Sources of particulate matter pollution in a small New Zealand city

Travis Anclet, Perry K. Davy, William J. Trompetter, Andreas Markwitz

GNS Science, 30 Gracefield Road, PO Box 31312, Lower Hutt, New Zealand

ABSTRACT

The sources of PM\textsubscript{10} in the Tahunanui airshed of Nelson, New Zealand were investigated using positive matrix factorization (PMF) on elemental data obtained from filters collected from September 2008–September 2009. Also, the source(s) of peak, non-winter PM\textsubscript{10} concentrations that exceeded the National Environmental Standard for PM\textsubscript{10} were investigated using PM\textsubscript{10} and meteorological data from 2007–2012 and the PMF results. Seven PM\textsubscript{10} sources were identified: biomass burning, motor vehicles, secondary sulfate, marine aerosol, crustal matter, protective coating activities and fertilizer. Overall, biomass burning was the dominant source contributor (35% of PM\textsubscript{10}). Analyses of PM\textsubscript{10} concentration dependences on meteorological variables showed that peak, non-winter PM\textsubscript{10} concentrations that occurred under moderate-to-high wind speeds from the southwest were the result of vehicular movements on unsealed roads in an industrial area. From this information, it is possible for Nelson City Council, who manages air quality at Tahunanui, to formulate mitigation strategies to reduce the impact of biomass burning and industrial vehicles on local air quality.

Keywords: Particulate matter, Ion beam analysis, Positive matrix factorization, New Zealand

doi:10.5094/APR.2014.066

1. Introduction

Air pollution has long been known to have adverse effects on human health. Recently, the International Agency for Research on Cancer (IARC) has concluded that outdoor air pollution, and specifically particulate matter (PM), is carcinogenic to humans (IARC, 2013). Particulate matter is a complex mixture of chemical species produced through natural and anthropogenic processes with particle sizes that vary over several orders of magnitude. These properties play important roles in the wide-ranging health risk posed by PM (Hannigan et al., 2005; Staniswalis et al., 2005; Epton et al., 2008; Fukuda et al., 2011; Vodonos et al., 2014), making the identification of PM sources and their contributions to measured PM concentrations crucial for providing information to policymakers so that they can develop relevant legislation to better manage air quality in different airsheds.

To identify the sources contributing to measured PM concentrations, multivariate receptor models are used. Positive matrix factorization (PMF) is a powerful and commonly used multivariate receptor model that is capable of resolving factors, or PM sources, without prior source knowledge. It is, however, important to note that source-specific profiles (fingerprints) must be known to properly assign the PMF model outputs. PMF has a number of advantages over traditional factor analysis techniques including non–negativity constraints and the ability to accommodate missing or below detection limit data. The results of the analysis are directly interpretable as mass contributions from each factor (Paatero and Tapper, 1994; Paatero, 1997; Song et al., 2001). Two receptor models are available to perform PMF, PMF2 (Paatero, 1997) and EPA PMF (U.S. EPA, 2008). EPA PMF adopts a bilinear model which is solved by the Multilinear Engine (Paatero, 1999) and incorporates a graphical user interface. When compared with PMF2, EPA PMF has been shown to provide similar results with some minor differences in the final solutions (Kim and Hopke, 2007; Hwang and Hopke, 2011).

In this study, EPA PMF (version 3.0.2.2) was used to identify sources of particulate matter less than 10 μm in aerodynamic diameter (PM\textsubscript{10}) at a monitoring site in Nelson, New Zealand (latitude =41.16°, longitude 173.17°). Nelson is a small city (population 43 000) located on the northern coast of New Zealand’s South Island. Nelson is known to suffer from poor air quality during the winter, when residential wood combustion for home heating and strong temperature inversions that limit the dispersion of pollutants are common. These conditions cause PM\textsubscript{10} concentrations in Nelson to exceed the New Zealand National Environmental Standard (NES) for PM\textsubscript{10} of 50 μg m\textsuperscript{-3} (24-hour average) a number of times each year, which has important implications for local policymakers, since the PM\textsubscript{10} standard cannot be exceeded more than once per year. Little is known about the specific sources contributing to measured PM\textsubscript{10} concentrations in Nelson, highlighting the importance of undertaking a source apportionment. Even more importantly, in some areas of the city, PM\textsubscript{10} concentrations regularly exceed the NES outside of winter under moderate–to–high speed winds from the southwest, making the identification of the offending PM source(s) even more critical for local policymakers because multiple sources appear to cause exceedance events. Along with identifying the sources contributing to PM\textsubscript{10} concentrations, this study also used a large set (hourly measurements from 2007–2012) of PM\textsubscript{10} concentrations and meteorological variables to identify the source of peak, non-winter PM\textsubscript{10} concentrations.
2. Methodology

