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Characterization and source apportionment of regional background inhalable particulate matter in Alberta

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Characterization and Source Apportionment of Regional Background Inhalable Particulate Matter in Alberta

SFM Network Project: Analysis of Particulate Matter Loading in Community Ambient Air

by

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EXECUTIVE SUMMARY

This study undertook air sampling, elemental analysis, and source apportionment receptor modeling for ambient particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}) at a representative site in Devon, Alberta over a two-month period (August and October 2000). The goal was to determine the level, chemical composition, and sources of regional background PM_{10} at this site.

Measurements taken using a Tapered Element Oscillating Microbalance (TEOM) showed that the ambient 1-hour and 24-hour average PM_{10} levels observed in Devon were low (i.e. <20 $\mu g/m^3$) for most of both sampling seasons. The mean 1-hour average concentration for the entire sampling period was 13 $\mu g/m^3$ and the mean 24-hour average concentration for the entire sampling period was 13 $\mu g/m^3$. In comparison to other studies, the levels measured in this study were as expected (i.e. similar to other regional background studies, higher than rural remote studies, and lower than rural industrial and urban studies). The 24-hour average concentrations measured over the two sampling seasons were not in violation of the current regulations of other jurisdictions. Samples collected using an Airmetrics Minivolume Portable Survey Sampler (MiniVol) and subsequently analyzed using a Scanning Electron Microscope with Energy Dispersive X-Ray (SEM-EDX) were dominated by lithophilic elements (Si, Ca, Fe, Al, K and Mg) and biological material. However, numerous trace metals were also detected in addition to elements such as S, V and Cl. Receptor modeling utilizing principle component analysis (PCA) apportioned PM_{10} collected to four main source categories that combined to account for 86% of total variance of the original data set. The largest contribution came from crustal material sources (30%) followed by coal emissions (22%), combustion sources (18%) and regional sulphate (15%).

The results of this study can be used to evaluate existing emission reduction strategies for ambient particulate matter levels, to devise more efficient emission reduction strategies for ambient particulate matter levels for industry and government, and to provide the necessary information for the development of particulate matter guidelines. In general, this study can equip society with an improved foundation upon which to make decisions about managing air quality issues that can have a maximum benefit to society. Better information about the levels, chemical composition, and source contributions to particulate matter in regional background settings can lead to a better basis for managing health, environmental and public welfare impacts of anthropogenic activities.

ACKNOWLEDGMENTS

This study would not have been made possible without the generous support of the Sustainable Forest Management Network. We are very grateful to Mr. Myron Siemans and family of Devon, Alberta for graciously providing a site where this research could be conducted. We would like to also acknowledge the information and materials provided by the Town of Devon. Finally, a special thanks to Kevin McCullum and George Braybrook of the University of Alberta for imparting invaluable technical insights and assistance.

INTRODUCTION

Background

Airborne particulate matter is an environmental contaminant that is unique among air pollutants. Elevated levels of particulate matter are abundantly evident. People do not need to be told there is a problem, they can see and taste it. Particulate matter is a generic term for a broad class of substances of varying size and chemical composition that are transported in the air as discrete solid particles or liquid droplets. The amount, size and chemical composition of particles can differ from location to location and over time, depending on the types of source emissions and atmospheric conditions.

Concern about airborne particulate matter in recent years has been largely driven by epidemiological studies that have reported relatively consistent links between ambient particulate matter levels and adverse health effects (NRC 1998). These and other scientific studies led the United States Environmental Protection Agency to announce revised National Ambient Air Quality Standards (NAAQS) for particulate matter with aerodynamic diameter less than or equal to 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$) in July 1997 (U.S. EPA 1997). The Government of Canada, in cooperation with the provincial and territorial governments, followed suit by ratifying a Canada-wide Standard (CWS) for $PM_{2.5}$ in June 2000 (CCME 2000). In addition, serious consideration is being given to implementing a CWS for PM_{10} in the future (CCME 2000).

Development of particulate matter control programs by government and industry and evaluation of their effectiveness as new standards and sources are introduced, necessitates an accurate understanding of the chemical and physical properties of particulate matter, its origins, and the contribution of each source to particulate matter levels. This understanding begins with ambient monitoring and sampling programs designed to complement studies of urban air quality with observations of regional background air quality. Without this knowledge it is difficult, if not impossible, to judge how much net impact anthropogenic activities are having on the quality of air we breathe. Regional background particulate matter is generally defined as the distribution of particulate matter concentrations as observed in the absence of local anthropogenic point source emissions, but still under the influence of local open and natural sources and from the long-range transport of anthropogenic particles and precursor gases. Ambient monitoring and sampling programs for regional background areas are necessary for a number of reasons (Munn 1981):

- so that regional background loadings can be subtracted from measured urban and industrial concentrations when pollution models are being validated;
- to separate the effects of long-term changes in emissions from changes in climate; and
- for public relations purposes and to provide citizens with urban-regional air quality comparisons.

Studies concerning levels, chemical composition, and sources of regional background PM_{10} in the atmosphere have been conspicuously lacking from the literature. One reason for this disparity is that it is becoming increasingly difficult to locate areas that are not under some degree of influence from local anthropogenic point source emissions. However, this does not mean that studies designed and conducted to determine the characteristics and sources of regional background particulate matter should be avoided. Rural sites located near urban areas where the information will be used can provide an adequate estimate of regional background particulate matter characteristics. This includes the measurement and characterization of particulate matter from open sources and from long-range transport of anthropogenic particles and precursor gases in the same geographical region (Munn 1981).

Such studies involving the collection of information regarding regional background PM_{10} from Alberta are absent and are of prime importance in regional air pollution health effects studies and regulatory assessment. These types of studies are needed in Canada, and especially Alberta, more than ever with the announcement of the previously mentioned CWS for particulate matter (CCME 2000). Among some of the issues the standard addresses are those directly involving regional background particulate matter. The standard states, for example, that "communities for which jurisdictions demonstrate that continued exceedance of the CWS levels is primarily due to…regional particulate matter and that best efforts have been made to reduce contributions to the excess levels from pollution sources within the jurisdiction, will be identified in reporting as "communities influenced by background or natural events" (CCME 2000)." This clause permits a community that is invariably reporting particulate matter levels beyond those allowed due to regional background influences to exceed the standard without penalty. However, "demonstration of background or natural influence is the (sole) responsibility of the affected jurisdiction (CCME 2000)." The trouble is that there are very few studies concerning the characteristics and sources of regional background PM_{10} in Canada and, until this study, none in Alberta, from which these jurisdictions can draw any conclusions about the influence of regional background particulate matter. Studies concerning the characteristics and sources of regional PM_{10} in Alberta are, therefore, required to assist communities in determining the impact that pollution is having on their daily lives.

Objectives

The primary purpose of this study was to establish the regional background level of PM_{10} in Alberta, characterize its chemical composition, and trace its origins using a receptor-based analysis method. The broad goal was to develop an enhanced foundation of information regarding the characteristics and sources of inhalable particulate matter in a rural community that is without major local anthropogenic point source emissions, but still under the influence of local open and natural sources and from long-range transport of anthropogenic particles and precursor gases. In other words, the goal was to fill a gap in the current literature regarding the characteristics and sources of regional background particulate matter in Alberta. The specific objectives of the study were:

- to determine the ambient levels of the PM_{10} in a regional background community and compare the results with those of similar studies and current regulations;
- to ascertain the elemental composition of the PM_{10} in a regional background community; and
- to establish the sources of the PM_{10} in a regional background community and evaluate their contributions to overall levels.

