trend analysis.

The raw data prior to adjustment for the impact of meteorological conditions suggest some decrease in PM_{10} concentrations may have occurred over the data record. An evaluation of year to year variations in the prevalence of meteorological conditions conducive to high pollution and the number of days that these conditions resulted in breaches of 50 µg m^{-3} also provided evidence of a decrease in PM_{10} emissions. The proportion of high pollution days resulting in NES breaches reduced from around 70-80% from 2000 to 2006 to 45-55% during 2007, 2008 and 2009.

The meteorological conditions as determined by the BRT that were most conducive to elevated PM_{10} was a 24-hour average wind speed of less than 3.8 ms^{-1} and 4-hour average temperature (8pm to

midnight) of less than 6.8 ºC. Over the whole record, 96% of days, when these conditions occurred, PM_{10} concentrations exceeded 50 µg m^{-3}. Similarly the NES was breached on 89% of days when the same temperature criterion was met and the wind speed was greater than 3.8 ms^{-1} but less than 5.0 ms^{-1}. NES breaches also occurred on 39% of days when the wind speed was less than 5.0 ms^{-1} but the temperature was greater than 6.8 ºC. A fourth high pollution classification was identified as days when the wind speed was between 5.0 and 7.3 ms^{-1} and the temperature was less than 5.8 ºC. NES breaches occurred on 45% of the days when these meteorological conditions prevailed.

Over the study period 252 days met these four criteria and the average PM_{10} concentration on these days was 57 µg m^{-3}. Trend analysis of these days indicates a decrease of around 23% in median PM_{10} concentrations from 2000 to 2009. A further evaluation of the higher PM_{10} concentrations was conducted with trend analysis on the two highest pollution nodes. This included 107 days (15%) when the wind speed was less than 5.04 ms^{-1} (24-hour average) and the temperature from 8pm to midnight was less than 6.81 ºC. Results suggest a higher decrease in PM_{10} concentrations of around 30-40%.

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 over the years 2000 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 TDC staff to undertake evaluation of trends in PM_{10} data monitored from 2010 onward.

1. Introduction

In Richmond, concentrations of PM_{10} breach the National Environmental Standards (NES) for PM_{10} of 50 µgm^{-3} (24-hour average) regularly each year during the months May to August. 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].

The Tasman District Council has adopted a number of measures to reduce concentrations of PM_{10} in the Richmond airshed. In April 2004 a ban on outdoor burning was brought in for areas in and around Richmond and Motueka and then in January 2007 a requirement to remove solid fuel burners and open fires not complying with the NES design criteria for wood burners at the time a house is sold was brought in within the Richmond airshed.

Based on a starting point for the SLiP of 111 µg m^{-3}, a reduction in total PM_{10} concentrations in Richmond of 55% (Wilton, 2005) is required to meet the NES. 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}, some reduction in emissions in Richmond could be expected as a result of the regulatory methods identified above and as a result of non regulatory replacement of older burners with lower emission NES compliant burners at the end of their useful life.

Tracking PM_{10} emissions and tracking PM_{10} concentrations are two methods of assessing trends in PM_{10} with time and evaluating compliance with the SLiP. The latter is the focus of this study. Methods for tracking changes in PM_{10} emissions include conducting air emission inventories and using house sales information and 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:

- assess the long term trend in PM_{10} air quality monitoring data for Richmond

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

- identify the meteorological conditions in Richmond that are likely to lead to high pollution events and

- to provide a tool (excel spreadsheet) that will allow TDC staff to assess future trends in PM_{10} emissions while taking account of the impact of variable meteorology.

2. Methodology

2.1. Monitoring data

Monitoring of PM_{10} in Richmond commenced in 2000 with gravimetric sampling using a high volume sampler installed on a building located on Queen Street and opposite the TDC offices. The sample frequency was one day in two during the winter months for the year 2000. No monitoring was conducted during 2001 and the sampling programme was re-established as a permanent programme in August 2002. In 2005 an alternative monitoring site was established at Richmond Central Plunket (Oxford Street) and for one winter PM_{10} data were collected at both sites. In August 2005 a beta attenuation monitor (BAM) was established as the main PM_{10} monitoring method for Richmond and was located at the Plunket site.

The data record used for this study was as follows:

2000 – Partisol data collected at the Library adjusted for Plunket site equivalency (see Appendix A for adjustment details)

2001 – No monitoring data available

2002 – Partisol data collected at the Library adjusted for Plunket site equivalency (August only)

2003 – 2005 - Partisol data collected at the Library adjusted for Plunket site equivalency

2006-2009 – BAM data collected at the Plunket site adjusted for gravimetric equivalency (as provided by TDC staff using the method detailed in Wilton, 2007).

The airport meteorological monitoring site was used for the analysis as it provides the longest continuous reliable record for this study. The two Tasman District Council meteorological monitoring sites in Richmond were established in 2006. The airport meteorological monitoring site is located approximately five kilometres north of Richmond near State Highway 6. A comparison of the wind roses for the airport and two MDC air quality monitoring sites for the months May to August over the years

2006 to 2009 is shown in Appendix B. The locations of the air quality monitoring sites and meteorological data site for Richmond are shown in Figure 2-1.