2.1. Sample collection

Particulate matter samples were collected at an ambient air quality monitoring station located on a property in the Nelson suburb of Tahunanui (latitude ~41.16°, longitude 173.17°, elevation: 5 m). The monitoring station was operated by Nelson City Council and featured a continuous PM$_{10}$ monitor (Thermo–Anderson FH62 beta–particle attenuation monitor (BAM)) and meteorological equipment. The location of the sampling site is shown in Figure S1 of the Supporting Material (SM). Tahunanui is located on a narrow coastal plain bordered by hills to the east (~200–300 m high). To the north lies Tasman Bay and to the west is the Waimea Inlet. To the southwest is the Waimea Plain. The Blackwood Street site lies on the border between industrial activities to the south and west with Nelson Airport located on the edge of the Waimea Inlet to the west of the monitoring site. Residential activities predominate immediately to the east and north, and a State Highway was 200 m east of the site. PM$_{10}$ samples were collected on a one–day–in–two (midnight to midnight) sampling regime from September 2008–September 2009. A total of 185 samples were collected on Teflon filters using a Partisol sampler (Thermo Scientific, Waltham, MA, USA) and mass concentrations of PM$_{10}$ were determined gravimetrically. Field and lab blanks were collected monthly and underwent the same analyses as loaded filters.

Hourly PM$_{10}$ concentrations and meteorological data from 2007–2012 were also provided by Nelson City Council to further investigate peak, non–winter PM$_{10}$ concentrations. These data were analyzed using the R statistical software and openair package (R Development Core Team, 2011; Carslaw, 2012; Carslaw and Ropkins, 2012). Openair was initially developed for the analysis of air pollution measurement data and has a range of tools for importing and manipulating data and for undertaking a wide range of analyses to enhance understanding of air pollution data. Using openair, data can be analyzed quickly and easily in an interactive way, allowing more time to understand and investigate the problem at hand.

2.2. Elemental analysis

Ion Beam Analysis (IBA) techniques were used to measure the concentrations of elements with atomic number above neon in the PM$_{10}$ samples collected. IBA measurements for this study were carried out at the New Zealand Ion Beam Analysis Facility operated by the Institute of Geological and Nuclear Sciences (GNS) in Gracefield, Lower Hutt (Trompetter et al., 2005; Barry et al., 2012). The full suite of analyses included Particle–Induced X–ray Emission (PIXE), Particle–Induced Gamma–ray Emission (PIGE), Rutherford Backscattering (RBS) and Particle Elastic Scattering Analysis (PESA). Black carbon (BC) was measured using a MA3D Digital Smoke Stain Reflectometer. The determination of BC concentrations from the reflectometer measurements has been reported previously (Aancelet et al., 2011). Elemental and BC concentrations were all below their respective limits of detection on the lab and field blank filters. The IBA process provides analytical uncertainties and limits of detection (LODs) for each element in each of the PM samples, with variations in these values dependent on the experimental conditions, filter matrix and sample loading. Both the analytical uncertainties and limits of detection are related to backgrounds present for each elemental peak.

2.3. Receptor modeling

Receptor modeling and apportionment of PM mass by PMF was performed using the EPA PMF version 3.0.2.2 program in accordance with the User’s Guide (U.S. EPA, 2008). With PMF, sources are constrained to have non–negative species concentrations, no sample can have a negative source contribution and error estimates for each observed point are used as point–by–point weights. This is a distinct advantage of PMF, since it can accommodate missing or below detection limit data that is a common feature of environmental monitoring (Song et al., 2001). Prior to the PMF analyses, data and uncertainty matrices were prepared for each site in the same manner as previous studies (Polissar et al., 1998; Song et al., 2001). Data screening and the source apportionment were performed in the same manner as previously reported (Aancelet et al., 2012).