Overview

The objectives of this study were accomplished by judgmentally selecting a representative site in a rural Albertan community which had minimal local anthropogenic point source emissions of particulate matter, but which was still under the influence of local open and natural sources, in addition to regional source emissions from industrial activities and large urban centers. The community selected was Devon, Alberta (Figure 1). Devon is a small, centrally located rural community with a population of about 5,000. It has no significant local industrial point source emissions of particulate matter, but it has potential open sources such as construction and agricultural activity. It is located approximately 30 km southwest of a large urban center (Edmonton, Alberta) and about 50 km east and southeast of a number of industrial point sources (i.e. coal fired power plants). Due to these characteristics, Devon was an ideal candidate community to execute a study to determine the characteristics and sources of regional background PM_{10} in Alberta.

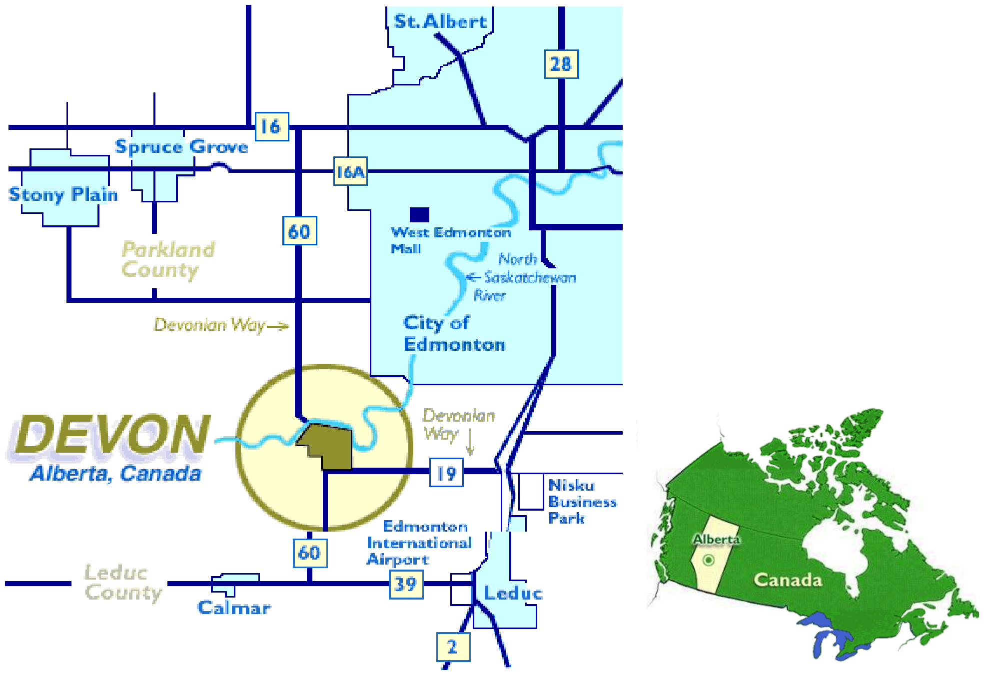

Figure 1. Location of Devon, Alberta.

Sampling and analysis methods were researched and developed for particulate matter monitoring, laboratory analysis, data analysis, and quality control and quality assessment. A representative location in the community of Devon, Alberta was judgmentally selected based on knowledge of siting requirements, potential sources and prevailing meteorological conditions (Figure 2). An air-sampling and monitoring program was developed which involved two 22-day sampling periods spread over two seasons (August and October of 2000) to account for seasonal, meteorological and human activity variability. A Tapered Element Oscillating Microbalance (TEOM)® Series 1400a ambient PM_{10} mass sampler (Rupprecht & Patashnick Co., Inc., Albany, NY, USA 1996) was used to continuously measure PM_{10} levels, and an Airmetrics Minivolume Portable Air Sampler (MiniVol)® (Airmetrics 1997) was used to collect 24-hour PM_{10} filter samples. Laboratory work involved Scanning Electron Microscopy with Energy Dispersive X-Ray (SEM-EDX) analysis to establish the elemental composition of the PM_{10} samples (Linton et al. 1980; Casuccio and Janocko 1981; Shaw 1983; Post and Buseck 1984; Saucy et al. 1987; Anderson et al. 1988; Dzubay and Mamane 1989; Hamilton et al. 1995). From the measurements obtained, a receptor model utilizing principle component analysis (PCA) was performed to determine the most likely elemental profiles of the sources (Henry and Hidy 1979; Cooper and Watson 1980; Roscoe et al. 1982; Pace 1985; Thurston and Spengler 1985; Watson 1988; Harrison et al. 1996; Harrison et al. 1997; Biegalski et al. 1998). These elemental profiles were then compared to the results of previous studies, to relevant literature, and to particulate matter databases (including the U.S. Environmental Protection Agency's SPECIATE database (U.S. EPA 1993)) to identify and categorize the most likely sources of PM_{10} at the receptor location. Quality control and quality assessment plans were developed and strictly followed. Refer to Schulz (2001) for a further explanation of methods, procedures and protocols.

