Masterton particulate monitoring methods and inter-site comparison, winter 2012

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GW/ESCI-T-13/25

March 2013

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The report may be cited as:

Mitchell, T. 2013. *Masterton particulate monitoring methods and inter-site comparison, winter 2012*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-13/25.

Executive summary

During winter 2012 the concentration of particulate matter (PM_{10} and $PM_{2.5}$) in outdoor air was measured at Greater Wellington Regional Council's permanent monitoring station in Masterton using three different measurement methods. Concurrent PM_{10} monitoring was also undertaken at a second site approximately 1 km to the southwest of the permanent monitoring site.

Five PM_{10} exceedances of the National Environmental Standards for Air Quality (NES-AQ) were recorded at the permanent monitoring station located at Wairarapa College using the existing compliance monitoring instrument (FH62). In contrast there were six to eight exceedances recorded by the 5014i instrument co-located at the Wairarapa College site. The 5014i instrument is less prone to the loss of the semi-volatile fraction of particulate matter which can be a significant component of ambient particulate matter when wood smoke levels are high. Using simple linear regression an adjustment factor was derived for converting historical FH62 monitoring results for 5014i equivalency. If the 5014i is adopted as the primary NES-AQ compliance monitoring instrument the number of exceedances reported may increase even if domestic emissions remain static. $PM_{2.5}$ concentrations at Wairarapa College site were frequently above the World Health Organisation recommended guideline, including nights when PM_{10} was below the NES-AQ threshold.

This study confirms that winter air quality measured at the second site located at Chanel College was poorer than that measured at the existing NES-AQ compliance monitoring site at Wairarapa College. There were 21 exceedances recorded by 5014i at the Chanel College site. The reason for the greater number of exceedances at this site was most likely related to patterns of down slope cold air drainage which entrain and transport emissions from domestic fires in the Masterton urban area towards the southwest. This finding has important implications for air quality management as greater reductions in domestic emissions than previously thought may be required to ensure future compliance with the NES-AQ.

It is recommended that a further 12 months of monitoring is carried out at the Chanel College site to assess inter and intra annual variation in PM_{10} levels. Further investigation into the spatial variability of PM_{10} concentrations is also required to determine the optimum location for PM_{10} compliance monitoring in the Masterton urban area.

Contents

1. Introduction and background

1.1 Inter-methods comparison

The measurement of suspended particulate matter in air is not straightforward. PM_{10} is a complex mixture of substances and the measurement method used can significantly influence the result. PM_{10}, and more recently $PM_{2.5}$, has been measured by Greater Wellington Regional Council (GWRC) at Wairarapa College using different methods (Table 1.1).

Table 1.1: Monitoring methods used at Wairarapa College by GWRC between 2003 and 2012. The grey shading indicates timing of instrument deployment at Wairarapa College

Method	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
High Volume sampler (PM_{10})										
TEOM (PM_{10})										
FH62 (PM_{10})										
5030 ($PM_{2.5}$)										
5014i (PM_{10})										

Although the TEOM, FH62 and 5014i can be used for National Environmental Standard for Air Quality (NES-AQ) PM_{10} compliance monitoring, these instruments do not produce identical results when measuring the same atmosphere. The variation in measured mass concentration of PM_{10} obtained by different monitoring methods is due to different measurement technologies (Bluett et al. 2007) as well as the random component of measurement error.

Due to the differences in monitoring methods it is common practice to co-locate two instruments for a period of time to assess their measurement equivalency. If a consistent relationship between the two instruments is found then an adjustment factor can be derived so that historical data collected by one method may be adjusted to be equivalent to measurements made by the newer method or vice versa. Advances in measurement technology and instrument design necessitate upgrading monitoring equipment as older methods become outdated or no longer available. For example, Thermo Scientific have released the 5014i model to replace the FH62.

1.2 Inter-site comparison

When the Wairarapa College monitoring site was established in 2002 the monitoring objective was consistent with monitoring PM_{10} at a *residential-neighbourhood* spatial scale (ie, 0.5 to tens of kilometres) as outlined in the then national *Good-practice guide for air quality monitoring and data management* (MfE 2000). With the introduction of the NES-AQ in 2005, the national focus for PM_{10} monitoring shifted to monitoring in the 'worst' location in an airshed (MfE 2009). This monitoring objective is probably best described as *peak-neighbourhood* spatial scale which represents concentrations over metres to tens of metres. Airshed modelling undertaken as part of a NIWA

FRST programme indicated that the Wairarapa College site was located just within the area in which the maximum ground level concentration for the Masterton urban area was predicted to occur (Gimson et al. 2005). Therefore it was considered that the monitoring station at Wairarapa College was also suitable for NES-AQ compliance monitoring.

In winter 2010, a GNS Science FRST programme collected and analysed particulate matter at three sites in the Masterton urban area for receptor modelling to examine difference in the relative source contributions at an hourly resolution (Ancelet et al. 2012). The results of this study, published in early 2012, indicated that concentrations at Chanel College, although measured by a non-reference method (E-BAM), were substantially higher than those measured at Wairarapa College site between July and September 2010. The study also found that the concentration of PM_{10} attributed to “biomass burning” (ie, wood smoke) was substantially higher at the Chanel College site than at the Wairarapa College site over the same period. The higher PM_{10} concentrations at Chanel College was attributed to the greater number of emission sources (ie, residential dwellings) upwind in the katabatic flow that occurred on cold stable nights (Ancelet et al. 2012).

1.3 PM_{10} and $PM_{2.5}$ comparison

It is now widely recognised that the adverse health effects associated with exposure to $PM_{2.5}$ are greater than those associated with PM_{10}. For this reason, various agencies, including the World Health Organisation (WHO), US Environmental Protection Agency (US EPA) and the European Union have all adopted targets or standards for $PM_{2.5}$. $PM_{2.5}$ is now becoming the air quality indicator of choice internationally due to its widespread use in epidemiological studies; it is more ubiquitous in the environment and is typically anthropogenic in origin and therefore more easily controlled by intervention measures (Air Quality Technical Advisory Group 2009).

The WHO (2006) recommends guidelines for both short and long term exposure to PM_{10} because the coarse fraction (between 2.5 and 10 μm) cannot be considered harmless. The WHO daily and annual guidelines for PM_{10} have the same numerical values as the NES-AQ – however, the WHO PM_{10} guidelines are based on the assumption that a $PM_{2.5}$:PM_{10} ratio of 0.5 exists. Therefore, the PM_{10} guideline may not afford the intended level of protection if the actual $PM_{2.5}$:PM_{10} ratio is greater than 0.5.

2. Aims and methods

2.1 Aims

This study has three aims:

i) **PM_{10} inter-method comparison**

To assess the equivalency of PM_{10} measurements made by two different instruments co-located at the permanent NES-AQ compliance monitoring site at Wairarapa College. A further aim is to determine a suitable adjustment factor to correct historical data when the new generation analyser (5014i) replaces the existing compliance monitoring instrument (FH62).

ii) **PM_{10} inter-site comparison**

To establish the whether there is any statistically significant and environmentally meaningful difference in PM_{10} levels measured at the permanent NES-AQ monitoring site and at a temporary monitoring site established at Chanel College during winter 2012. A further aim is to explore the influence of meteorology on any observed site differences in PM_{10} levels.

iii) **$PM_{2.5}$ and PM_{10} comparison**

To explore the relationship between $PM_{2.5}$ concentration and PM_{10} concentrations measured by two different methods at Wairarapa College in order to assess the suitability of these data for establishing the $PM_{2.5}$:PM_{10} ratio.

2.2 Monitoring sites

The study was undertaken from May to September 2012 in Masterton, a large rural town with a population of around 20,200, situated on the Wairarapa valley plains. PM_{10} has been monitored in Masterton at the Wairarapa College site since 2002 with zero to five exceedances of the NES-AQ daily average concentration threshold of 50 $\mu g/m^3$ recorded each year during the winter months. These exceedances occurred on nights where there was a significant contribution of particulate (primarily as $PM_{2.5}$) emitted from domestic fires in the presence of meteorological conditions that restricted the dispersion of these emissions (ie, low surface wind speeds and temperature inversions) (Mitchell 2012).

Air quality analysers were located at two sites within Masterton (Figure 2.1). The Wairarapa College monitoring site (red dot on Figure 2.1) is a permanent air quality monitoring station operated by GWRC. The station is located in the grounds of the Wairarapa College with the nearest residential house 86 m to the southwest. The closest major road, Cornwall Street, is located approximately 122 m southwest. The station contained the following monitoring instruments: FH62 (PM_{10}), 5014i (PM_{10}), SHARP 5030 ($PM_{2.5}$), API300E (carbon monoxide) and API200E (nitrogen oxides). Meteorological parameters were also measured at mast heights of 5m, 10m and 15m.

The temporary Chanel College monitoring site (green dot on Figure 2.1) was established on the edge of the school grounds with the nearest residential house 15 m to the northwest. The closest major road, Herbert Street, is located approximately 82 m to the northeast. The station contained a 5014i (PM_{10}) analyser and meteorological parameters were measured at a height of 6 m.