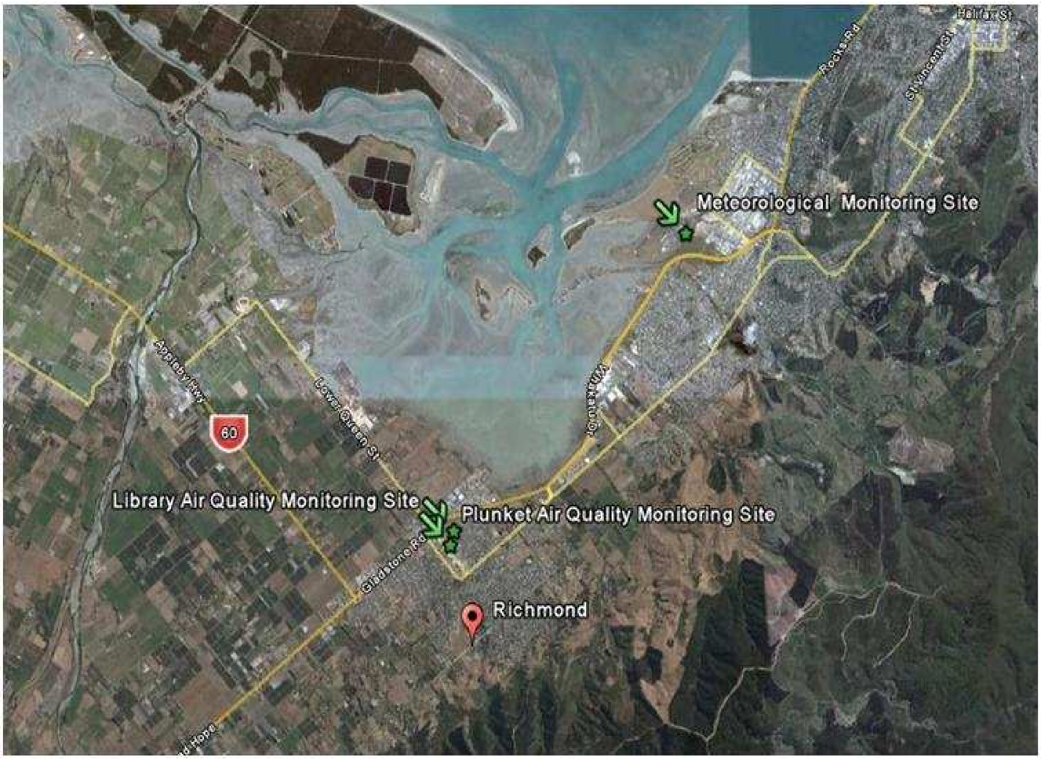

Figure 2-1: Location of the Library and Plunket PM_{10} monitoring sites in Richmond and the Nelson Airport meteorological monitoring station in Stoke, Nelson

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 and no NES exceedence has been recorded outside this period. A total of 718 days of PM_{10} monitoring data was collected during the months May to August over the nine year period from 2000 to 2009.

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 trees 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 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. Regularisation 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 in Richmond are shown in Figure 3-1. Data illustrated includes the median (middle ranked 24-hour average PM_{10} concentration), 25th and 75th percentile concentrations (indicated by the edges of the box), the concentrations within which 96% of the data lie (two standard deviations, indicated by the whiskers) and extreme values (indicated by the circles). Note that 2001 and 2002 are not represented in Figure 3-1 has the PM_{10} data set for those years is not complete.

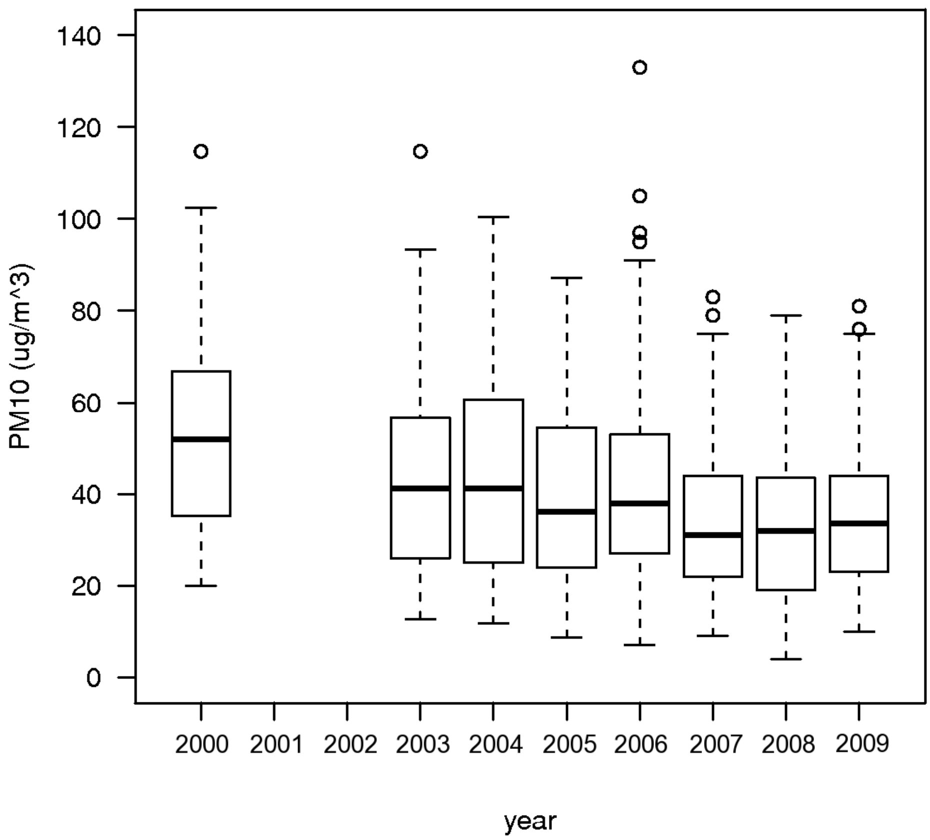

Figure 3-1: Distribution of 24-hour average PM_{10} concentrations in Richmond 2000 to 2009

Figure 3.1 shows PM_{10} concentrations may have decreased slightly from 2000 to 2009. A test of year-to-year differences in PM_{10} for statistical significance was carried out using a Kruskal-Wallis test. Results of these tests confirmed that data for the year 2000 was significantly different to data for the years 2007, 2008 and 2009 ($p=0.05$). A clearer indication of trends in PM_{10} over time will be obtained once year-to-year variations in meteorology have been allowed for.