3. Results and Discussion

3.1. Concentrations and sources of ambient PM$_{10}$

PM$_{10}$ concentrations, determined gravimetrically, during the study period are presented in Figure 1. PM$_{10}$ concentrations peaked during winter (May–August) when domestic wood combustion for home heating is common (Aancelet et al., 2012; Davy et al., 2012; Trompetter et al., 2010). Several individual peaks in PM$_{10}$ concentrations were also apparent during spring (September–November). These non–winter peaks in PM$_{10}$ concentrations occurred regularly in Nelson, as shown in the SM Figure S2. Figure S2 presents a plot of PM$_{10}$ concentrations obtained by Nelson City Council’s BAM used for compliance monitoring from 2008–2012. The dashed line indicates the New Zealand NES for PM$_{10}$ and Figure S2 shows that non–winter PM$_{10}$ concentrations can exceed the NES, which has important implications for the management of PM$_{10}$ by Nelson City Council. Understanding the sources of PM$_{10}$ in Nelson is therefore critical for developing air quality management strategies.

Table S1 in the SM summarizes the elemental concentration data obtained using IBA techniques and light reflection (for BC). Table S1 shows that some measured species were generally close to or below the limits of detection over all samples. Carbonaceous species, represented by BC, were found to dominate PM$_{10}$ mass concentrations. Al, Si, Na, Cl and S were important elemental constituents, indicating that combustion sources, crustal matter (soil), marine aerosol and secondary sulfate particles are likely important contributors to ambient PM$_{10}$ concentrations at the Tahunanui site in Nelson.

Using the elemental concentration data, seven PM$_{10}$ factors were identified by PMF. The factor profiles obtained are presented in Figure 2 and these sources were found to explain 97% of the gravimetric PM$_{10}$ mass on the average. The first factor was characterized as biomass burning because of the presence of H (an indicator of organic compounds), BC and K as primary species, along with some S and Cl, which is consistent with previous studies (Aancelet et al., 2012; Davy et al., 2012). Biomass burning contributions are from domestic wood combustion for home heating during the winter. Overall, biomass burning accounted for 35% of PM$_{10}$ mass during the sampling period, but on peak PM$_{10}$ pollution days, the contribution of biomass burning to PM$_{10}$ mass could exceed 70%.

The second factor was identified as motor vehicles based on the presence of H, BC, Al, Si, Ca and Fe as significant elemental components. This profile represents both exhaust (tailpipe) emissions and non–exhaust (road dust and brake and tire wear) emissions. The motor vehicle profile presented appears to contain a significant proportion of re–entrained road dust (crustal matter suspended by vehicular movements), suggesting that vehicles travelling on unscaled roads influence the monitoring site. This is discussed in more detail in Sections 3.2 and 3.3. Motor vehicles accounted for 11% of measured PM$_{10}$ during the sampling period on the average.
The third and fourth factors were characterized as secondary sulfate and marine aerosol, respectively. The sulfate factor profile featured S as the dominant elemental constituent, while the marine aerosol profile featured high concentrations of Na and Cl, along with Mg, S, K and Ca, all major constituents of seawater. The sulfate and marine aerosol sources accounted for 7 and 18%, respectively, of PM$_{10}$ mass on average.

The fifth factor was identified as airborne crustal matter and contained Al, Si, S, K, Ca and Fe as primary species. On the average, crustal matter contributed 16% to measured PM$_{10}$ mass. The sixth factor contained most of the elemental zinc measured and was characterized as being related to surface coating activities because zinc is the primary component of surface coatings for the protection of steel. There were several industrial locations where the remediation of steel surfaces (shot blasting and sand blasting) and protective coatings containing zinc were applied located to the west of the monitoring site within a short distance. Overall, surface coating activities were a minor source contributor, accounting for 5% of PM$_{10}$ mass on average.

The seventh factor was identified as fertilizer because the chemical profile is very similar to NPK fertilizer and, on average, contributed to 8% of PM$_{10}$ mass. Contributions from this source were intermittent and showed strong wind direction dependence; indicating measured contributions resulted from a point source. A large fertilizer storage and distribution center was located to the southwest of the monitoring site and it is likely that the loading and unloading of fertilizer from the center was responsible for the measured contributions.

Analysis of seasonal variations in PM$_{10}$ sources (see the SM, Figure S3) revealed that the primary source of PM$_{10}$ during winter 2009 (June–August) at Tahunanui was biomass burning, associated with solid fuel fire emissions for domestic heating. Average PM$_{10}$ concentrations were found to be significantly higher in winter (29 μg m$^{-3}$) compared to other seasons. Average PM$_{10}$ concentrations during autumn (March–May) were 20 μg m$^{-3}$, during spring (September–November) were 19 μg m$^{-3}$ and during summer were (December–March) 16 μg m$^{-3}$. Contributions from biomass burning during summer were very low, with marine aerosol and crustal matter the predominant sources of PM$_{10}$ during summer. The source contributions were also analyzed for weekday/weekend differences. Figure S4 (see the SM) shows that two sources, motor vehicles and surface coating activities, showed significantly higher contributions during weekdays compared to weekends. This result is consistent with the sources being associated with commuter traffic and commercial activities that are conducted predominantly during normal weekday working hours.