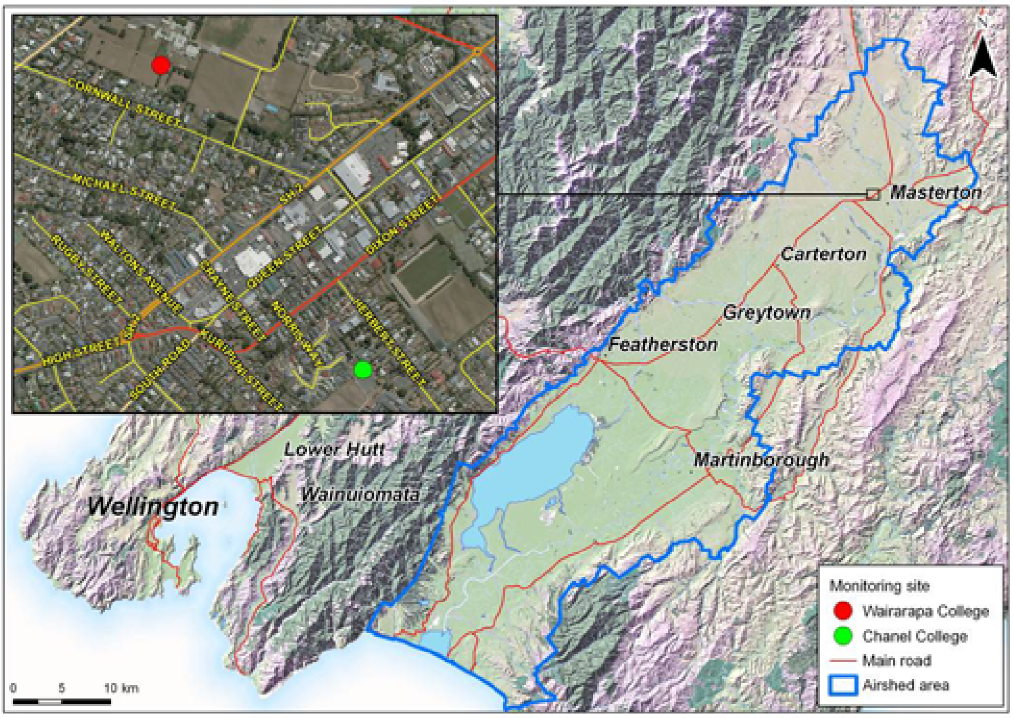

Figure 2.1: Map of the Wairarapa airshed (outlined in blue). Photo inset shows the location of Greater Wellington's permanent air quality monitoring station at Wairarapa College (NZTM E 1822750 N 5463157) and the temporary site at Chanel College (NZTM E 1823278 N 5462377) during winter 2012

The location of the two monitoring sites with respect to surrounding emissions density by census area unit is shown in Figure 2.2. Emissions density was calculated based on the number of households that reported using wood or coal for home heating in the 2006 census and information in the 2008 Masterton emissions inventory on wood burner age (Wilton & Baynes 2008).

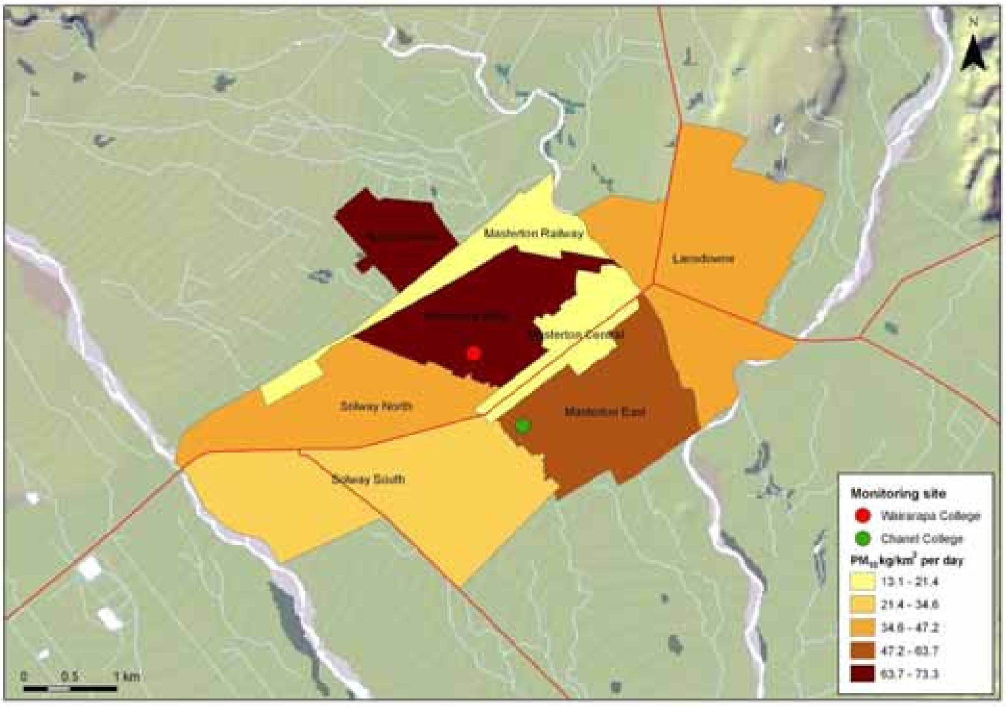

Figure 2.2: PM_{10} emissions estimates (kg/km²/day) for the Masterton urban area delineated by census area unit for a winter day in July 2008

2.3 Instruments

2.3.1 FH62

The Thermo Scientific series FH62 C14 is an USEPA Automated Equivalent Method for PM_{10} monitoring (EQPM-1102-150) and therefore is a NES-AQ compliant monitoring method. The sample inlet heater was set to 40°C in accordance with recommended best practice (MfE 2009). The filter tape was set to advance at midnight. All concentrations were corrected to 0°C and standard pressure. Thermo Scientific PM_{10} heads (20XXA467460903 and 20XXA459590803) were used interchangeably following a monthly cleaning schedule.

2.3.2 5014i

The Thermo Scientific series 5014i beta attenuation continuous instrument is an USEPA Automated Equivalent Method for PM_{10} monitoring (EQPM-1102-150) and therefore is a NES-AQ compliant monitoring method. In contrast to the FH62, the instrument controls moisture level in the sampled air through a dynamic sample heating system based on a relative humidity sensor upstream of the sample that has been set to a threshold of 35%. There is no temperature sensor for the inlet heater - although the temperature of the sample air is measured close to the sampling head. The temperature of the sampled air during the data collection period ranged from 16.6 °C to 31.6 °C (mean of 22.9 °C) at Chanel College and from 15.9 °C to 35.2 °C (mean of 22.8 °C) at Wairarapa College. The filter tape was set to advance at midnight. All concentrations were corrected to 0°C and standard pressure. PM_{10} heads (20XXA467460903 and 20XXA459590803) were used interchangeably following a monthly cleaning schedule.

2.3.3 SHARP 5030

The Thermo Scientific model SHARP 5030 has USEPA designation as an Automated Equivalent Method for $PM_{2.5}$ (EQPM-0609-184). This instrument uses both aerosol light scattering (nepholometer) and beta attenuation to measure particulate mass. The instrument controls moisture level in the sampled air through a dynamic sample heating system based on a relative humidity sensor upstream of the sample that has been set to a threshold of 35%.

2.4 Data acquisition system (DAS)

PM_{10} and $PM_{2.5}$ were measured continuously with the FH62, 5014i and SHARP 5030 connected by digital interface to IQUEST 4483 data loggers. Ambient air was sampled at 10 to 20 second intervals (depending on the number of instruments at a site) and these measurements were recorded by the data logger as 10-minute averages at New Zealand Standard Time. These data were telemetered via General Radio Packet Transmission to Hydrotel where they were uploaded to the Hilltop time series database at four hourly intervals.

A software fault in the logger programme at Chanel College meant that the telemetered data from this site failed quality assurance protocols and therefore were not suitable for analyses. Instead the data were downloaded directly from the 5014i internal data logger which recorded measurements as 1-hour averages.

2.5 Datasets and statistical analyses

One-hour averages for PM_{10}, $PM_{2.5}$ and meteorological variables were calculated using Hydrotel and downloaded directly from the 5014i PM_{10} analysers. These one-hour averages were aggregated using R version 2.13.0 (R Development Core Team 2011) to produce 24-hour averages (with at least 75% data capture) for the period midnight to midnight (ie, 00:00 to 23:00).

The difference between daily average PM_{10} measurements obtained by FH62 and 5014i instruments co-located at Wairarapa College site was assessed graphically using a modified Bland-Altman plot (Bland & Altman 1999). The Bland-Altman approach plots the difference between the measurements against the mean of the two measurements in order to assess bias and non-constant variance across the range of measured values.

In this study it was assumed that the FH62, 5014i and SHARP 5030 instruments have the same level of measurement error. The instrument manufacturer, Thermo Scientific, reports a precision of ±2 $\mu g/m^3$ (24-hour) for each instrument model. It was therefore assumed that the uncertainty in the difference between 24-hour measurements made by the co-located instruments is the sum of the individual measurement error, ie, ±4 $\mu g/m^3$ (Taylor 1997). Accordingly, if the difference between 24-hour PM_{10} measurements made at the same site by these two instruments was within ±4 $\mu g/m^3$ it was assumed that there may have been no actual difference between the measurements.

The relationship between PM_{10} measurements obtained by FH62 and 5014i instruments co-located at Wairarapa College site was also investigated by linear regression using ordinary least squares (OLS) and the reduced major axis (RMA) method (Davis 1986). RMA regression has been recommended by Ayers (2001) to be the appropriate method for comparison of air quality data obtained by different monitoring methods since it does not assume that the independent variable (x) is known without error. The main advantage of OLS over RMA is the ability to perform residual diagnostics in order to confirm that the assumptions underlying linear regression are met (ie, the model residuals are independent and identically distributed) and to assess the goodness of fit of the model.

Simple and multiple linear regressions were performed using R version 2.13.0 (R Development Core Team 2011). Data aggregation, diurnal plots, time series, scatter plots, wind roses and polar plots were produced using the R package *Openair* (Carslaw & Ropkins 2012).

3. Results

A statistical summary of the FH62, 5014i and SHARP 5030 measurements from the two sites during winter 2012 is shown in Table 3.1. The daily time series of PM_{10} and $PM_{2.5}$ are shown in Figures 3.1 and 3.2 and the full data set of 24-hour averages is presented in Appendix 1. There were periods of missing data for each instrument due to planned services, calibrations and PM head cleaning. There were also periods of missing record due to instrument malfunctions, insects and power outages.