3.2. Identifying and grouping days with highest PM_{10} concentrations

Meteorological data for the period 2000 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}.

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

	Period	PM_{10}	Wind speed (ms^{-1})	Temperature (^oC)	Wind direction (^oN)
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		✓	✓	✓
No of hours	5 pm to midnight		<1ms-1 <2 ms-1 <3ms-1	<1 ºC <5 ºC <10 ºC	

BRT analysis showed that 24-hour average wind speed and the average temperature between 8pm and midnight were the meteorological variables that best explained the variation in PM_{10} concentrations. Around 55% of the variability in PM_{10} concentrations was able to be explained by these meteorological variables.

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. 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 seven terminal nodes, one of which was designated as containing the days with the highest pollution potential and three others which all contained a high proportion of days when PM_{10} concentrations exceeded 50 µg m^{-3}. These four nodes are circled in red in Figure 3.2. Around 34% of the dataset are contained within these highest pollution nodes. The mean value of PM_{10} within these nodes are 86, 65, 49 and 47 µgm^{-3} and the average of the four nodes was 57 µg m^{-3}. The high pollution nodes are defined by the predictor variables detailed in Table 3-2.

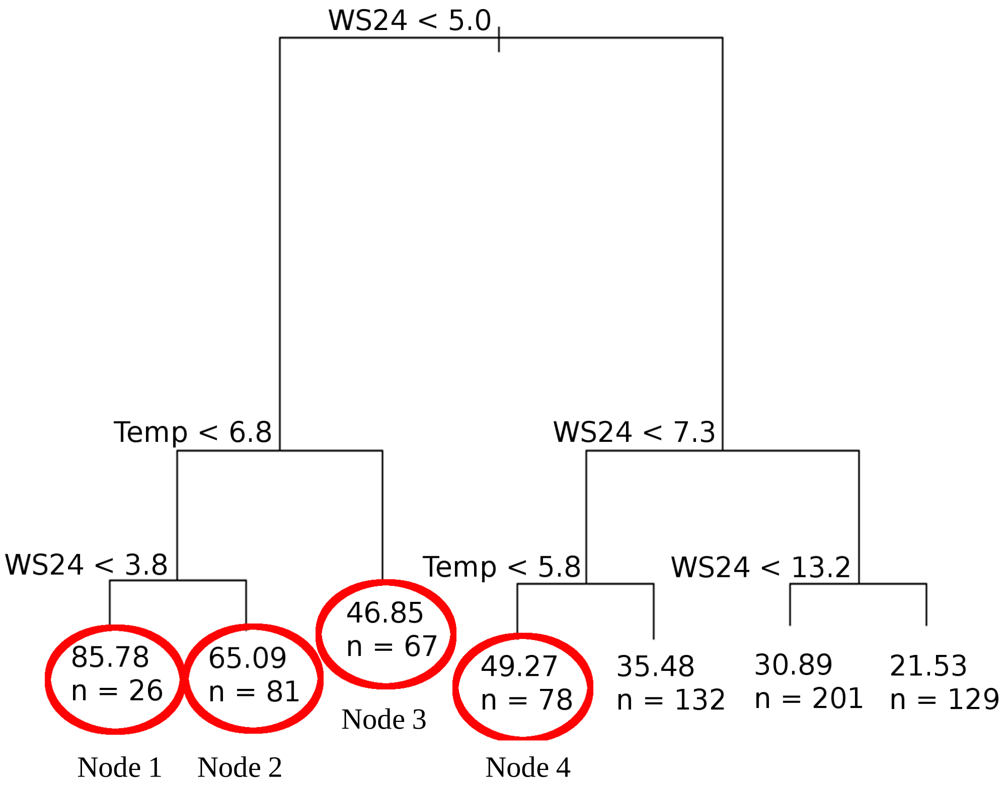

Figure 3-2: Normal regression tree to fit full 24-hour average PM_{10} data set, where WS24 is the 24-hour average wind speed and Temp is the 4-hour average temperature from 8pm to midnight

Table 3-2: Predictor variables which define the high pollution nodes

	NODE 1	NODE 2	NODE 3	NODE 4
4-hour Temperature from 8pm to midnight (^{o}C)	<6.8	<6.8	<6.8	<5.8
24 hour wind speed (m/s)	<3.8	3.8-5.0	<5.0	5.0-7.3
Mean PM_{10} (µg m^{-3})	86	65	47	49
NES Breaches %	96%	89%	38%	45%
Number of days within this node	26	81	67	78

The PM_{10} dataset for 2005 to 2009 includes 190 days when concentrations exceeded 50 µgm^{-3}. The greatest proportion (38%) of high pollution days occurred within node 2 (mean = 65.09). However, node 1 was really the highest pollution node as almost all of the days (96%) when node 1 (mean = 86 µg m^{-3}) conditions occurred the NES was breached. Moreover, the five highest PM_{10} concentrations in Richmond measured from 2000 to 2001 occurred under node 1 conditions. Although node 2 conditions resulted in lower average concentrations than node 1 conditions, a large proportion (89%) of node 2 conditions also resulted in NES breaches.