### 3.2. Temporal variations in PM$_{10}$ Concentrations with wind speed and direction

To identify the source(s) of peak PM$_{10}$ concentrations originating from the southwest under moderate to high wind speeds, it was necessary to identify how these conditions differed from all other conditions (wind speeds and direction). As such, average diurnal PM$_{10}$ concentrations were investigated as to how those PM$_{10}$ concentrations varied by day of the week and month. Figure S5 (see the SM) shows that PM$_{10}$ concentrations varied throughout each day of the week and by month using all of the available Tahunanui air quality data (hourly data from 2007–2012). Light red shading indicates the 95% confidence intervals. A number of features were immediately apparent from these plots. Average hourly PM$_{10}$ concentrations showed similar profiles on weekdays and very different profiles on weekends. On weekdays, PM$_{10}$ concentrations were highest during typical work day hours, with peak concentrations occurring between 10:00–11:00 am. A smaller evening peak in concentrations was also apparent, particularly in Figure S5b, which presents the overall average hourly PM$_{10}$ concentrations. The weekday/weekend difference is particularly apparent from Figure S5d, which shows that PM$_{10}$ concentrations are significantly higher during the week than on the weekend. These diurnal profiles and weekday/weekend differences suggest that human activities during the normal working week may be responsible for elevated PM$_{10}$ concentrations. If peak PM$_{10}$ concentrations resulted from natural phenomena then one would expect no significant difference between weekday and weekend concentrations. Also apparent from Figure S5c is that PM$_{10}$ concentrations were substantially higher during the winter.
To identify the source(s) responsible for the observed diurnal profiles and the peak non-winter PM$_{10}$ concentrations measured by NCC, analyses were focused on PM$_{10}$ concentrations when winds were from the southwest. Figure S6 (see the SM) presents a polar plot of PM$_{10}$ concentrations and highlights the influence of southwesterly winds at the Tahunanui monitoring site. For these analyses, wind directions were broken into quadrants, so that all wind directions from 180–270° were considered as southwesterly winds. Similarly, PM$_{10}$ concentration variations were examined under northeasterly, northwesterly and southeasterly wind directions. To illustrate how PM$_{10}$ concentrations varied according to wind direction, Figures 3 and 4 present diurnal, monthly and weekday/weekend variations from the southwesterly and all other quadrants, respectively.

Figure 2. Source profiles obtained.
Figure 3. Southwesterly winds: Average hourly PM$_{10}$ concentrations (μg m$^{-3}$) during each day of the week (a), overall average hourly PM$_{10}$ concentrations (μg m$^{-3}$) (b), average PM$_{10}$ concentrations (μg m$^{-3}$) by month (c), and average PM$_{10}$ concentrations (μg m$^{-3}$) by day of the week (d) when winds were from the southwest quadrant (180°–270°). Light shading indicates the 95% confidence intervals.

Figure 4. Northeasterly, northwesterly and southeasterly winds: Average hourly PM$_{10}$ concentrations (μg m$^{-3}$) during each day of the week (a), overall average hourly PM$_{10}$ concentrations (μg m$^{-3}$) (b), average PM$_{10}$ concentrations (μg m$^{-3}$) by month (c), and average PM$_{10}$ concentrations (μg m$^{-3}$) by day of the week (d) when winds were from the NE, NW and SE quadrants (0°–180° and 270°–360°). Light shading indicates the 95% confidence intervals.
From Figures 3 and 4 it is apparent that under winds from the southwest quadrant a significant workday and weekday increase in PM$_{10}$ concentrations occurred when compared with winds from all other quadrants. It should also be noted that the scales in Figure 4 are lower than those in Figure 3. Based on these results, the source(s) responsible for both the observed daytime peaks in PM$_{10}$ concentrations and the non–winter peak PM$_{10}$ concentrations were strongly wind direction dependent, otherwise similar diurnal and weekday/weekend trends would be apparent from each of the wind quadrants. Nelson City Council identified that peak non–winter PM$_{10}$ concentrations were also associated with moderate to high wind speeds. Therefore Figure 5 presents PM$_{10}$ concentration variations when winds were from the southwest and wind speeds were greater than 3 m s$^{-1}$. Figure 5 shows that PM$_{10}$ concentrations were only elevated during workdays, with peak concentrations between 10:00 am and 5:00 pm. A clear weekday/weekend difference is apparent, with weekday PM$_{10}$ concentrations significantly higher than those during the weekend. In contrast to Figure S5, by excluding low wind speeds from the analysis, the wintertime peak in PM$_{10}$ concentrations was much decreased. Elevated PM$_{10}$ concentrations during the winter are typically associated with low wind speeds resulting from the formation of inversion layers which limit the dispersion of pollutants (Grange et al., 2013).