Table 3.1: Summary of PM_{10} and $PM_{2.5}$ µg/m^3 (24-hour averages with at least 75% data capture) measurements by monitoring method and site between 17 May and 20 September 2012

	Wairarapa College				Chanel College
Parameter	PM_{10}	PM_{10}	PM_{10}	$PM_{2.5}$	PM_{10}
Instrument	FH62	5014i	5014i	SHARP 5030	5014i
DAS	Telemetry	Telemetry	Instrument	Telemetry	Instrument
Mean	22.5	23.5	23.4	22.0	30.0
Median	19.2	20.4	20.1	18.9	26.5
SD	12.4	13.5	13.4	14.8	17.9
Inter-Quartile Range	13.9 - 27.2	13.9 - 29.3	13.9 – 29.1	11.2 - 27.2	15.4 - 40.9
Minimum	4.8	2.7	2.6	1.6	5.0
Maximum	56.1	62.4	61.9	79.7	85.4
No. ≥ 51 µg/m^3	5	6	8	32[1]	21
Sample size	122	95	99	117	126
Data capture rate	96.1%	74.8%	77.9%	92.1%	99.2%

[1] Refers to exceedances of the WHO guideline for $PM_{2.5}$ of 25 µg/m^3 (24-hour average)

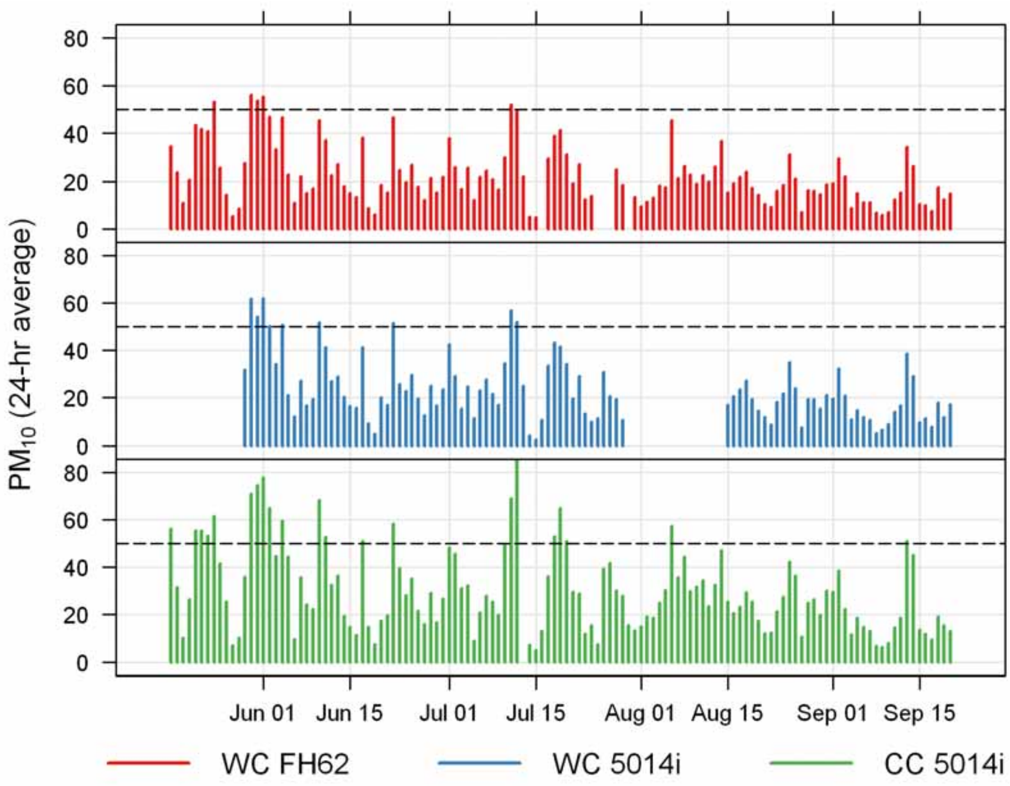

Figure 3.1: Time series of PM_{10} µg/m³ (24-hour averages with at least 75% data capture) measured at Wairarapa College (WC) and Chanel College (CC) between 17 May and 20 September 2012 by different monitoring methods. The dashed line shows the NES-AQ daily threshold of 50 µg/m³

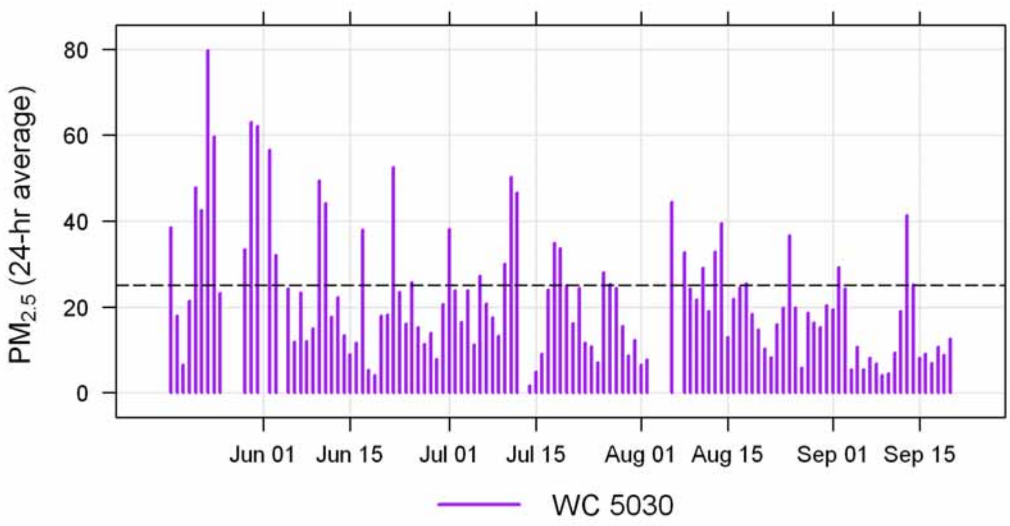

Figure 3.2: Time series of $PM_{2.5}$ µg/m³ (24-hour averages with at least 75% data capture) measured at Wairarapa College (WC) between 17 May and 20 September 2012. The dashed line shows the WHO (2006) daily threshold of 25 µg/m³

3.1 Inter-methods comparison: Wairarapa College

3.1.1 PM_{10} concentrations

PM_{10} levels measured by two different methods (5014i and FH62) co-located at Wairarapa College showed the same diurnal evening and morning peaks (Figure 3.3). PM_{10} concentrations measured by 5014i during the evening hours appeared to be higher than those measured by FH62, although there was overlap in the 95% confidence intervals of the respective means. A paired t test (assuming equal variance) shows that the average difference in paired 24-hour averages of 1.9 μg/m^3 [1.5, 2.3 at the 95% confidence interval] is different from zero. Although this difference is statistically significant, the magnitude of the difference is small and within the expected measurement error range. Figure 3.3 shows the 24-hour averages obtained from the 5014i is positively skewed in the upper tail of the distribution compared to measurements obtained with the FH62. There were some slight differences in the 5014i 24-hour averages calculated using the data that was obtained via telemetry from a data logger compared to those that were downloaded from the instrument. This requires further investigation as it may be that there were subtle differences between instrument and the data logger regarding the handling of sub-10 minute averaging periods.

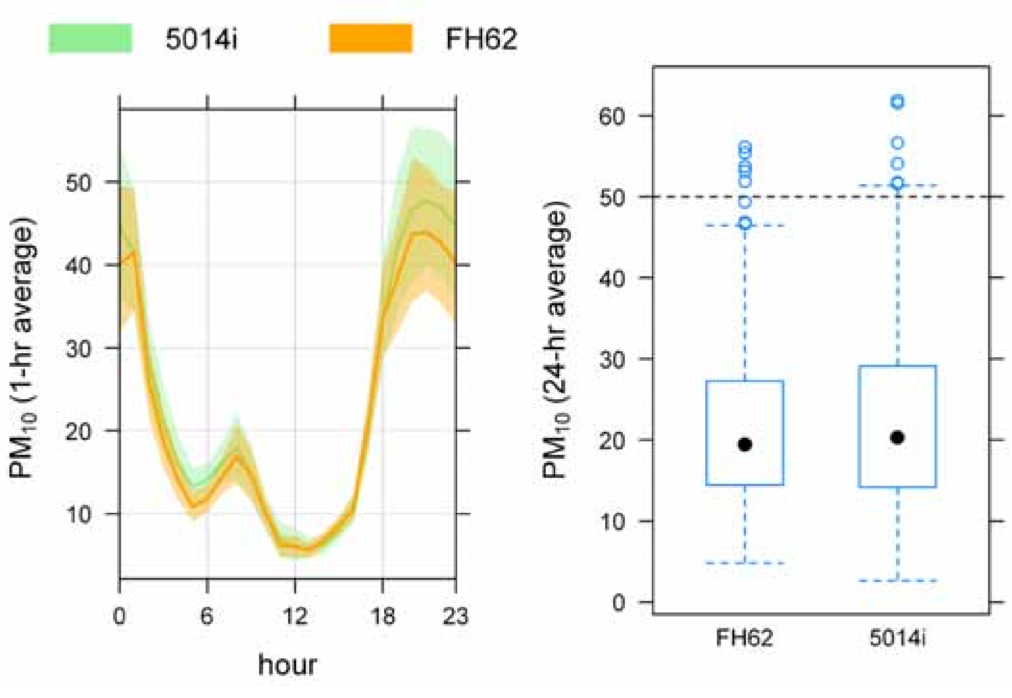

Figure 3.3: Left: Diurnal plot of aggregated PM_{10} μg/m^3 (1-hour average) measured by 5014i (green) and by FH62 (orange) at Wairarapa College during winter 2012. The shaded areas show 95% confidence intervals in the mean. Right: Box plot of PM_{10} μg/m^3 (24-hour average) measured by 5014i and by FH62 at Wairarapa College. The dashed line shows the threshold for the NES-AQ and the black dots show the median

3.1.2 Relationship between measurement methods

In order to assess the relationship between the two measurement methods, the 24-hour average 5014i measurements were regressed against FH62 measurements (Figure 3.4). Both OLS and RMA regression showed close correlation of the paired measurements during the study period (R^2 = 0.98, slope = 1.09 [1.08, 1.10]). The 95% confidence interval of the OLS intercept contained zero and therefore was dropped from the linear regression model.