The four highest pollution nodes from Figure 3.2 contain 83% of the high pollution days (158 in total) as well as 94 days when PM_{10} concentrations were less than 50 µg m^{-3}.

Breaches of the NES occurred on 45% of the days when meteorological conditions were consistent with node 4 specifications and on 38% of the days when they were consistent with node 3 specifications.

3.3. Trend analysis of days with high pollution potential

Trends in 24-hour average PM_{10} concentrations within the 252 days identified as having meteorological conditions conducive to elevated pollution (nodes 1-4) are displayed in Figure 3-3. Results suggest a decrease in both median and upper quartile PM_{10} concentrations from 2000 to 2009. The median PM_{10} concentration decreased from around 67 µg m^{-3} in 2000 to 52 µg m^{-3} in 2009 (23% decrease). In comparison, a reduction in the upper quartile concentrations of around 34% was also observed. A test of year-to-year differences in PM_{10} for statistical significance was carried out using a Kruskal-Wallis test. The difference in the median for the data from the four highest nodes of 2000 and 2009 is significantly different. The trend observed in nodes 1-4 was investigated further through trend analysis on the node 1 and 2 data only (highest PM10 concentrations).

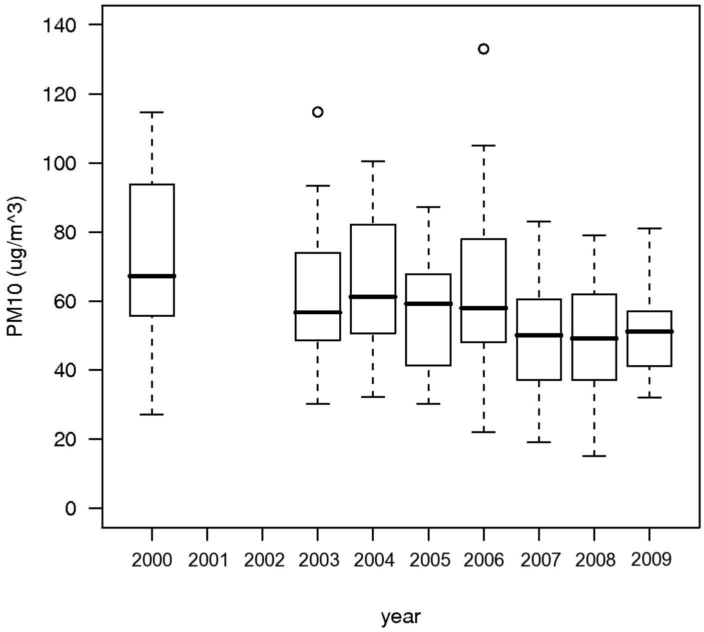

Figure 3-3: Variations in 24-hour average PM_{10} concentration for the 252 days when meteorological conditions were most conducive to elevated PM_{10} (nodes 1, 2, 3 and 4)

Figure **3-4** Figure 3-5shows an even greater decrease in median PM_{10} concentrations within the two highest PM_{10} nodes. The median PM_{10} concentration decreased from around 100 µg m^{-3} in 2000 to 60 µg m^{-3} in 2009 (40% decrease). In comparison, a reduction in the upper quartile concentrations of around 35% (115 to 75 µg m^{-3}) was also observed. A test of year-to-year differences in PM_{10} for statistical significance was carried out using a Kruskal-Wallis test. The difference in the median for the data from the two highest nodes of 2000 and 2009 is significantly different.