To highlight the influence of wind direction and speed on PM$_{10}$ concentrations at Tahunanui, Figure S7 (see the SM) presents a comparison of PM$_{10}$ concentrations under winds greater than 3 m s$^{-1}$ from the southwest with PM$_{10}$ concentrations under all other wind speed and direction conditions. Figure S7 shows that under high southwesterly winds, diurnal, weekly and seasonal PM$_{10}$ concentrations are dramatically different than those under other meteorological conditions, highlighting the significant influence of the source(s) located to the southwest of the sampling site. Based on these analyses, the source(s) of the peak PM$_{10}$ concentrations during southwest winds was likely to be of anthropogenic origin and appeared to be associated with normal workday activities. To help identify the source(s), results from the source apportionment presented in Section 3.1 were used.

3.3. Temporal variations in source contributions with wind speed and direction

The source apportionment results presented in Section 3.1 were used to understand how the source contributions varied by wind speed and direction. A number of the sources identified (biomass burning, marine aerosol and surface coating activities) were unlikely to be responsible for the peak, non–winter PM$_{10}$ concentrations measured at Tahunanui because they were unlikely to originate from the southwest or were likely associated with low wind speed conditions. However, for assurance, contributions from these sources were also included in analyses.

Using the Openair package in R, hourly wind speeds and directions were converted to daily averages using a vector averaging procedure. A full description of this process can be found in the Openair manual (Carslaw, 2012). Using the vector averaged wind directions, wind speeds and PM$_{10}$ source contributions, analyses were performed as to how source contributions varied by wind direction. Similar to Section 3.2, wind directions were grouped into quadrants, with winds from 180–270° considered to be southwesterly (northwest=270–360°; northeast=360–90°; southeast=90–180°). Motor vehicle and soil source contributions were strongly influenced by southwesterly winds. Figures 6 and 7 present scatterplots of motor vehicle and soil contributions, respectively, from the southwest quadrant and from all of the other quadrants. As comparisons, similar scatterplots for sulfate

![Figure 5. Average hourly PM$_{10}$ concentrations (µg m$^{-3}$) under southwest winds with wind speeds greater than 3 m s$^{-1}$ during each day of the week (a), overall average hourly PM$_{10}$ concentrations (µg m$^{-3}$) (b), average PM$_{10}$ concentrations (µg m$^{-3}$) by month (c), and average PM$_{10}$ concentrations (µg m$^{-3}$) by day of the week (d). Light shading indicates the 95% confidence intervals.](image-url)
and surface coating contributions are shown in Figures S8 and S9 (see the SM), respectively. Marine aerosol and biomass burning contributions were also not strongly influenced by southwesterly winds. The fertilizer source identified also showed southwesterly wind dependence, but the intermittent nature of the source would not produce the PM$_{10}$ concentration profiles presented in Section 3.2, and therefore activities associated with the loading and unloading of fertilizer are not considered responsible for the regular peak PM$_{10}$ concentrations from the southwest at Tahunanui.

![Figure 6](image6.png)

**Figure 6.** Scatterplot of motor vehicle contributions (μg m$^{-3}$) versus PM$_{10}$ concentrations (μg m$^{-3}$) under winds from the southwest (blue) and all other wind quadrants (red).

![Figure 7](image7.png)