In order to assess variability in the magnitude of the differences in same day 24-hour PM_{10} averages measured by the two instruments across the entire range of values, the differences were plotted against the mean concentration of both methods (Figure 3.5). There appears to be a tendency for the differences to be positively biased with increasing mean concentration as shown by linear regression of difference between measurements on mean concentration (R^2 = 0.48, slope = 0.085 [0.075, 0.096]). In other words, the tendency for the 5014i to overestimate concentrations relative to the FH62 was more pronounced at higher PM_{10} concentrations.

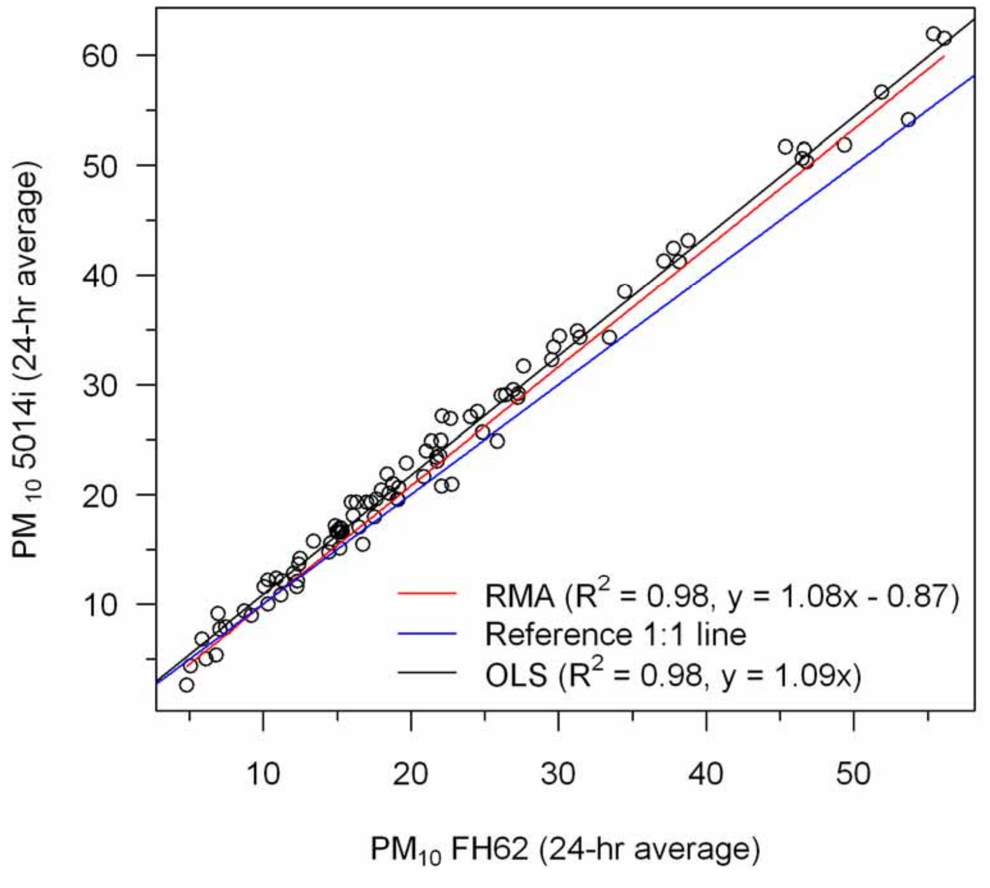

Figure 3.4: Correlation scatter plot and fitted linear regression lines for the 24-hour averaged PM_{10} data from the 5014i and FH62 monitors at Wairarapa College site (90 data points with 100% data capture) from 26 May to 20 September 2012

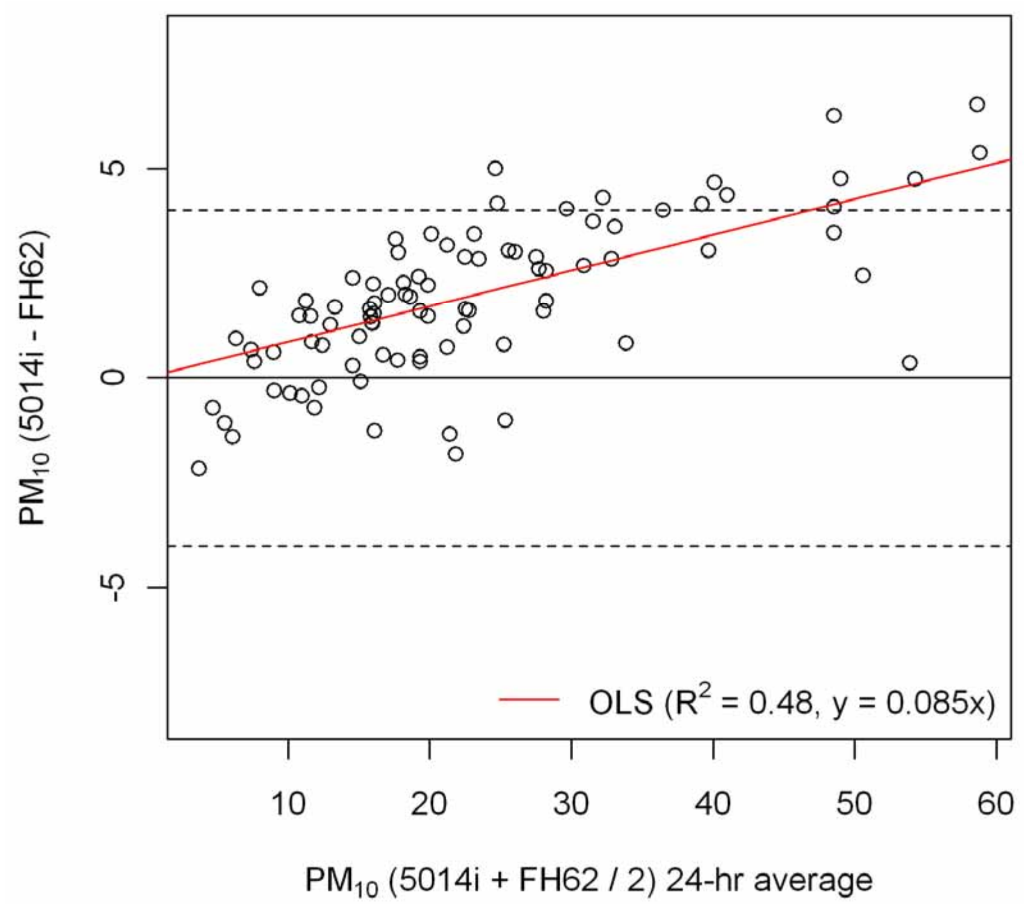

Figure 3.5: Bland-Altman plot of the difference in μg/m³ between daily pairs of 5014i and FH62 PM_{10} measurements versus the mean concentration of both methods at Wairarapa College (90 data points with 100% data capture) from 26 May to 20 September 2012. A difference of zero indicates perfect agreement. The dashed lines represent the combined uncertainty of the difference between measurements (±4 μg/m³). The OLS regression line is shown in red

3.2 Inter-site comparison: Chanel College and Wairarapa College

3.2.1 PM_{10} concentration

PM_{10} levels measured by two 5014i instruments, one sited at Wairarapa College and one at Chanel College, showed similar diurnal evening and morning peaks (Figure 3.6). Apart from during the middle part of the day, averages for each hour of the day recorded at Chanel College were higher than those found at Wairarapa College, although there is overlap in the 95% confidence intervals of the respective means. The distribution of PM_{10} 24-hour averages from Chanel College were positively skewed compared to those from Wairarapa College (Figure 3.6).

A paired t test (assuming unequal variance) of the difference in 24-hour averages recorded at each site found an average site difference of 5.7 μg/m³ [4.3, 7.2 at the 95% confidence interval]. This difference is statistically significant and the magnitude of the difference is greater than the expected combined uncertainty of the two measurement devices.

Based on matched 24-hour periods where there was 100% data capture at each site (ie, 29/5/2012 to 20/09/2012, n=91) there were the equivalent of 14 exceedances of the NES-AQ at Chanel College and nine at Wairarapa College recorded by the 5014i instrument.

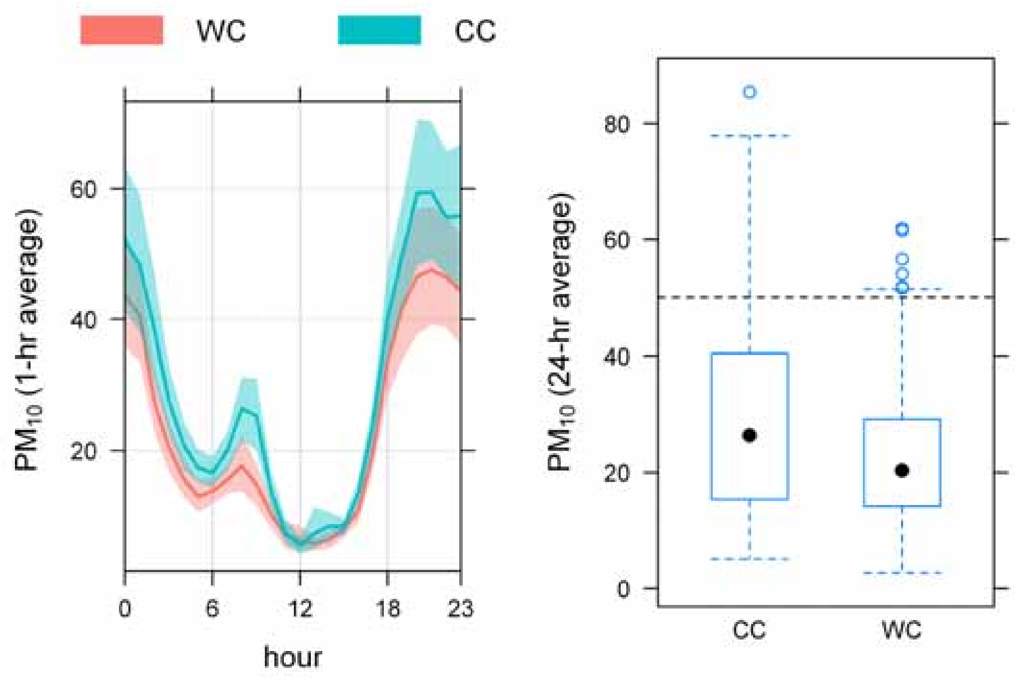

Figure 3.6: Left: Diurnal plot of aggregated PM_{10} 1-hour averages measured by 5014i at Wairarapa College (red) and Chanel College (blue) during winter 2012. The shaded areas show 95% confidence intervals in the mean. Right: Box plot of 24-hour average PM_{10} measured by 5014i at Wairarapa College and at Chanel College. The dashed line shows the threshold for the NES-AQ. The black dots show the median