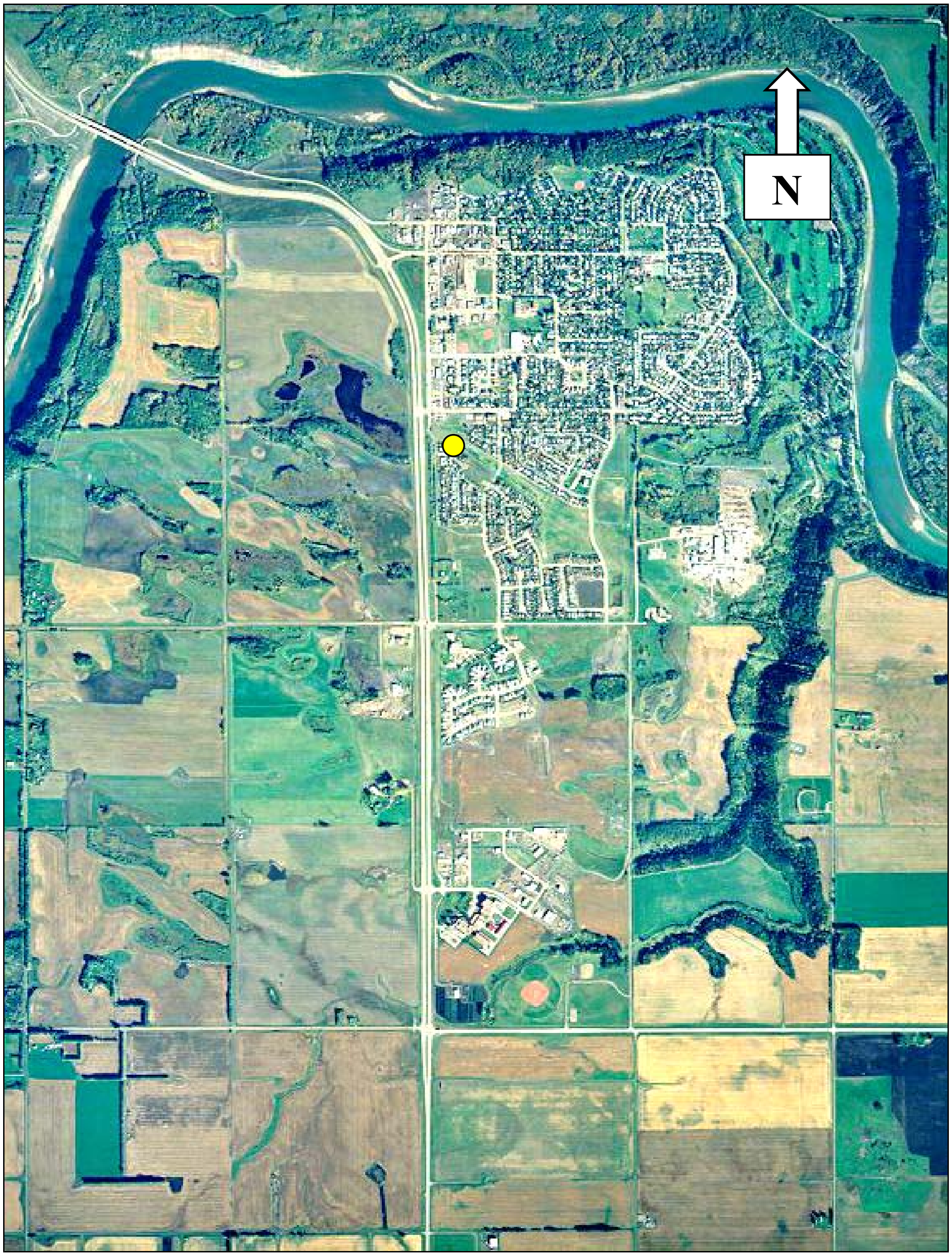

Figure 2. Overview of sampling site in Devon, Alberta.

Note: ● indicates the sampling site.

DATA ANALYSIS

Particulate Matter Level Results

Levels

Continuous ambient air monitoring was performed using a TEOM to measure regional background PM_{10} concentrations at a representative location in Devon, Alberta for the periods of August 1 through August 23 and October 3 through October 25 of 2000. A total of twenty-two consecutive days for each month were monitored for a total of forty-four monitoring days. The monitoring adhered to the techniques and protocols outlined in Schulz (2001). Comprehensive data was collected by the TEOM for mass concentration, 30-minute average concentration, 1-hour average concentration, 24-hour average concentration, total mass, temperature and atmospheric pressure for both the August and October monitoring periods. The results for the PM_{10} 1-hour average concentrations for August 1 through August 23, 2000 are presented in Figure 3. The results for the PM_{10} 1-hour average concentrations for October 3 through October 25, 2000 are presented in Figure 4. The results for the PM_{10} 24-hour average concentrations for August 1 through August 23, 2000 are presented in Figure 5. Finally, the results for the PM_{10} 24-hour average concentrations for October 3 through October 25, 2000 are presented in Figure 6.

It was observed that 1-hour average PM_{10} levels were very low (i.e. $<20\ \mu g/m^3$) for most of both sampling seasons (Figures 3 and 4). However, a number of peaks did occur on several occasions and there were times of sustained elevated levels (especially during the October sampling season). Depending on local meteorological conditions, short-term fluctuations in PM_{10} levels at a fixed location (such as the monitoring site in Devon) can generally be attributed to near-field sources and/or atmospheric transport from sources further away under prevailing winds. For instance, the elevated levels observed during the periods of August 18 to August 23, October 11 to October 14, and October 23 to October 25 could most likely be attributed to near-field sources. Roadwork, construction and lawn maintenance all occurred during these time frames in very close proximity (i.e. <100 m) to the receptor location. Whereas on August 1, August 4, October 8, and October 16, elevated levels of PM_{10} were due mainly to regional emissions from distant forest fires and prescribed agricultural burning events that were carried to the area by the prevailing winds.

Prolonged durations of low 1-hour average PM_{10} levels can more than likely be explained by the influences from precipitation events and snow cover, which work to scavenge particles from the atmosphere and to inhibit the re-suspension of particulate material. For example, the low levels observed in the middle of August (i.e. August 11 to August 14) are due mainly to the large amount of precipitation that was detected during this time (Environment Canada 2000). The low levels of PM_{10} observed for early October (i.e. October 3 to October 7) are explained mainly by the snow cover present during that time (Environment Canada 2000).

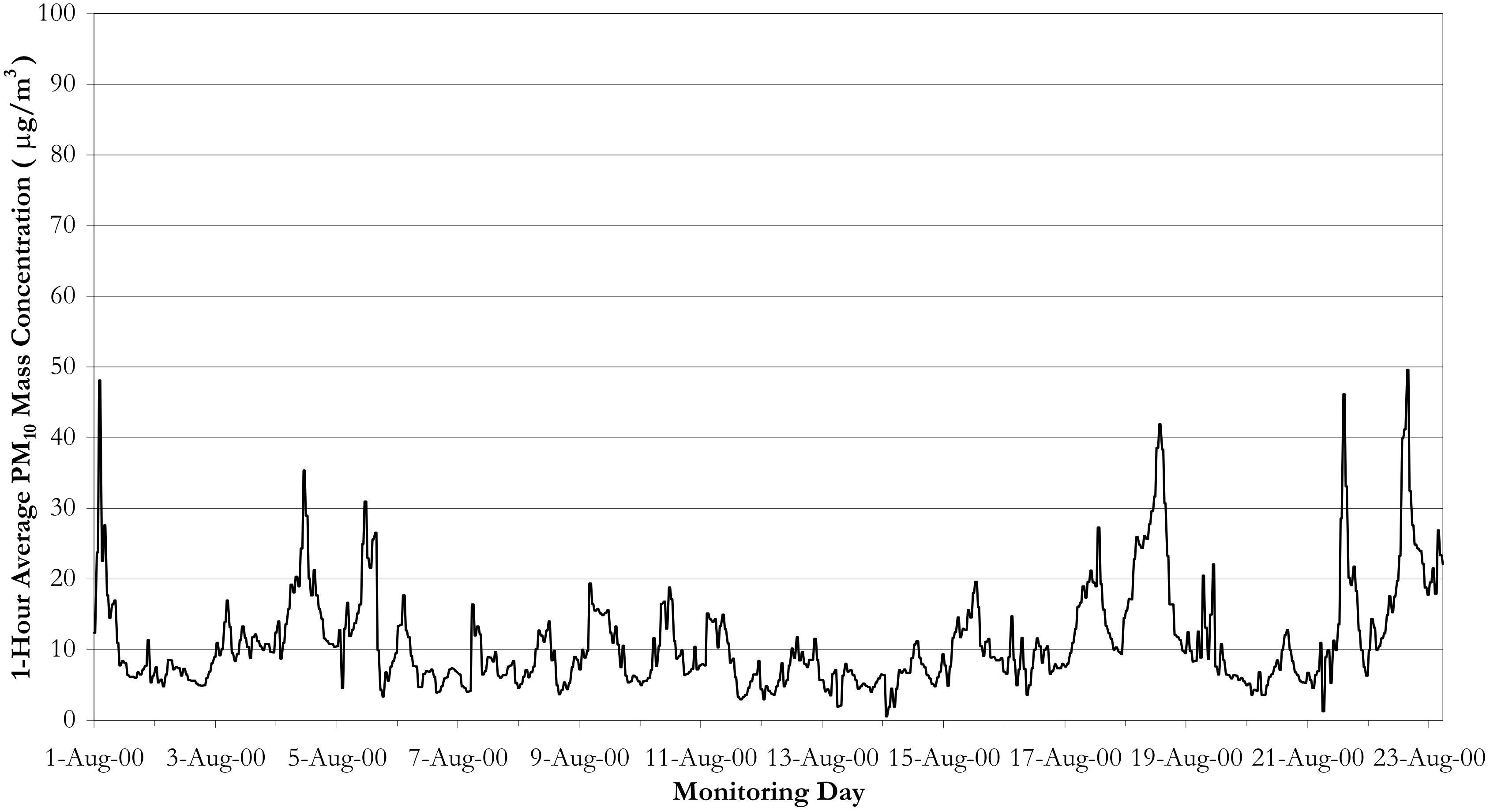

Figure 3. TEOM 1-hour average PM_{10} mass concentration air sampling results for Devon, Alberta for August 1, 2000 to August 23, 2000.