**Figure 7.** Scatterplot of soil contributions (μg m$^{-3}$) versus PM$_{10}$ concentrations (μg m$^{-3}$) under winds from the southwest (blue) and all other wind quadrants (red).
The good correlations of the soil ($r^2=0.35$) and motor vehicle ($r^2=0.52$) source contributions with winds from the southwest is in agreement with the conclusion from Section 3.2 that the peak PM$_{10}$ concentrations during southwest winds were likely to be of anthropogenic origin and appeared to be associated with normal workday activities. The association of soil and vehicular sources of PM$_{10}$ originating from the southwest suggests that it is vehicular movements on unsealed yards or roadways in the industrial area that are responsible for the peak PM$_{10}$ concentrations. The association of soil and motor vehicles indicates that along with vehicular tailpipe emissions, vehicle movements and wind–action re–suspend dust from unsealed yards and other roadways to produce high contributions from soil. This result is also consistent with results presented in Section 3.1, where the relatively high soil contribution and similar vehicular and soil source profiles at Tahunanui appeared to be the result of mixed profiles resulting from traffic movements in the industrial area southwest of the Tahunanui air quality monitoring site. Since it is likely that the majority of soil was the result of re–enainment by vehicles, the motor vehicle and soil source contributions were combined to produce a scatterplot under southwesterly and all other wind directions (see the SM, Figure S10). Figure S10 shows that PM$_{10}$ associated with motor vehicle emissions and crustal matter from the industrial area to the southwest of the Tahunanui monitoring site are most likely responsible for the observed PM$_{10}$ concentration profiles (Section 3.2) and the non–peak PM$_{10}$ concentrations recorded by NCC because of their strong correlation with southwesterly winds ($r^2=0.59$). When only elemental concentrations were used to derive a soil contribution (using reconstructed mass calculations (Malm et al., 1994)), a similar plot to Figure S10 arises under winds from the southwesterly quadrant (Figure 8).

4. Conclusions

PM$_{10}$ samples were collected onto filters at the Tahunanui air quality monitoring site in Nelson from September 2008 to September 2009. Particle mass concentrations were determined gravimetrically and concentrations of elements present in the particulate matter samples were determined by ion beam analysis techniques. Receptor modeling of the elemental concentrations was used to identify sources and provide source mass contributions to ambient particle concentrations.

The receptor modeling results for Tahunanui indicated that anthropogenic sources, primarily emissions from solid fuel fires for domestic heating during winter were responsible for exceedances of the PM$_{10}$ NES. Marine aerosol and crustal matter (soil) were the significant sources of natural airborne particles at Tahunanui. It was also found that local industrial sources impacted on PM$_{10}$ concentrations at the Tahunanui monitoring station.

Meteorological and PM$_{10}$ concentration data from 2007–2012 were used in conjunction with source apportionment data to identify the source(s) of peak, non–winter PM$_{10}$ concentrations at Tahunanui that occurred under moderate to high wind speeds from the southwest. We found that these peak PM$_{10}$ episodes only occurred during normal weekday working hours and were generally absent during the weekend, ruling out the possibility that it was entirely due to natural phenomena which would be equally likely to occur during the week or weekend. Detailed analyses identified that the PM$_{10}$ particles were largely composed of crustal matter (soil) and that the source of these PM$_{10}$ concentrations was likely to be the movement of vehicles around an industrial area to the southwest of the monitoring site. These vehicle movements not only produced direct (tailpipe) emissions, but also re–entrained dust from unsealed yards or other roadways to the atmosphere. Combining the soil and motor vehicle contributions from the source apportionment study produced a strong correlation with winds from the southwest. Importantly, the anthropogenic nature of this PM$_{10}$ source suggests that emissions from these activities could be managed by Nelson City Council.

![Figure 8. Scatterplot of soil contributions (ng m$^{-2}$) calculated from mass reconstruction versus PM$_{10}$ concentrations (μg m$^{-3}$) under winds from the southwest (blue) and all other wind quadrants (red).](image)

Ancelet et al. – Atmospheric Pollution Research (APR)
Acknowledgments

The authors thank Chris Purcell for maintaining the 3 MV accelerator used for the IBA analyses. Thanks also go to Nelson City Council, and in particular Paul Sheldon, for their support of this study. This study was funded by Nelson City Council and the Ministry of Business, Innovation and Employment under the Envirolink scheme (Grants 872–NLCC 45 and NLCC 67).

Supporting Material Available

A map showing the location of the monitoring site (Figure S1), a plot of daily PM$_{10}$ concentrations at the monitoring site from 2006–2012 (Figure S2), a table of the elemental analysis results and associated statistics (Table S1), seasonal and weekday/weekend source contributions (Figures S3 and S4, respectively), a plot of average diurnal, daily and monthly PM$_{10}$ concentrations (Figure S5), a polar plot of PM$_{10}$ concentrations (Figure S6), a plot comparing diurnal, daily and monthly PM$_{10}$ concentrations when winds were from the southwest with all other wind directions (Figure S7), scatterplots of sulfate, surface coating, and combined vehicle motor and soil contributions under southwest winds and all other wind directions (Figures S8, S9 and S10, respectively). This information is available free of charge via the Internet at http://www.atmospolres.com.

References