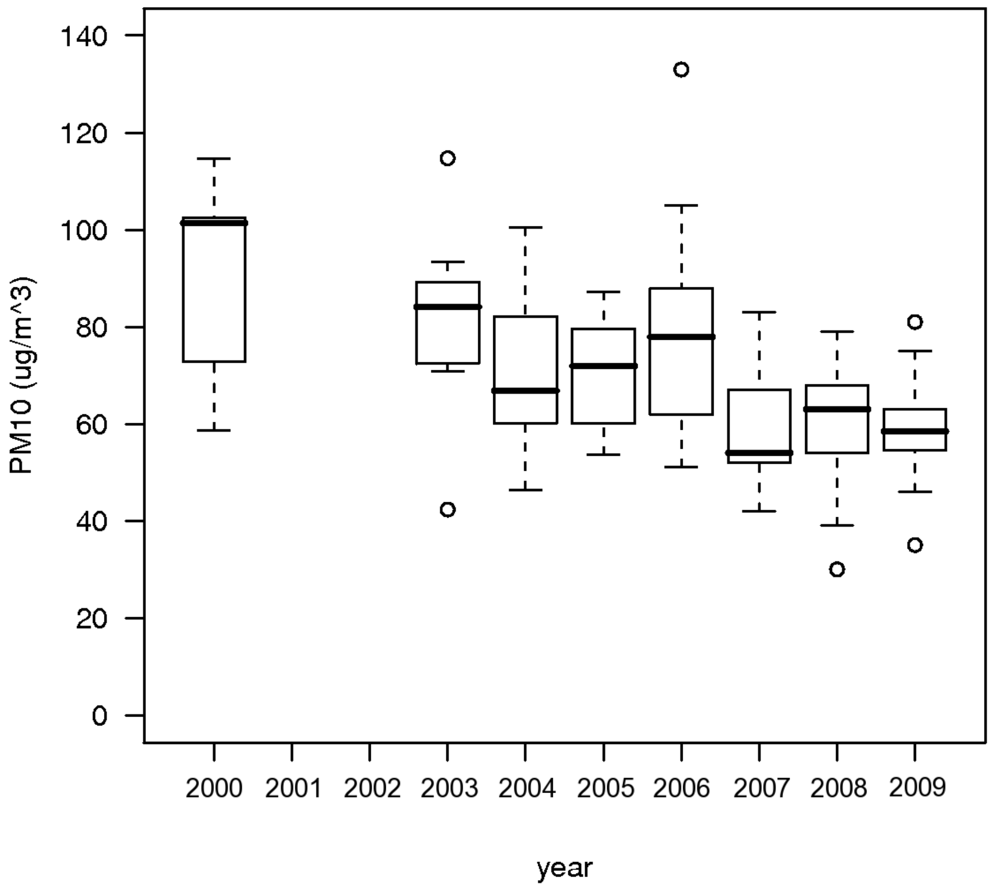

Figure 3-4: Variations in 24-hour average PM10 concentration for the 107 days when meteorological conditions were most conducive to elevated PM10 (nodes 1 and 2)

The smaller nodes 1&2 dataset, however, is limited for evaluation of year to year trends because of the smaller sample size. For example, year 2000, which is used to evaluate changes comprises only 9 data points and therefore estimated reductions contain a high degree of uncertainty. Notwithstanding this a reduction of around 30-40% would seem likely based on these data and on the upper quartile reduction from the 252 data points for nodes 1-4. This trend is important as it indicates an overall decline in the highest PM10 concentrations, which are most important in terms of compliance with the NES.

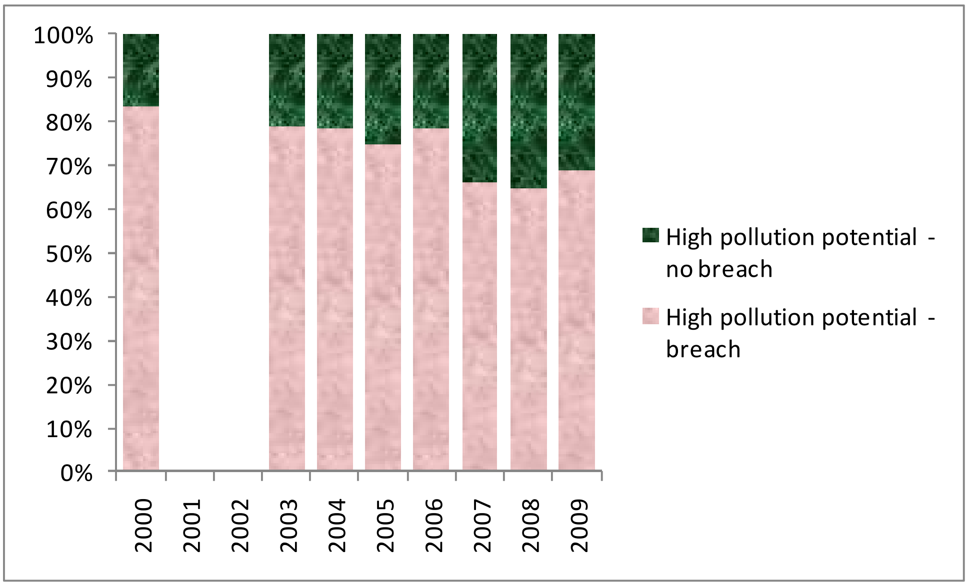

Figure 3-5: Year-to-year variation of the percentage of high potential pollution days with PM_{10} concentrations of greater than 50 µgm^{-3} (24-hour average).

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

Within the 252 high potential pollution days, the NES for PM_{10} (50 µgm^{-3}, 24-hour average) was exceeded at total of 158 times. Figure 3-5 shows the year-to-year variation in the percentage of high pollution days when the NES was breached. From 2000 – 2006 the proportion of high pollution days that resulted in NES breaches was around 70-80% compared with 45-55% for 2007 to 2009. This is a strong indicator that PM_{10} emissions have decreased in Richmond with the most noticeable decrease between 2006 and 2007 following the introduction of regulations on solid fuel burners.

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 described in Section 3.2. This involves normalising PM_{10} data from 2010 based on meteorological conditions associated with high pollution over the years 2000 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 wind speed is less than 7.3 ms^{-1} (e.g., nodes 1-5 from 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 (daily average wind speed less than 7.28 ms^{-1}).

- If the daily average wind speed is >5.03 ms^{-1} and the temperature is greater than 5.78 ºC do not adjust PM_{10} data.
- If daily average wind speed is less than 3.8 ms^{-1}, subtract 36.5 µg m^{-3} from PM_{10} value
- If daily average wind speed is less than 5.04 ms^{-1} and greater than 3.8 ms^{-1} subtract 15.8 µg m^{-3} from PM_{10} value
- If daily average wind speed is less than 5.04 ms^{-1} and the temperature is greater than 6.81 ºC subtract 11.4 µg m^{-3} from PM_{10} value
- If the daily average wind speed is >5.03 ms^{-1} and the temperature is less than 5.78 ºC, subtract 13.8 µg m^{-3} from PM_{10} value

Note the following:

* Wind speed refers to the 24-hour average wind speed from midnight to midnight on the sample day.

* Temperature refers to the 4-hour average temperature on the sample day between 8pm and midnight.

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

5. Conclusions

The objective of this study are to:

- assess the long term trend in PM_{10} air quality monitoring data for Richmond
- identify the meteorological conditions in Richmond that are likely to lead to high pollution events and
- provide a tool (excel spreadsheet) that will allow TDC staff to assess trends in PM_{10} emissions while taking account of the impact of variable meteorology.