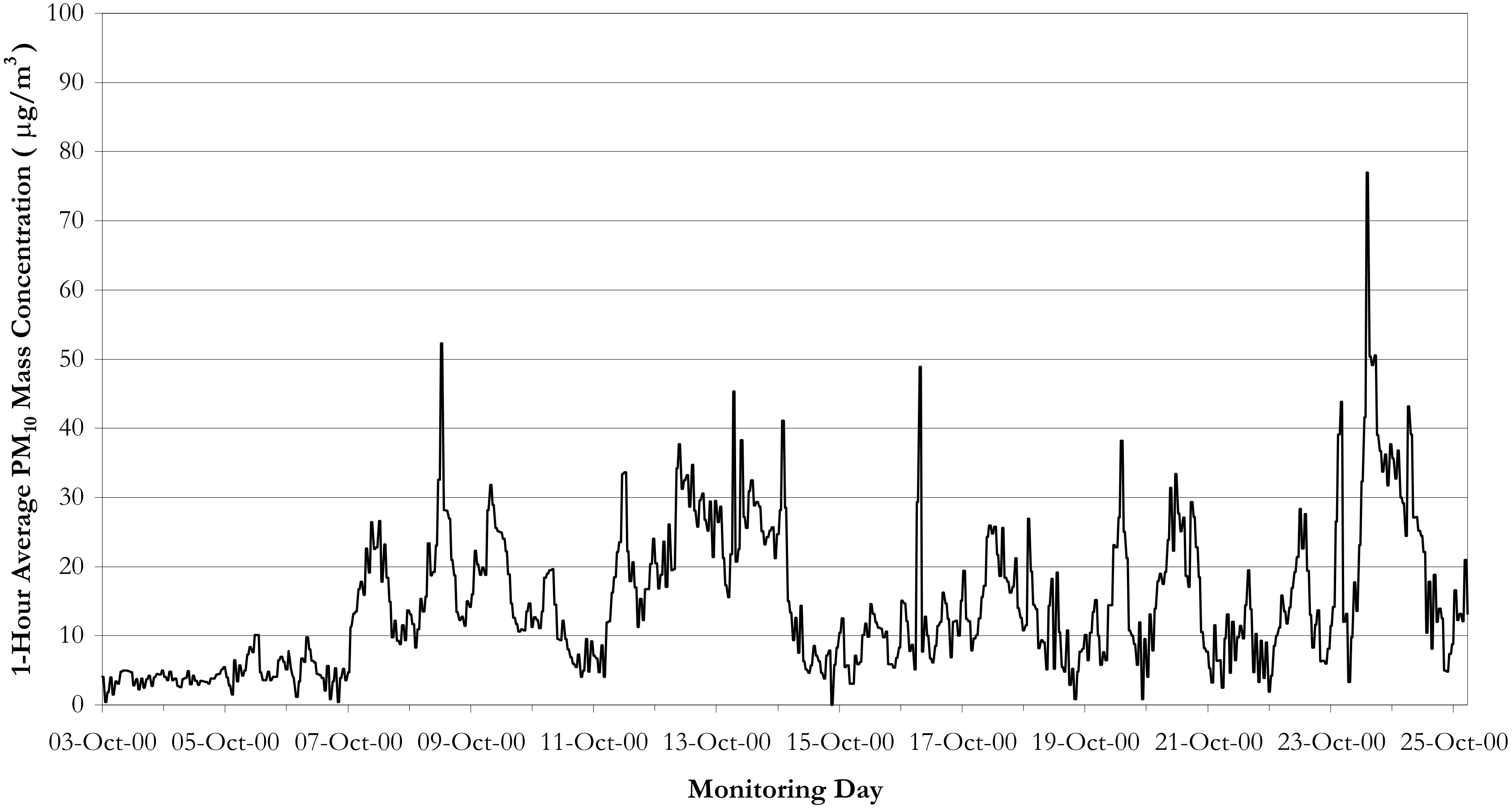

Figure 4. TEOM 1-hour average PM_{10} mass concentration air sampling results for Devon, Alberta for October 3, 2000 to October 25, 2000.