3.2.2 Relationship between sites

There was a close relationship between 24-hour averages recorded at Chanel College and those found at Wairarapa College (R^2=0.92) (Figure 3.7). The OLS slope was 1.26 [1.22, 1.30] indicating that concentrations measured at Chanel College were, on average, 26% higher than those measured at Wairarapa College on the same day. However, there is some divergence from the linear fitted line at higher concentrations suggesting a weaker linear relationship between the sites at higher concentrations. Including the strength of the early morning temperature inversion as a predictor in the linear model improves the model fit (R^2=0.94).

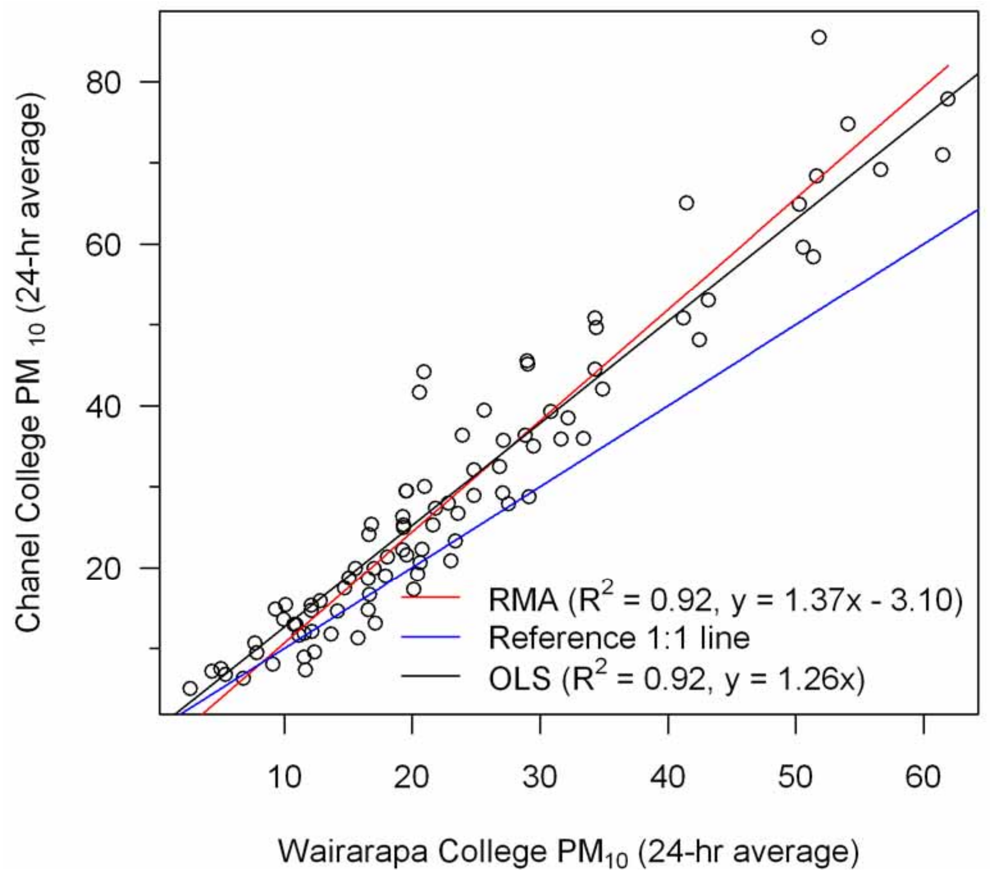

Figure 3.7: Correlation scatter plot and fitted linear regression line for 24-hour averaged PM_{10} data from 5014i instruments at Chanel College and Wairarapa College (91 data points with 100% data capture) from 29 May to 20 September 2012

The magnitude of, and bias in, the difference between same-day 24-hour average concentrations recorded at Chanel College and at Wairarapa College tended to increase when concentrations at Chanel College were above 20 µg/m^3 and at concentrations above 40 µg/m^3, the divergence between the sites became wider and more variable (Figure 3.8).

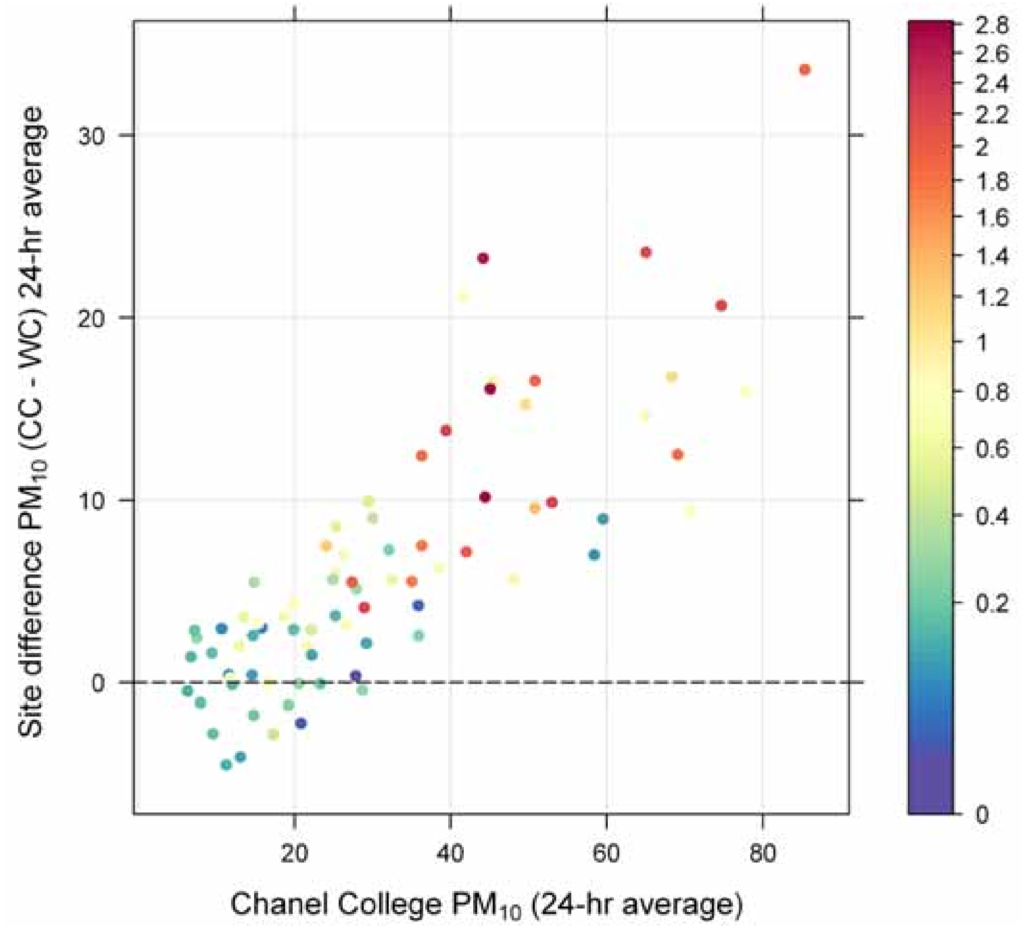

Figure 3.8: Scatter plot of 24-hour average PM_{10} measured by 5014i at Chanel College versus difference in 5014i measurements between Chanel College (CC) and Wairarapa College (WC) sites for 91 data points from 29 May to 20 September 2012. The dashed line shows a difference of zero which indicates perfect agreement. The scale bar shows strength of the early morning temperature inversion

3.2.3 Influence of meteorology on PM_{10} levels

Wind roses for the entire sampling period showed the dominance of the north to northeasterly wind component and to a lesser extent the south westerly component at both sites (Figure 3.9). The mean wind speed measured over the period was 1.9 m/s at Wairarapa College (10m) and 1.5 m/s at Chanel College (6m). Differences in wind measurements between the sites may be due to the differences in measurement heights and differences in instrumentation (ie, Vaisala WS425/H425 ultrasonic at 6m at Chanel College and a Vector A101M anemometer at 10m at Wairarapa College) as well as local site conditions.

Polar plots show that the largest contribution to overall average winter concentration recorded at both sites occurred during low wind speeds (< 1 m/s) that originated from the north to northeast sectors (Figure 3.10).