Concentrations of PM_{10} measured in Richmond from 2000 to 2009 were used in the assessment. Data were adjusted to ensure equivalency in terms of monitoring method and site location. A total of 718 days of PM_{10} monitoring data was collected over the 9 year period. However, no data were available for 2001 and 2002 data were limited to August measurements.

An evaluation of summary statistics for the whole data set for each year suggests some decrease in the annual median. Trends in PM_{10} concentrations were further examined in this study by minimising the impact of meteorological conditions on PM_{10} concentrations.

The method used to account for year-to-year variation in meteorological conditions and to analyse the long term trend in PM_{10} concentrations was a combination of a boosted regression tree (BRT) analysis and normal regression tree analysis. The BRT was used to identify the most important meteorological parameters explaining the variation in PM_{10} values. Based on these important meteorological parameters, normal regression tree analysis was used to group PM_{10} values measured under similar meteorological conditions together. Meteorological conditions most conducive to elevated PM_{10} concentrations were identified as those detailed in Table 5-1.

Table 5-1: Predictor variables which define the high pollution nodes

	NODE 1	NODE 2	NODE 3	NODE 4
4-hour Temperature from 8pm to midnight (^oC)	<6.8	<6.8	<6.8	<5.8
24 hour wind speed (m/s)	<3.8	3.8-5.0	<5.0	5.0-7.3
Mean PM_{10} ($\mu g\ m^{-3}$)	86	65	47	49
NES Breaches %	96%	89%	38%	45%
Number of days within this node	26	81	67	78

Trend analysis was conducted on the group of 252 days when these meteorological conditions were met and on a subset of this group comprising nodes 1 and 2 (the two highest pollution nodes). Results suggested a decrease in PM_{10} concentrations over the period 2000 to 2009 of around 20-30%.

An evaluation of year to year variations in the prevalence of meteorological conditions conducive to high pollution and the number of days that these conditions resulted in breaches of 50 $\mu g\ m^{-3}$ also provided evidence of a decrease in PM_{10} emissions. The proportion of high pollution days resulting in NES breaches reduced from around 70-80% from 2000 to 2006 to 45-55% during 2007, 2008 and 2009.

A method has been developed to normalise (adjust up or down) future PM_{10} data to allow TDC staff to evaluate the ongoing effectiveness of air plan measures on PM_{10} concentrations.

The overall results of this study suggest that a significant decrease in PM_{10} concentrations has occurred in Richmond from 2000 to 2009.

6. Acknowledgements

This project was funded by the Foundation for Research Science and Technology through an Envirolink medium advice grant (Regional Council Advice number: 849-TSDC60).

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7. References

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Appendix A: Correlation of Library Roof and Plunket Monitoring site PM_{10} data

Figure A1 shows the relationship between PM_{10} concentrations measured at the Library and Plunket air quality monitoring sites during 2005. Based on this relationship, concentrations of PM_{10} measured at the Library site from 2000 to 2004 were adjusted upwards to be equivalent of the Plunket site measurements. The adjustment equation was as follows:

Plunket equivalent = 1.02 x Library PM_{10} + 1.5 $\mu g\ m^{-3}$

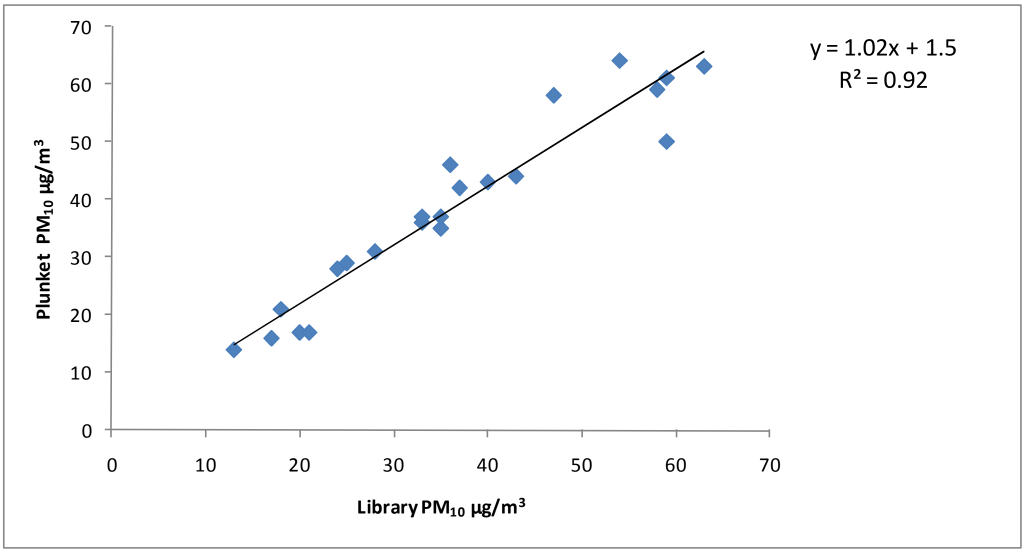

Figure A1: Relationship between PM_{10} concentrations measured at the Library and Plunket sites during 2005.

Appendix B: Wind roses from Nelson City Airport and MDC Air Quality Monitoring sites

Wind roses generated by Tasman District Council.