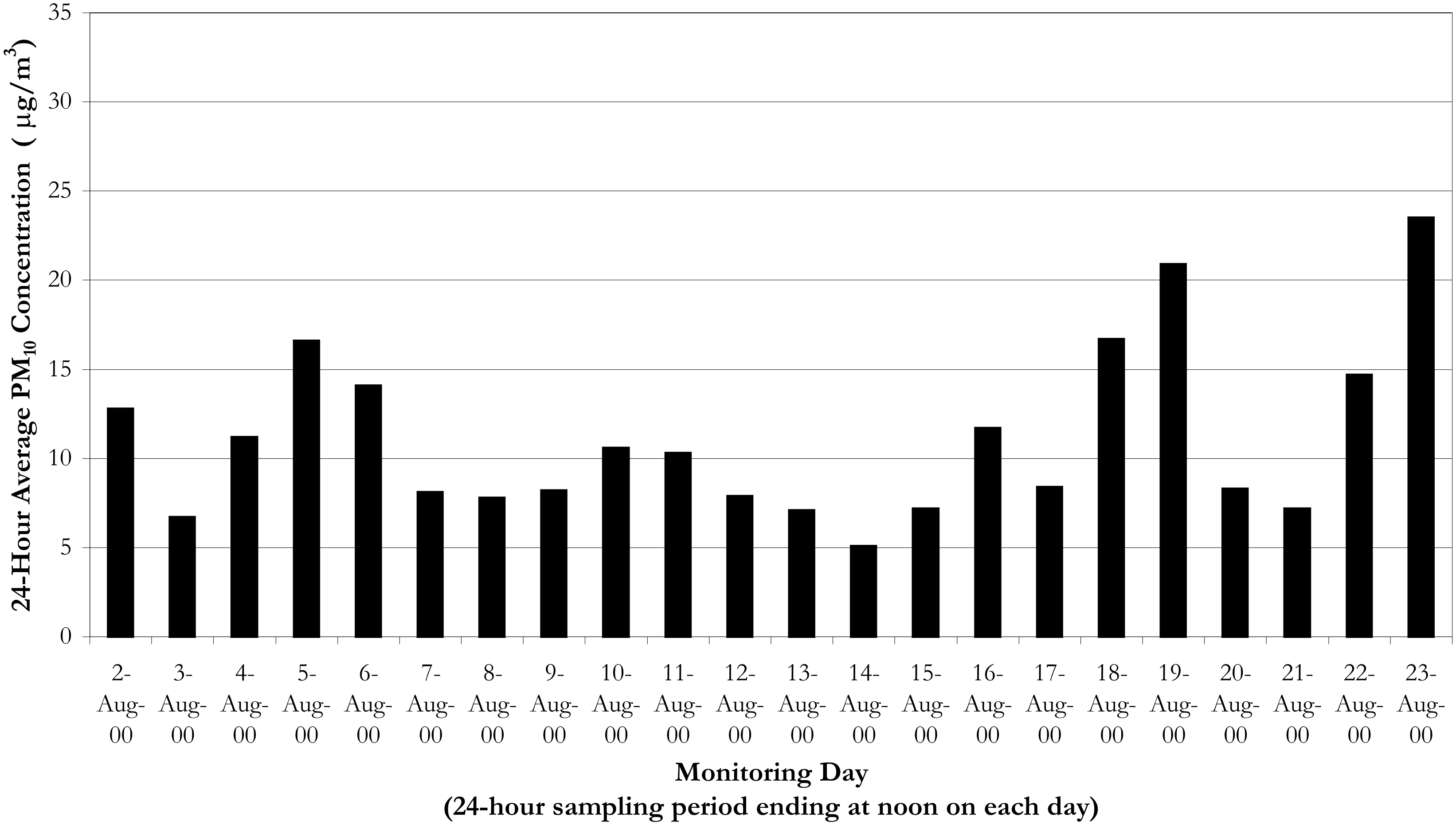

Figure 5. TEOM 24-hour average PM_{10} mass concentration air sampling results for Devon, Alberta for August 2, 2000 to August 23, 2000.

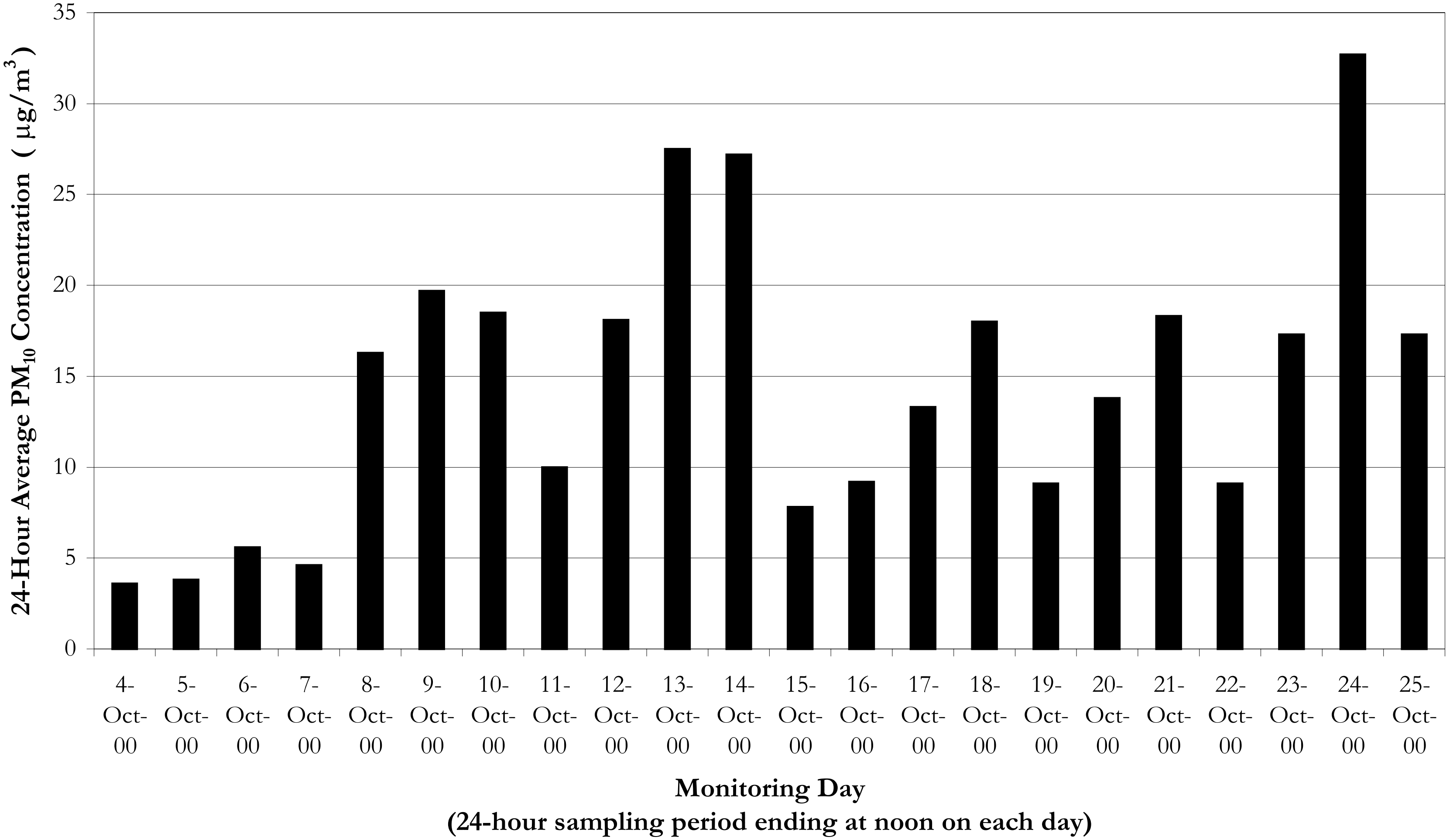

Figure 6. TEOM 24-hour average PM_{10} mass concentration air sampling results for Devon, Alberta for October 4, 2000 to October 25, 2000.

The 1-hour average PM_{10} levels exhibited a cyclical trend characteristic of the daily trends of outdoor pollutants, increasing in concentration during the day and decreasing at night. The lowest levels were often observed during the very early hours of the morning when the least amount of human activity was occurring. The highest levels were observed between the hours of 5:00 am in the morning and midnight when the greatest amount of human activity was occurring. In addition to diurnal patterns, weekly patterns were also observed. In this case, levels were found to be higher during the weekdays and lower on the weekends. This is again a result of the greatest amount of human activity occurring during the weekdays.

It was observed that 24-hour average PM_{10} levels were very low (i.e. <20 $\mu g/m^3$) for most of both sampling seasons (Figures 5 and 6). However, average daily levels over 20 $\mu g/m^3$ were observed on a number of occasions including: August 19, August 23, October 13, October 14 and October 24. In each of these instances, the elevated levels can be attributed to the influences of near-field activities. Roadwork, construction and lawn maintenance were all observed during these days in very close proximity (i.e. <100 m) to the receptor location. Those average daily levels that were very low (i.e. <10 $\mu g/m^3$) are due mainly to the affects of precipitation and snow cover. Substantial amounts of precipitation was observed during the time periods of August 12 to August 15 and October 15 to October 16, and the time period of October 4 to October 7 was dominated by snow cover (Environment Canada 2000).

Table 1 describes the relevant descriptive statistics for the 1-hour average PM_{10} mass concentration data for the entire sampling period. The mean 1-hour average concentration for the August sampling period was 11 $\mu g/m^3$ and the standard deviation was 7.2 $\mu g/m^3$. The mean 1-hour average concentration for the October sampling period was 15 $\mu g/m^3$ and the standard deviation was 10 $\mu g/m^3$. The mean 1-hour average concentration for the entire sampling period (i.e. August and October) was 13 $\mu g/m^3$ and the standard deviation was 8.8 $\mu g/m^3$. The maximum 1-hour average concentration over the entire sampling period was 77 $\mu g/m^3$, which occurred on October 23 at 9:00 p.m., and the minimum 1-hour average concentration over the entire sampling period was 2.0 $\mu g/m^3$, which occurred on numerous occasions.