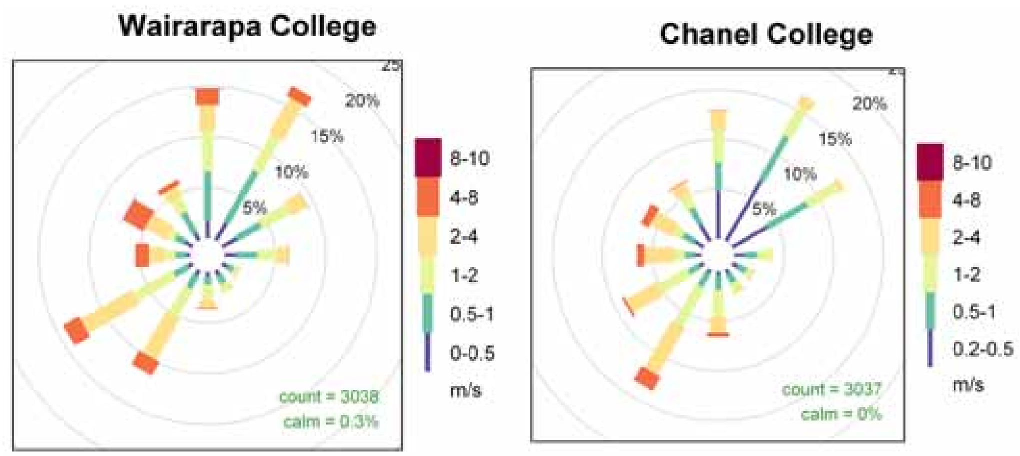

Figure 3.9: Wind roses showing frequency of wind speed and wind direction counts recorded at Wairarapa College at 10m and at Chanel College at 6m from 17 May to 20 September 2012

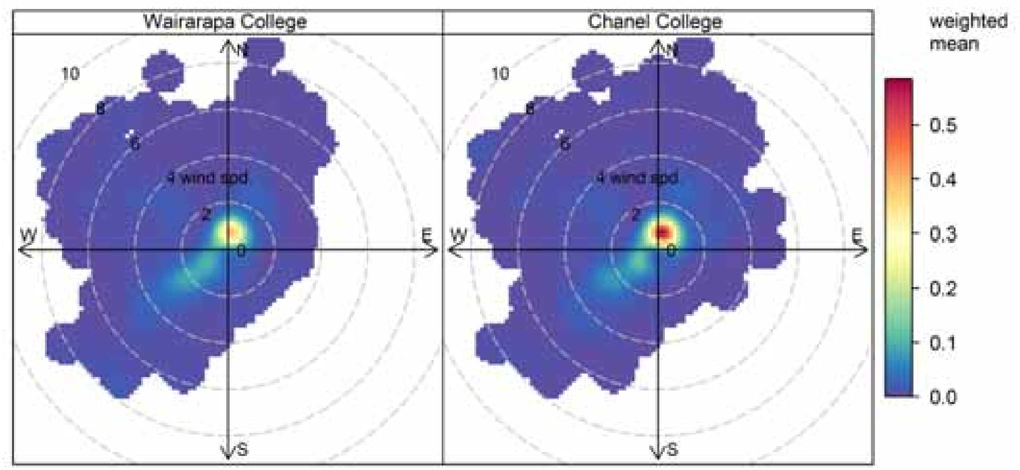

Figure 3.10: Polar plots showing how concentrations vary by wind direction and speed at Wairarapa College and at Chanel College from 17 May to 20 September 2012. Weighted mean concentrations in the right hand scale bar are used to provide an indication of concentrations weighted by frequency in order to highlight the wind speed and direction conditions that dominate the overall mean

The ability of meteorological factors to explain the statistical variation in daily average PM_{10} concentrations measured by the 5014i instruments at both sites and the difference in concentrations measured between sites was explored using multiple linear regression. The two best predictor variables for 24-hour average concentration observed at each site were average daily wind speed and the strength of temperature inversion between 1700 and midnight (Wairarapa College $R^2 = 0.71$ and Chanel College $R^2 = 0.66$). Therefore, at both sites an increase in PM_{10} concentration was associated with a decrease in wind speed and increase in the strength of the evening temperature inversion.

The difference between 24-hour average PM_{10} concentrations at the two sites was best explained by mean daily wind speed and the strength of temperature inversion between midnight and 0500 ($R^2 = 0.52$). Therefore, the positive bias in Chanel College daily PM_{10} averages increases as average wind speed decreases and strength of early morning inversion conditions increases. Just over half of the variability in the observed difference in PM_{10} concentration was explained by these particular meteorological variables.

3.3 Relationship between PM_{10} and $PM_{2.5}$: Wairarapa College

There was a close relationship between $PM_{2.5}$ (24-hour average) and PM_{10} (24-hour average) measured by both 5014i and FH62 instruments (Figure 3.11). This result is not unexpected given that $PM_{2.5}$ is a significant component of PM_{10} during the winter months when domestic heating is the principal source of PM emissions (Davy 2007, Wilton & Baynes 2008).

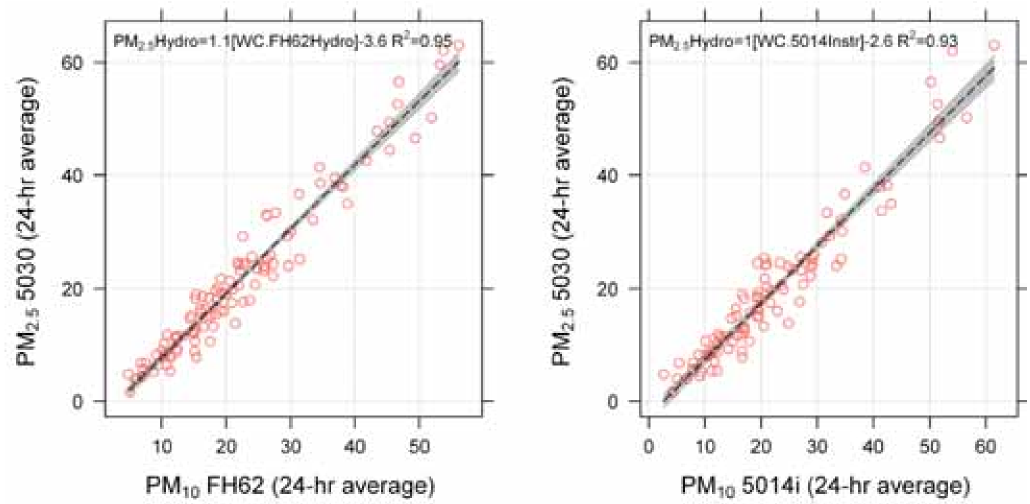

Figure 3.11: Correlation scatter plots and fitted linear regression line for 24-hour averaged PM_{10} and $PM_{2.5}$ measurements at Wairarapa College from 26 May to 20 September 2012. Left: PM_{10} (FH62) vs $PM_{2.5}$ (5030) for 103 data points with 100% data capture. Right: PM_{10} (5014i) vs $PM_{2.5}$ (5030) for 93 data points with 100% data capture

Theoretically you would expect the ratio of $PM_{2.5}$:PM_{10} measured by co-located $PM_{2.5}$ and PM_{10} analysers to be less than or equal to 1 because $PM_{2.5}$ is, by size definition, a subset of PM_{10}. In this study there were many days when the $PM_{2.5}$ 24-hour average (SHARP 5030) was higher than the PM_{10} 24-hour average measured by the FH62 and by the 5014i

The tendency for $PM_{2.5}$ to be higher than PM_{10} measured by the FH62 was more pronounced on days where PM_{10} 24-hour averages were greater than 30 $\mu g/m^3$ (Figure 3.12). In contrast, the tendency for $PM_{2.5}$ to be higher than PM_{10} measured by 5014i was more random and does not show systematic variation with 24-hour PM_{10} concentration measured by 5014i (Figure 3.13).

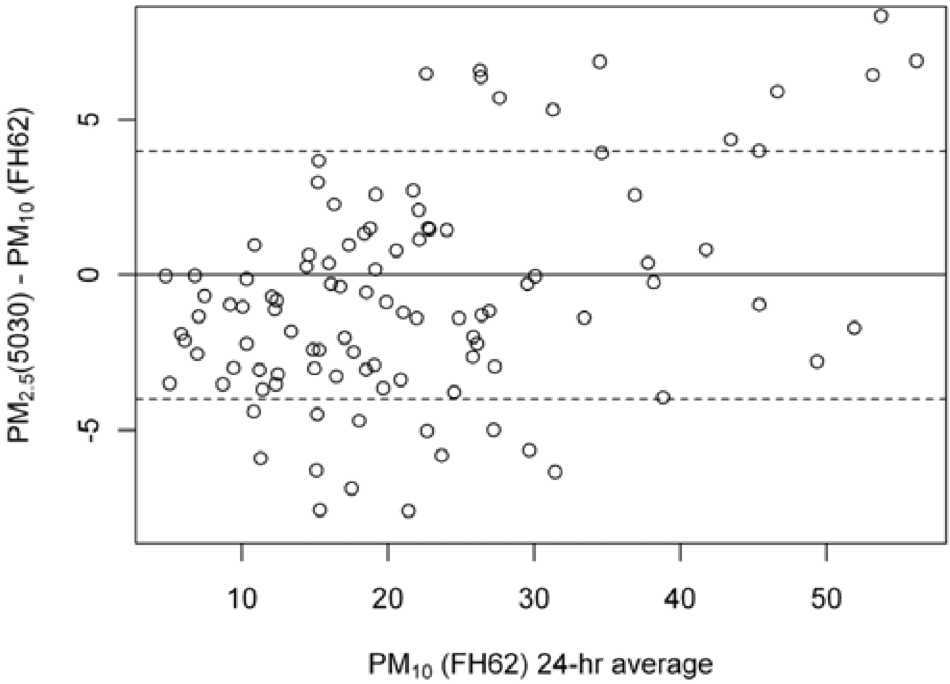

Figure 3.12: Plot of the difference in µg/m³ between daily pairs of 5030 $PM_{2.5}$ and FH62 PM_{10} measurements versus the FH62 PM_{10} at Wairarapa College. A difference of zero indicates perfect agreement. The dashed lines represent the combined uncertainty of the difference between measurements (±4 µg/m³)