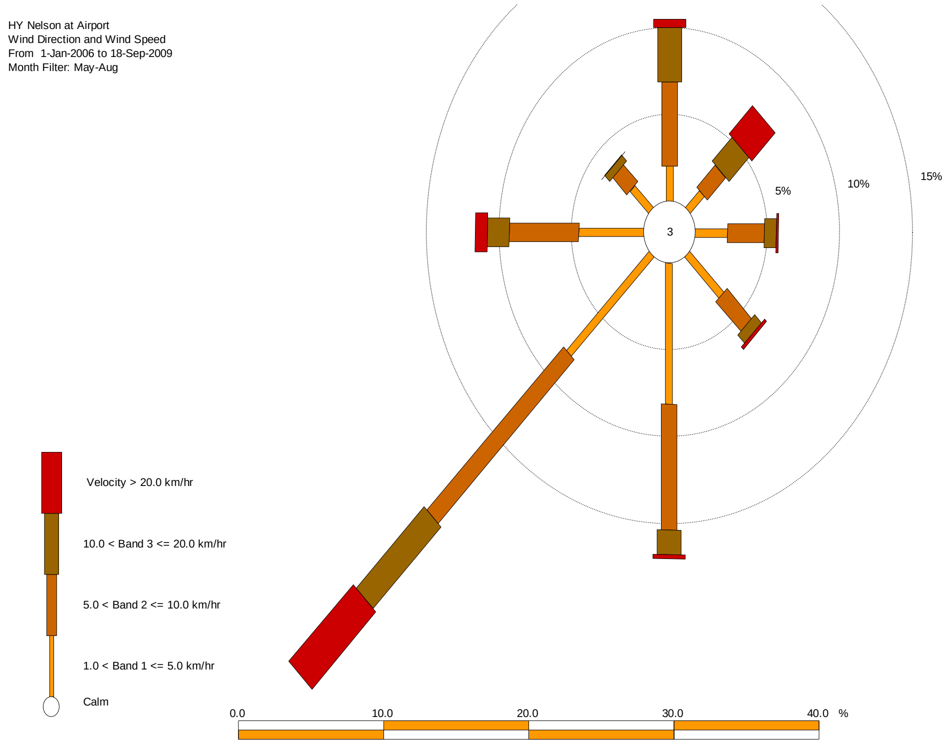

Figure B1: Wind rose for Nelson Airport, May to August, 2006 to 2009

Number of data points read	11795
Number of Velocities outside limits	0
Number of Directions <0.0 or >360.0 degrees	0
Number of Data points used	11795
Limits of valid velocities is 0.0 to 150.0 km/hr	

Direction	Band 1	Band 2	Band 3	Band 4	Total
337.5 - 22.4	2.0	4.8	3.1	0.5	10.5
22.5 – 67.4	1.4	1.8	1.9	2.3	7.5
67.5 – 112.4	2.2	2.5	0.8	0.2	5.8
112.5 – 157.4	3.3	2.5	0.6	0.2	6.6
157.5 – 202.4	8.1	7.2	1.4	0.2	16.9
202.5 – 247.4	8.1	13.3	6.6	6.3	34.2
247.5 – 292.4	4.5	4.8	1.5	0.8	11.6
292.5 – 337.5	1.8	1.4	0.4	0.0	3.7
Total	31.4	38.3	16.3	10.6	96.7
		Calm 3.3			

Velocity band ranges:

0.0 < calm < = 1.0	1.0 < Band 1 < = 5.0
5.0 < Band 2 < = 10.0	10.0 < Band 3 < = 20.0
20.0 < Band 4	

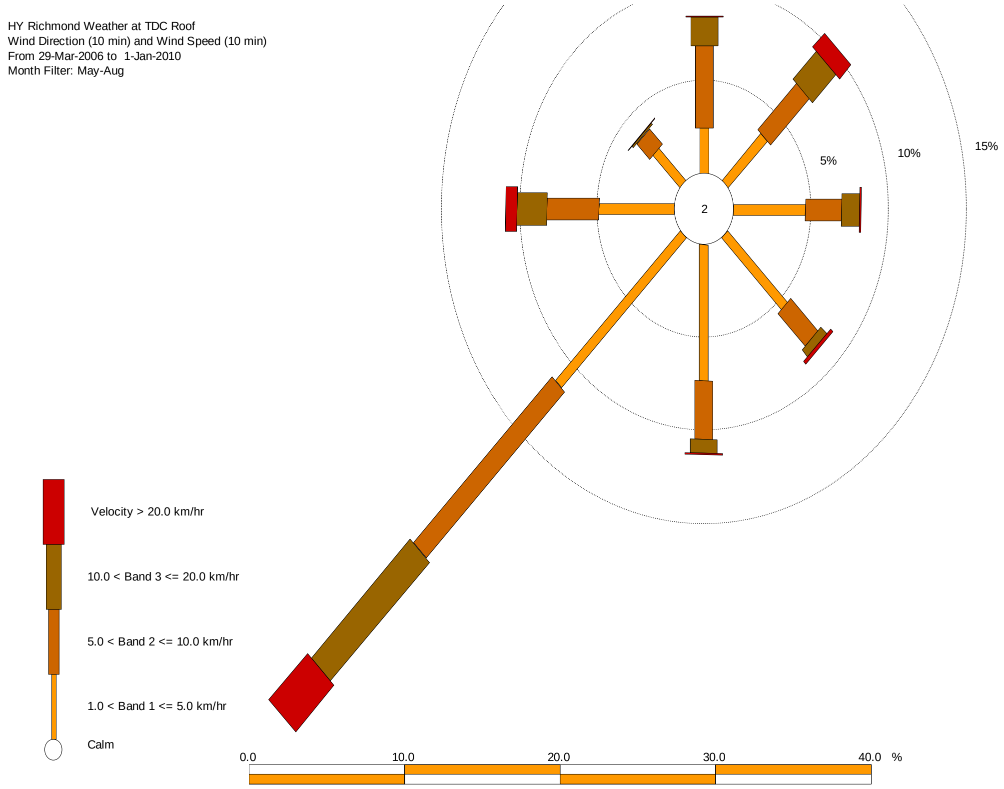

Figure B2: **Wind rose for Tasman District Council Roof, May to August, 2006 to 2009**