Table 1. 1-Hour average PM_{10} concentration statistics summary

Sampling Period	Mean	Standard Deviation	Maximum	Minimum
August	11 $\mu g/m^3$	7.2 $\mu g/m^3$	50 $\mu g/m^3$	*2.0 $\mu g/m^3$
October	15 $\mu g/m^3$	10 $\mu g/m^3$	77 $\mu g/m^3$	*2.0 $\mu g/m^3$
Total	13 $\mu g/m^3$	8.8 $\mu g/m^3$	77 $\mu g/m^3$	*2.0 $\mu g/m^3$

(* Method detection limit)

Table 2 describes the relevant descriptive statistics for the 24-hour average PM_{10} mass concentration data for the entire sampling period. The mean 24-hour average concentration for the August sampling period was 11 µg/m^3 and the standard deviation was 4.9 µg/m^3. The mean 24-hour average concentration for the October sampling period was 15 µg/m^3 and the standard deviation was 8.0 µg/m^3. The mean 24-hour average concentration for the entire sampling period (i.e. August and October) was 13 µg/m^3 and the standard deviation was 6.4 µg/m^3. The maximum 24-hour average concentration over the entire sampling period was 33 µg/m^3, which occurred on October 24, and the minimum 24-hour average concentration over the entire sampling period was 3.6 µg/m^3, which occurred on October 4.

Table 2. 24-Hour average PM_{10} concentration statistics summary

Sampling Period	Mean	Standard Deviation	Maximum	Minimum
August	11µg/m^3	4.9 µg/m^3	24 µg/m^3	5.1 µg/m^3
October	15 µg/m^3	8.0 µg/m^3	33 µg/m^3	3.6 µg/m^3
Total	13 µg/m^3	6.4 µg/m^3	33 µg/m^3	3.6 µg/m^3

Comparison of results to similar studies and regulations

In Table 3 results of the present study are compared with those of similar studies conducted in Alberta and some current regulations. A number of observations can be made. In comparison to other regional background studies, the results of this study are very analogous. The mean 24-hour PM_{10} average mass concentration measured in other regional background sites throughout Alberta was reported to be 17 μg/m^3 (Cheng et al. 2000) compared to 13 μg/m^3 for Devon. This comparability suggests that the emission sources and quantities in Devon are similar to those found in other regional background sites in Alberta. A comparison of the results with those of rural remote studies (8.8 μg/m^3 (Cheng et al. 2000)) indicates that non-point anthropogenic sources (i.e. vehicles, road dust, agriculture, construction) have a significant influence on the PM_{10} concentrations in Devon. As expected, the results from the present study are lower than those of rural industrial sites (i.e. rural areas with near-field industrial activates). Measured rural industrial concentrations of approximately 25 μg/m^3 (McCullum and Kindzierski 2000) imply that near-field industrial activities can have a substantial influence on local ambient PM_{10} levels. The results of Alberta urban studies (29 μg/m^3 for Edmonton and 26 μg/m^3 for Calgary (Alberta Environment 1996)) demonstrate much higher ambient levels of PM_{10} than those measured in Devon, which indicates urban activities can have a large impact on local PM_{10} levels. Finally, at no time were the 24-hour average concentrations measured in Devon during the two sampling seasons in violation of any relevant current regulations of other jurisdictions.

Table 3. Comparison of mean 24-hour PM_{10} levels to various locations and regulations

Site Type	Location/Source	Mean 24-Hour PM_{10} Concentration
Regional Background	Devon, Alberta – August (present study)	11 μg/m^3
Regional Background	Devon, Alberta – October (present study)	15 μg/m^3
Regional Background	Devon, Alberta – Total (present study)	13 μg/m^3
Regional Background	Numerous Alberta Locations (Cheng et al. 2000)	17 μg/m^3
Rural Remote	Numerous Alberta Locations (Cheng et al. 2000)	8.8 μg/m^3
Rural Industrial	High Level, Alberta (McCullum and Kindzierski 2000)	25 μg/m^3
Urban	Edmonton, Alberta (Alberta Environment 1996)	29 μg/m^3
Urban	Calgary, Alberta (Alberta Environment 1996)	26 μg/m^3
Regulation	U.S. Environmental Protection Agency (U.S. EPA 1997)	150 μg/m^3
Regulation	California, USA (Pryor and Barthelmine 1996)	50 μg/m^3

Particulate Matter Chemical Composition Results

Ambient air sampling was conducted using the MiniVol to obtain regional background PM_{10} filter samples. A total of forty-four samples, in addition to blanks and replicates, were collected and subsequently analyzed by means of the SEM-EDX for a total of nineteen elements (Si, Ca, Fe, Al, K, Na, Mg, Mn, Cl, S, P, Ti, V, Pb, Cr, Ni, Cu, Zn and As) and their biological material content. These elements were chosen for analysis because of their suspected abundances, strong tracer characteristics, and a qualitative knowledge of possible SEM-EDX elemental interference problems (G. Braybrook, Scanning Electron Microscope (SEM) Technician, University of Alberta. Edmonton, Alberta, pers. comm.) The SEM-EDX analysis adhered to the techniques and protocols outlined in Schulz (2001).

The results of the SEM-EDX analysis for the total PM_{10} elemental composition and biological material content for August 1 through August 23, 2000 and October 3 through October 25, 2000 as a whole are presented in Figure 7. The elemental composition is presented as a percent relative abundance of the total composition and the biological material content is presented as a ratio between the number of biological particles counted per ten particles elementally analyzed.

The results illustrate a distinct difference between those elements that were found to be highly abundant (i.e. >1%) and those that were found only in trace amounts (i.e. <1%). The elements that were highly abundant contributed the vast majority (93%) to the total composition of the PM_{10} samples and included: Si, Ca, Fe, Al, K and Mg. These elements tend to be associated with crustal or lithophilic sources such as agricultural activities, undisturbed soil, paved roads, unpaved roads, construction and others (Beceiro-Gonzalez et al. 1997). They can, however, also indicate the presence of particles originating from coal combustion (Chow 1995). An additional abundant element, Cl, is usually associated with combustion and incineration activities and salt aerosols (Marcazzan 1998; U.S. EPA 1993). Those elements that were present in trace amounts included: Na, Mn, S, P, Ti, V, Pb, Cr, Ni, Cu, Zn and As. The majority of these trace elements are heavy metals that are indicative of industrial and other anthropogenic activities (Chow 1995). The other trace elements such as V and S are indicative of oil combustion and regional sulphates (Tuncel et al. 1985; Marcazzan 1998). The amount of biological material (measured as a ratio), including organic and elemental particles, was just below one. This value indicates that approximately an equal amount of particles of biological origin were present in the atmosphere at the sampling location as inorganic particles during the sampling periods. This result is not surprising since biological material has been consistently shown to make-up a large proportion of the PM_{10} found in ambient air (Hopke 1985).