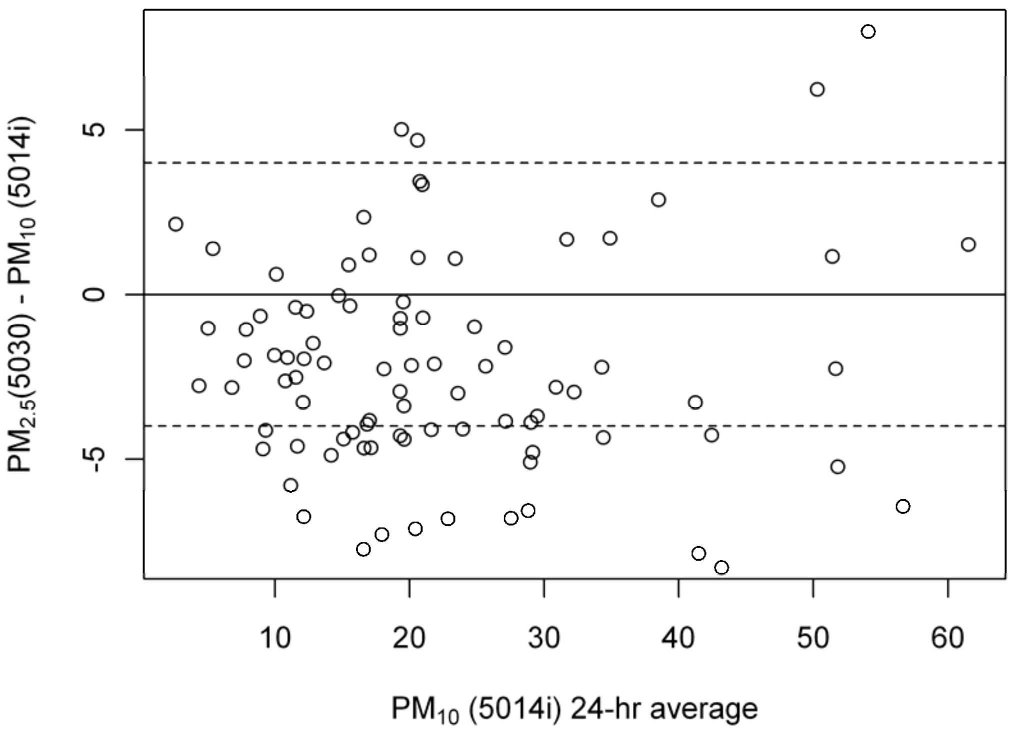

Figure 3.13: Plot of the difference in µg/m³ between daily pairs of 5030 $PM_{2.5}$ and 5014i PM_{10} measurements versus the 5014i PM_{10} at Wairarapa College. A difference of zero indicates perfect agreement. The dashed lines represent the combined uncertainty of the difference between measurements (±4 µg/m³)

4. Discussion

This investigation compared measurements recorded by two co-located beta attenuation PM_{10} analysers (FH62 and 5014i) at Wairarapa College during winter 2012. The FH62 has been used at Wairarapa College for NES-AQ compliance monitoring since winter 2008. The FH62 model is no longer being manufactured and the 5014i is the new generation replacement model for the FH62. Using linear regression, a suitable site-specific adjustment factor was derived based on 90 days of paired 24-hour average measurements. On average, the 24-hour average concentration measured by the 5014i was 9% higher than the FH62. Therefore, when the 5014i replaces the FH62 there may be a slight rise in the number of NES-AQ exceedances per year due to the change in instrumentation. For undertaking trends analyses it will be necessary to take into account the change in instrumentation on measured concentrations by adjusting the historical FH62 record upwards to estimate what would have been measured, had the 5014i instrument been used.

The positive bias in the concentrations measured by the 5014i is most likely due to its ‘smart’ heater technology which regulates inlet temperature based on ambient relative humidity - unlike the FH62 which heats incoming air using a constant temperature setting. Wood smoke contains semi-volatile material that is evaporated by heat. Consequently, the loss of volatile material during sampling means this component of PM_{10} is not measured. However, it is necessary for the sampled air to be heated to remove particle-bound water which can lead to overestimation of PM_{10} mass. The 5014i-FH62 adjustment factor developed during this study may only be applicable to the winter months and a longer period of data will need to be examined to determine whether a different relationship between these two methods exists during the summer months when the contribution of wood smoke to PM_{10} is minor compared to natural sources such as marine aerosol and re-suspended dust.

This investigation also examined the differences in PM_{10} concentrations measured by the same instrument type (5014i) at Wairarapa College and at Chanel College. These sites are approximately 1 km apart. The two sites showed very similar diurnal patterns, with distinct morning and evening peaks in PM_{10} concentrations. When PM_{10} levels were low or moderate (ie, less than 30 $\mu g/m^3$ 24-hour average) there was no systematic difference in concentrations recorded at the two sites. Conversely, when PM_{10} levels were elevated (ie, above 30 $\mu g/m^3$) there was a positive bias in measurements at Chanel College relative to those from Wairarapa College. This finding is attributed to differing impacts of wood smoke from domestic fires on PM_{10} levels measured at each site.

Consistent with previous observations, PM_{10} concentrations were strongly influenced by meteorological conditions that restricted the dispersal of air pollutants, such as low wind speeds and overnight temperature inversions. On high pollution days, when concentrations above 50 $\mu g/m^3$ were recorded at Chanel College, most of the overall contribution to the winter PM_{10} concentration occurred during very light wind speeds from the north and northeast wind sectors. The same pattern was observed for Wairarapa College, albeit with lower overall PM_{10} concentration. This pattern is generally consistent with there being more residential dwellings to the north and northeast of Chanel College compared to Wairarapa College. Therefore, there is likely to be a larger ‘plume’ of pollutants from domestic fires impacting on the Chanel College site that are transported via katabatic down slope flows (Ancelet et al. 2012). The monitoring sites are both located in areas with similar estimated emissions densities from home heating sources. This supports the conclusion that the relatively higher concentrations observed at Chanel College on elevated PM_{10} days were due in part to meteorological effects rather than solely due to emissions in the immediate vicinity of the monitoring station. However, the Chanel College site is much closer to residential housing than is the Wairarapa College site and more investigation is required to discount micro-scale impacts at Chanel College.

Understanding the $PM_{2.5}$:PM_{10} ratio is relevant to air quality management because it reveals that on many occasions well over half of the observed PM_{10} concentration was composed of $PM_{2.5}$. Therefore attaining the NES-AQ for PM_{10} does not necessarily protect against adverse health effects from exposure to $PM_{2.5}$. Establishing the $PM_{2.5}$:PM_{10} ratio was problematic when different measurement methods were used for these metrics. This study found that SHARP 5030 systematically recorded higher $PM_{2.5}$ than FH62 PM_{10} but this positive bias was not observed with 5014i PM_{10} measurements. A likely reason for this difference in $PM_{2.5}$:PM_{10} ratios is that the 5014i and SHARP 5030 apply less heat to the sampled air and therefore retain more of the semi-volatile component of PM_{10} (associated primarily with the sub 2.5 µm size range) compared to the FH62.

5. Conclusions

In this investigation the performance of the new generation beta attenuation monitor 5014i was evaluated against the existing FH62 instrument used for PM_{10} NES-AQ compliance at the long term monitoring site at Wairarapa College, Masterton. The FH62 slightly underestimated PM_{10} relative to the 5014i because the 5014i's dynamic heating system results in less loss of the semi-volatile component of the sampled wood smoke. Consequently the number of future exceedances at Wairarapa College may be greater if the 5014i instrument is used permanently at this site.

The study provides further evidence that the Wairarapa College monitoring site does not represent the area of Masterton that has the poorest winter air quality. On days where PM_{10} concentrations were elevated, concentrations at Chanel College, located approximately 1 km to the south-east, were substantially higher than at Wairarapa College. The higher concentrations observed at Chanel College were attributed to this site being down wind of a greater number of wood burning dwellings than Wairarapa College. Depending on inter-annual variability, the average number of exceedances per year at Chanel College may be greater than 10 which could shift the airshed compliance target date from 2016 to 2020. This finding has important implications for air quality management as greater reductions in domestic emissions than previously thought may be required to ensure future compliance with the NES-AQ.

The study highlights the difficulty of using emissions inventories for predicting concentrations. Areas with the poorest air quality may not necessarily have highest emissions density due to the impact of topography and meteorology. More investigation is required to fully understand the interactions between meteorological effects and emission sources in the Masterton urban area. This would inform the NES-AQ requirement to monitor air quality in the 'worst' location.

On high pollution nights, most of the observed PM_{10} was composed of particles in the sub 2.5 μm fraction. $PM_{2.5}$ concentrations measured at Wairarapa College frequently exceed the WHO (2006) guideline and it is likely that more exceedances of this guideline would be found at Chanel College. This study concludes that meaningful $PM_{2.5}$:PM_{10} ratios need to be established using PM_{10} and $PM_{2.5}$ data obtained using the same measurement method.

5.1 Recommendations

1. Continue to monitor PM_{10} at Chanel College until at least the end of winter 2013 to establish inter-annual variability.

2. At Wairarapa College monitoring site, replace FH62 monitoring instrument with 5014i in 2014 and adjust historical FH62 record to 5014i equivalency.

3. Undertake airshed modelling to better determine spatial variability of PM_{10} in the Masterton urban area and use the results to inform the establishment of a more appropriate NES-AQ compliance monitoring site.

4. At Wairarapa College monitoring site, replace the SHARP 5030 instrument with 5014i for measuring $PM_{2.5}$ in 2014.

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Acknowledgements

Thank you to Darren Li (GWRC) for site installation, instrument maintenance and data collection underpinning this investigation. We are grateful to Chanel College for allowing us to install the monitoring site on their school grounds. The maps (Figures 2.1 and 2.2) were produced by Shyam Moar (GWRC). Thank you to Teresa Aberkane and Vincent Salomon from Environment Canterbury who provided constructive comments that improved this report. Thank you to Laura Keenan (GWRC) for proof reading the report.

Appendix 1

Table A1.1: Dataset of PM_{10} and $PM_{2.5}$ 24-hour averages (µg/m³). NA denotes less than 75% data capture and therefore average not reported. Grey shading shows values with less than 100% but greater than 75% data capture that are valid averages for reporting but not used in the inter-methods or inter-site comparisons.