Number of data points read	66814
Number of Velocities outside limits	0
Number of Directions <0.0 or >360.0 degrees	0
Number of Data points used	66814
Limits of valid velocities is 0.0 to 150.0 km/hr	

Direction	Band 1	Band 2	Band 3	Band 4	Total
337.5 - 22.4	2.5	4.4	1.5	0.1	8.5
22.5 – 67.4	3.6	3.5	2.1	1.1	10.3
67.5 – 112.4	4.6	2.3	1.1	0.1	8.2
112.5 – 157.4	5.5	2.4	0.5	0.2	8.6
157.5 – 202.4	7.3	3.1	0.7	0.1	11.2
202.5 – 247.4	11.4	12.6	9.0	3.5	36.5
247.5 – 292.4	4.9	3.3	1.9	0.7	10.8
292.5 – 337.5	2.5	1.2	0.1	0.0	3.8
Total	42.2	32.9	17.0	5.8	97.9
		Calm 2.1			

Velocity band ranges:

0.0 < calm < = 1.0	1.0 < Band 1 < = 5.0
5.0 < Band 2 < = 10.0	10.0 < Band 3 < = 20.0
20.0 < Band 4	

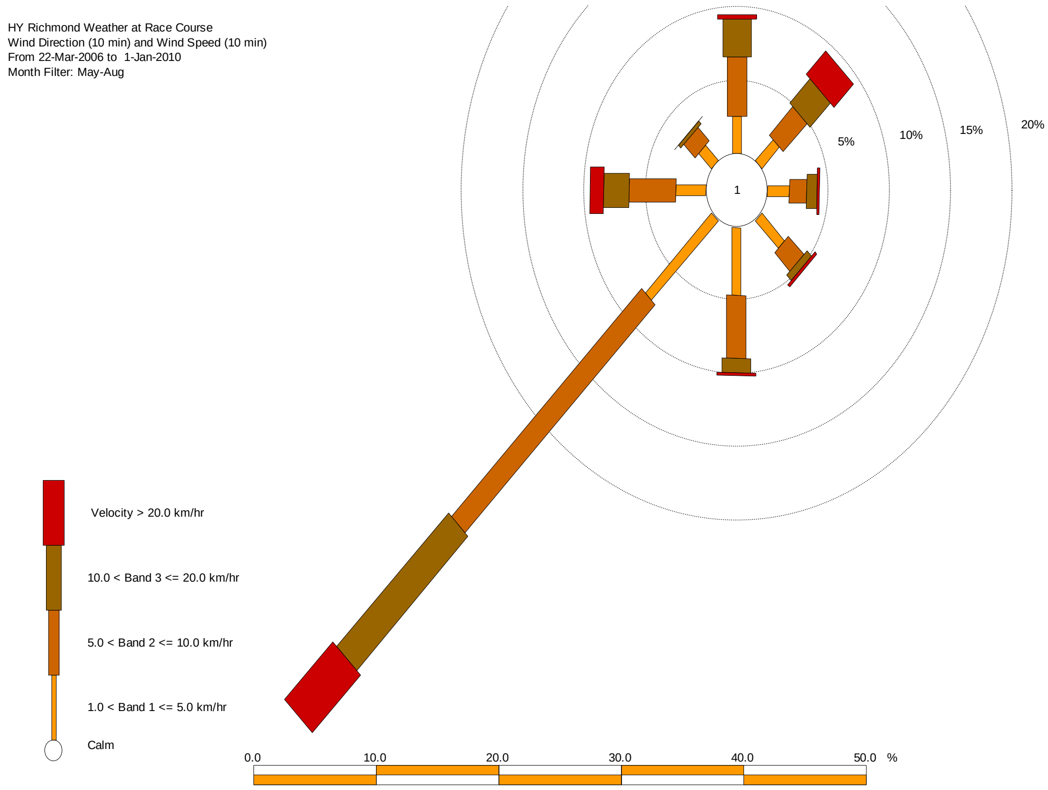

Figure B3: **Wind rose for Race Course, May to August, 2006 to 2009**

Number of data points read	70675
Number of Velocities outside limits	0
Number of Directions <0.0 or >360.0 degrees	0
Number of Data points used	70675
Limits of valid velocities is 0.0 to 150.0 km/hr	

Direction	Band 1	Band 2	Band 3	Band 4	Total
337.5 - 22.4	2.5	4.1	2.6	0.3	9.5
22.5 – 67.4	2.0	2.8	2.3	2.2	9.4
67.5 – 112.4	1.8	1.4	0.8	0.2	4.2
112.5 – 157.4	2.6	1.8	0.6	0.2	5.2
157.5 – 202.4	4.6	4.3	1.0	0.2	10.1
202.5 – 247.4	7.7	22.0	12.9	5.5	48.1
247.5 – 292.4	2.5	3.8	2.1	1.1	9.5
292.5 – 337.5	1.5	1.3	0.2	0.0	3.0
Total	25.3	41.4	22.5	9.7	98.9
		Calm 1.1			

Velocity band ranges:

0.0 < calm < = 1.0	1.0 < Band 1 < = 5.0
5.0 < Band 2 < = 10.0	10.0 < Band 3 < = 20.0
20.0 < Band 4	