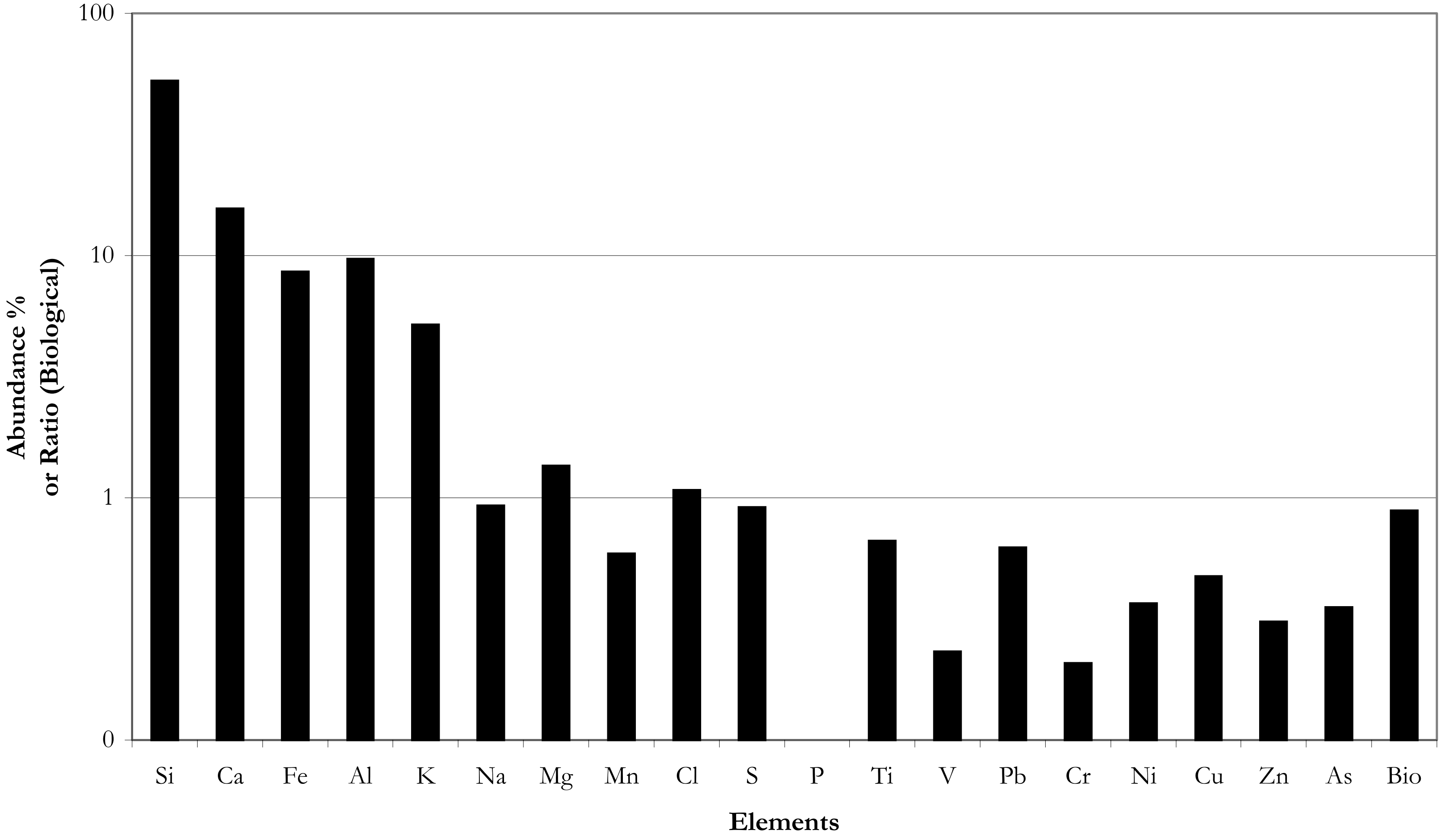

Figure 7. Results of the SEM-EDX PM_{10} elemental analysis for the entire sampling period.

Particulate Matter Source Apportionment Results

A principle component analysis (PCA) was performed using elemental abundance data provided by the SEM-EDX analysis of particulate matter (PM_{10}) collected. A total of forty-four filters were analyzed by SEM-EDX for a total of nineteen elements (Si, Ca, Fe, Al, K, Na, Mg, Mn, Cl, S, P, Ti, V, Pb, Cr, Ni, Cu, Zn and As). The PCA preparation and execution adhered to the techniques and protocols outlined in Schulz (2001). Specifically, using the TEOM mass concentration data ($\mu g/m^3$) and the elemental abundance (%) results from the SEM-EDX analysis, elemental concentrations (ng/m^3) were determined for each of the forty-four filters. The elemental concentration data for each of the nineteen elements were first standardized by calculating the z-scores. The z-scores were then used in conjunction with SYSTAT Version 9.0® for the PCA utilizing a Varimax rotation (SPSS 2000).

In keeping with the protocols of other regional background studies (Shaw 1983; Stevens et al. 1984; Rahn and Lowenthal 1984; Hidy 1988; Sharma and Singh 1991; Xhoffer et al. 1991; Harrison et al. 1997), elements and their data were incrementally eliminated and the analysis repeated until only those elements that did not possess any of the following characteristics remained:

- Elements that had low abundances or that were thought to have been unreliably determined by the SEM-EDX analysis. These determinations were based upon a qualitative knowledge of SEM-EDX elemental interference problems and a quantitative determination of the significance of elemental concentrations relative to their reported values and uncertainties.
- Elements that were clearly not distinctive to one source or factor. This determination was made based on the criteria that any element which had a factor loading greater than ± 0.4 for three or more factors was not indicative of any one source.
- Elements that are known to be a distinctive tracer for more than one source and were, therefore, adding confusion and uncertainty to the analysis.
- Elements that were not significantly contributing any further information in identifying a source.

This elimination procedure resulted in a total of twelve elements being incrementally removed from further analysis (Si, Ca, Al, K, Na, Mg, P, Ti, V, Cr, Ni and Cu). The subsequent PCA utilizing the remaining seven elements (Fe, Mn, Cl, S, Pb, Zn and As) resulted in a total of four factors with eigenvalues greater than one (eigenvalues which are less than one were presumably dominated by error variance (Thurston and Spengler 1985)) that combined to account for 86% of total variance of the original data set (Table 4).

Table 4. Results of the PCA

Factors	1	2	3	4
Fe	0.92	0.09	-0.06	-0.14
Mn	0.89	0.05	0.06	0.03
Cl	0.00	0.00	0.95	-0.08
S	-0.04	0.00	-0.04	0.98
Pb	-0.03	0.94	-0.10	-0.11
Zn	0.60	0.22	0.49	0.22
As	0.34	0.77	0.29	0.20
Eigenvalue	2.59	1.26	1.11	1.03
Variance Explained by Rotated Components	2.12	1.54	1.24	1.08
Percent of Total Variance Explained	30.29	22.06	17.76	15.43

The results of the PCA were compared to previous studies, relevant literature, and particulate matter databases (including the U.S. Environmental Protection Agency's SPECIATE database (U.S. EPA 1993)) to identify and categorize the most likely sources of PM_{10} at the receptor location. The result of the PCA are presented again in Table 5 with the factors labeled as probable sources and with only those factor loadings that indicated an element was strongly associated with a particular source shown (i.e. greater than ± 0.4).

Table 5. Results of the PCA summarized by source

Sources	Crustal Material	Coal Emissions	Combustion	Regional Sulphate
Fe	**0.9**			
Mn	**0.9**			
Cl			**1.0**	
S				**1.0**
Pb		**0.9**		
Zn	**0.6**		**0.5**	
As		**0.8**		
Eigenvalue	2.6	1.3	1.1	1.0
Variance Explained by Rotated Components	2.1	1.5	1.2	1.1
Percent of Total Variance Explained	30.3	22.1	17.8	15.4

The first factor was identified as crustal material due to its strong association with the lithophilic marker elements iron and manganese (Beceiro-Gonzalez et al. 1997). Zinc, which is considered to make up an important part of the chemical profile of crustal material (Hammerle and Pierson 1975; Chow 1995), also had a significant association to this factor. The procedure developed for applying PCA in regional background studies has a downside in that a more specific identification of a source is not possible. Therefore, the sources of crustal material could have included such things as agricultural activities, undisturbed soil, paved roads, unpaved roads, construction and others (Weir and Ireson 1988).