		Wairarapa College				Chanel College
Date	Obs	PM_{10} FH62 Telemetry data	PM_{10} 5014i Telemetry data	PM_{10} 5014i Instrument data	$PM_{2.5}$ 5030 Telemetry data	PM_{10} 5014i Instrument data
17/05/2012	1	34.62	NA	NA	38.54	56.3
18/05/2012	2	23.68	NA	NA	17.87	31.51
19/05/2012	3	10.82	NA	NA	6.43	10.01
20/05/2012	4	20.57	NA	NA	21.36	26.37
21/05/2012	5	43.46	NA	NA	47.82	55.55
22/05/2012	6	41.76	NA	NA	42.58	55.36
23/05/2012	7	40.81	NA	NA	79.68	53.28
24/05/2012	8	53.17	NA	NA	59.62	61.61
25/05/2012	9	25.82	29.5	NA	23.18	41.34
26/05/2012	10	14.44	12.68	NA	NA	25.34
27/05/2012	11	5.40	5.73	NA	NA	6.99
28/05/2012	12	8.45	9.34	NA	NA	10.18
29/05/2012	13	27.64	31.53	31.67	33.35	35.88
30/05/2012	14	56.15	61.2	61.52	63.05	70.93
31/05/2012	15	53.72	53.88	54.08	62.07	74.75
1/06/2012	16	55.39	62.40	61.91	NA	77.85
2/06/2012	17	46.82	49.69	50.29	56.52	64.91
3/06/2012	18	33.45	34.94	34.28	32.08	44.44
4/06/2012	19	46.51	50.26	50.59	NA	59.55
5/06/2012	20	22.76	21.44	20.95	24.29	44.20
6/06/2012	21	10.89	12.33	12.36	11.86	9.57
7/06/2012	22	22.14	26.87	27.13	23.28	35.68
8/06/2012	23	14.97	16.82	16.62	11.96	24.11
9/06/2012	24	17.03	19.04	19.3	15.01	22.17
10/06/2012	25	45.39	51.53	51.64	49.39	68.39
11/06/2012	26	37.13	41.00	41.27	44.12	52.69
12/06/2012	27	22.69	27.38	26.86	17.67	32.49
13/06/2012	28	27.23	28.88	28.82	22.25	36.33
14/06/2012	29	18.02	20.44	20.44	13.33	19.20
15/06/2012	30	15.12	16.57	16.57	8.84	14.78

		Wairarapa College				Chanel College
Date	**Obs**	**PM_{10} FH62** **Telemetry data**	**PM_{10} 5014i** **Telemetry data**	**PM_{10} 5014i** **Instrument data**	**$PM_{2.5}$ 5030** **Telemetry data**	**PM_{10} 5014i** **Instrument data**
16/06/2012	31	13.39	15.70	15.77	11.58	11.26
17/06/2012	32	38.17	41.18	41.22	37.94	50.78
18/06/2012	33	8.71	9.48	9.32	5.20	14.80
19/06/2012	34	6.11	5.05	5.03	4.01	7.47
20/06/2012	35	18.53	20.05	20.13	17.98	17.31
21/06/2012	36	15.21	16.40	16.99	18.20	19.48
22/06/2012	37	46.64	49.18	51.40	52.56	58.40
23/06/2012	38	24.86	28.74	25.65	23.48	39.44
24/06/2012	39	19.68	21.91	22.85	16.04	27.97
25/06/2012	40	26.93	29.83	29.49	25.79	35.03
26/06/2012	41	17.66	19.95	19.59	15.19	21.59
27/06/2012	42	12.06	12.69	12.84	11.37	15.83
28/06/2012	43	21.41	24.94	24.85	13.82	28.94
29/06/2012	44	15.35	16.62	16.65	7.79	16.63
30/06/2012	45	21.97	23.40	23.58	20.59	26.69
1/07/2012	46	37.79	42.51	42.45	38.18	48.10
2/07/2012	47	26.10	29.00	28.98	23.89	45.50
3/07/2012	48	16.75	15.46	15.48	16.39	30.95
4/07/2012	49	25.85	24.95	24.83	23.86	32.08
5/07/2012	50	12.26	11.43	11.54	11.16	8.87
6/07/2012	51	21.80	22.85	23.04	27.20	20.83
7/07/2012	52	24.52	27.69	27.54	20.75	27.88
8/07/2012	53	20.88	21.71	21.61	17.50	25.27
9/07/2012	54	16.47	17.02	17.02	13.20	19.91
10/07/2012	55	30.08	34.21	34.39	30.05	49.62
11/07/2012	56	51.90	56.50	56.64	50.20	69.12
12/07/2012	57	49.36	51.66	51.81	46.58	85.42
13/07/2012	58	22.06	25.29	24.90	NA	NA
14/07/2012	59	5.08	4.35	4.36	1.59	7.20
15/07/2012	60	4.81	2.66	2.64	4.79	5.04
16/07/2012	61	NA	10.87	10.92	9.01	12.91
17/07/2012	62	29.67	33.29	33.4	24.03	35.95
18/07/2012	63	38.81	43.03	43.17	34.88	53.03
19/07/2012	64	41.17	41.38	41.48	33.62	65.06
20/07/2012	65	31.44	34.57	34.28	25.10	50.81

		Wairarapa College				Chanel College
Date	**Obs**	**PM_{10} FH62** **Telemetry data**	**PM_{10} 5014i** **Telemetry data**	**PM_{10} 5014i** **Instrument data**	**$PM_{2.5}$ 5030** **Telemetry data**	**PM_{10} 5014i** **Instrument data**
21/07/2012	66	19.08	19.53	19.57	16.18	29.47
22/07/2012	67	27.31	29.20	29.15	24.36	28.71
23/07/2012	68	12.39	13.71	13.65	11.58	11.74
24/07/2012	69	13.77	10.06	10.10	10.72	15.39
25/07/2012	70	NA	11.64	11.66	7.05	7.32
26/07/2012	71	NA	30.76	30.87	28.06	39.30
27/07/2012	72	NA	20.55	20.58	25.27	41.66
28/07/2012	73	25.08	19.48	19.39	24.41	29.93
29/07/2012	74	18.51	11.07	10.91	15.46	27.92
30/07/2012	75	NA	NA	NA	8.69	15.48
31/07/2012	76	13.31	NA	NA	12.23	13.22
1/08/2012	77	9.45	NA	NA	6.46	15.02
2/08/2012	78	11.42	NA	NA	7.73	19.04
3/08/2012	79	13.03	NA	NA	NA	18.48
4/08/2012	80	18.32	NA	NA	NA	24.87
5/08/2012	81	17.57	NA	NA	NA	30.30
6/08/2012	82	45.40	NA	NA	44.46	57.35
7/08/2012	83	21.35	NA	NA	NA	35.69
8/08/2012	84	26.36	NA	NA	32.74	44.28
9/08/2012	85	22.84	NA	NA	24.31	29.64
10/08/2012	86	18.85	NA	NA	21.72	31.62
11/08/2012	87	22.63	NA	NA	29.12	34.32
12/08/2012	88	19.88	NA	NA	19.02	23.55
13/08/2012	89	26.29	NA	NA	32.89	32.49
14/08/2012	90	36.89	NA	NA	39.47	47.08
15/08/2012	91	15.31	16.95	16.84	12.90	25.38
16/08/2012	92	19.17	20.59	20.64	21.77	20.57
17/08/2012	93	21.74	23.38	23.38	24.48	23.29
18/08/2012	94	24.03	27.05	27.08	25.48	29.21
19/08/2012	95	17.32	19.40	19.31	18.29	25.28
20/08/2012	96	14.44	14.73	14.73	14.71	17.42
21/08/2012	97	10.34	12.15	12.17	10.22	12.05
22/08/2012	98	9.21	8.87	8.91	8.27	12.18
23/08/2012	99	16.11	17.92	18.09	15.83	21.29
24/08/2012	100	18.4	22.03	21.84	19.74	27.35

		Wairarapa College				Chanel College
Date	**Obs**	**PM_{10} FH62** **Telemetry data**	**PM_{10} 5014i** **Telemetry data**	**PM_{10} 5014i** **Instrument data**	**$PM_{2.5}$ 5030** **Telemetry data**	**PM_{10} 5014i** **Instrument data**
25/08/2012	101	31.28	34.56	34.89	36.61	42.04
26/08/2012	102	21.06	24.28	23.95	19.86	36.35
27/08/2012	103	7.06	7.78	7.73	5.73	10.67
28/08/2012	104	16.31	19.23	19.31	18.59	24.95
29/08/2012	105	15.97	19.28	19.29	16.35	26.3
30/08/2012	106	14.58	15.57	15.56	15.23	19.88
31/08/2012	107	18.79	20.98	21.00	20.30	30.02
1/09/2012	108	19.15	19.44	19.54	19.33	29.48
2/09/2012	109	29.54	32.35	32.22	29.26	38.49
3/09/2012	110	22.10	20.69	20.76	24.2	22.24
4/09/2012	111	8.81	11.21	11.18	5.39	11.60
5/09/2012	112	15.18	15.12	15.09	10.70	18.70
6/09/2012	113	11.28	12.13	12.13	5.38	14.68
7/09/2012	114	11.21	10.73	10.77	8.15	12.97
8/09/2012	115	6.80	5.38	5.39	6.79	6.77
9/09/2012	116	5.87	6.83	6.80	3.98	6.32
10/09/2012	117	6.96	9.22	9.11	4.42	8.00
11/09/2012	118	12.48	14.15	14.17	9.29	14.56
12/09/2012	119	15.27	16.34	16.59	18.95	18.65
13/09/2012	120	34.49	NA	38.49	41.37	50.88
14/09/2012	121	26.41	NA	29.02	25.13	45.11
15/09/2012	122	10.34	NA	9.97	8.13	13.56
16/09/2012	123	10.07	NA	11.56	9.05	11.80
17/09/2012	124	7.47	NA	7.86	6.81	9.46
18/09/2012	125	17.53	NA	17.94	10.65	18.96
19/09/2012	126	12.33	NA	12.10	8.82	15.31
20/09/2012	127	14.88	NA	17.13	12.48	13.06

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