The second factor was clearly recognized as coal emissions because of its strong association to the very distinctive marker elements arsenic and lead (Parekh and Husain 1981; Fung and Wong 1995; Alves et al. 1998). This coal component was most likely the result of the long-range transport of coal flyash from the numerous coal-fired power plants situated over 50 km to the west and west-northwest of the receptor location. This supposition was validated by the detection and identification of a substantial amount of individual coal flyash particles by the SEM (Schulz 2001) and by the wind direction analysis indicating most of the arsenic detected at the receptor location was originating from the west and west-northwest (Schulz 2001).

The third factor was identified as the total of contributions from numerous combustion sources. Again, a more specific identification of a source was not possible with this type of analysis. These combustion sources could have included: biomass burning, refuse incineration, vehicle combustion, forest fires and residential wood burning. The presence of chlorine would initially indicate that the source was a salt aerosol. However, as this study was conducted in the summer and fall months, no road salt was used in the area for de-icing activities. In addition, there were no marine aerosol sources for thousands of kilometers. The most important source for chlorine, after salt aerosols, is considered to be combustion activities (Marcazzan 1998; U.S. EPA 1993). Its moderate association with zinc further supported the labeling of this factor as combustion sources. Zinc is highly indicative of combustion processes such as refuse incineration, biomass and vegetation burning, and vehicular fuel and oil combustion (Lowenthal and Rahn 1987; Morales et al. 1990; Sharma and Singh 1992; Huang et al. 1994).

The final factor, factor four, had only one element for which it was strongly associated. The sulphur component, in this situation, was identified as a background regional sulphate source (Dzubay et al. 1988). Sulphate has long been recognized as a regional pollutant. As it is formed slowly into secondary aerosols from SO_2 via atmospheric chemistry while traveling distances of hundreds of kilometers, its ambient levels are not much affected by local sources. Concentrations are only slightly higher in urban areas than in surrounding rural areas (Tuncel et al. 1985). Wind direction analysis indicated that the sulphur detected at the receptor location originated from all directions more or less equally (Schulz 2001), thereby suggesting that the sulphur source is more of a ubiquitous source than a point source. This background regional sulphate was likely due to the high amount of oil and gas activity in Alberta (that often results in gas flaring and other industrial processes), emissions from coal-fired power plants, and emissions from other primary industrial sources that cannot be singled-out. This assertion is validated by

Cheng et al. (1998), who report that Alberta has higher levels of SO_2, NO_x and VOCs compared to all bordering provinces and states, and that for Edmonton and Calgary the largest mass fraction of the fine particulate matter, which is incorporated in PM_{10}, is sulphate.

The results of the source apportionment reveal that PM_{10} sampled at the representative receptor location in Devon, Alberta was composed of the contributions of at least four sources (not including biological material), which combined to account for 86% of total variance of the original data set (Figure 8). The largest contribution was from sources of crustal material and accounted for 30% of the PM_{10} sampled. The next most significant source, contributing 22%, was coal emissions originating most likely from long-range transport of coal flyash from the numerous coal-fired power plants located to the west and northwest. Combustion sources and regional background sulphate contributed 18% and 15% of the PM_{10}, respectively. A total of 14% of the PM_{10} at the receptor location originated from unknown sources that could not be explained by the PCA.

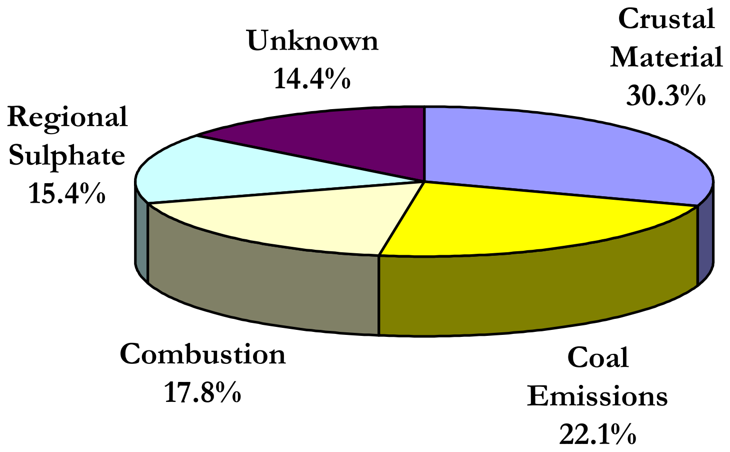

Figure 8. Sources of PM_{10} in Devon, Alberta.

CONCULSIONS AND MANAGEMENT APPLICATIONS

An extensive ambient air-monitoring program was conducted during August and October of 2000 in Devon, Alberta in order to provide detailed information on the characteristics and sources of regional background inhalable particulate matter (PM_{10}) in Alberta.

The first objective of the study was to determine the ambient levels of the PM_{10} in a regional background community and compare the results with those of similar studies and current regulations. The results of the study show:

- The ambient 1-hour and 24-hour average PM_{10} levels observed in Devon were low (i.e. <20 $\mu g/m^3$) for most of both sampling seasons. The mean 1-hour average concentration for the entire sampling period was 13 $\mu g/m^3$ and the mean 24-hour average concentration for the entire sampling period was 13 $\mu g/m^3$.
- In comparison to other studies, the levels measured in this study were as expected (i.e. similar to other regional background studies, higher than rural remote studies, and lower than rural industrial and urban studies). The 24-hour average concentrations measured over the two sampling seasons were not in violation of the current regulations of other jurisdictions.

The second objective of the study was to ascertain the elemental composition of the PM_{10} in a regional background community. The results of the study show:

- The PM_{10} sampled was dominated by lithophilic elements (i.e. Si, Ca, Fe, Al, K and Mg) and biological material. However, numerous trace metals were also detected in addition to elements such as S, V and Cl.

The third objective of the study was to establish the sources of the PM_{10} in a regional background community and evaluate their contributions to overall levels. The results of the study show:

- The PM_{10} collected during the two sampling seasons originated from four main source categories that combined to account for 86% of total amount of particulate matter collected. The largest contribution came from crustal material sources (30%) followed by coal emissions (22%), combustion sources (18%) and regional sulphate (15%).

As with most detailed studies it becomes apparent that there are improvements in methods and approaches which might yield further useful information. There are also numerous avenues of research that could not be addressed within the constraints of the current study but which could improve the foundation of knowledge pertaining to particulate matter. Some of these improvements and suggestions are noted here:

- Additional useful information on seasonal and long-term variability could have been obtained if this research had been conducted over a one-year period.
- Additional useful information on spatial variability could have been obtained if this research had been conducted at multiple sites.

- A complementary study should be conducted in Devon to determine the characteristics and sources of regional background $PM_{2.5}$.

The results of this study can be used to evaluate existing emission reduction strategies for ambient particulate matter levels, to devise more efficient emission reduction strategies for ambient particulate matter levels for industry and government, and to provide the necessary information for the development of particulate matter guidelines. In general, this study can equip society with an improved foundation upon which to make decisions about managing air quality issues that can have a maximum benefit to society. Better information about the levels, chemical composition, and source contributions to particulate matter in regional background settings can lead to a better basis for managing health, environmental and public welfare impacts of anthropogenic activities.

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