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# Analysis of particulate matter origin in ambient air at High Level, Alberta

**Kevin McCullum and Warren Kindzierski**

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# Analysis of Particulate Matter Origin in Ambient Air at High Level, Alberta

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

by

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**May 2001**

# EXECUTIVE SUMMARY

This research project involves the analysis of particulate matter (PM) loading in community ambient air. Ambient PM is a growing concern to regulatory bodies due to potential adverse health effects from exposure. This study was conducted to characterize source contributions of PM to the airshed in High Level, Alberta. Of primary interest was a wood waste burner, operated by High Level Forest Products Ltd., Tolko Industries (formally Daishowa-Marubeni International Ltd.). The focus has been placed on the wood waste burner, due to current interest in phasing out of such burners within the wood processing industry. Thus a field study involving a detailed air-sampling program in High Level was conducted during winter, spring, summer and fall of 1999. For each of the seasons, air sampling equipment was placed at three separate locations (two elevated and one ground level) around the community of High Level. The Field sampling utilized a TEOM-Series 1400a continuous ambient particulate monitor (for $PM_{10}$), a Minivol $PM_{2.5}$ and Minivol $PM_{10}$ low volume portable air samplers, and a Campbell Scientific meteorological station.

The scope of this research was to study and evaluate new methodologies pertaining to low volume air samplers and micro-analytical analysis in order to optimize receptor-model techniques. The receptor sampling approach involved collecting and analyzing ambient air samples at a given site, and inferring the contribution of sources to the total (PM) mass measured. The low volume sampling technique is more portable and more cost effective for industry, compared to the use of large and costly mid to high volume samplers. In addition to evaluating new methodologies, the main objective was to identify the potential source effect of the wood waste burner on the community of High Level. Thus along with the receptor model a tracer analysis and trajectory analysis were also utilized to characterize the source to site effects. In addition, ambient levels of PM collected were analyzed and compared to levels observed in other communities of Alberta to demonstrate similarities in ambient air PM concentration without wood waste burners.

Using the collected continuous air sampling data from the TEOM, the average 24-hour $PM_{10}$ levels were recorded for each season as follows, 16 $\mu g/m^3$ during the winter, 20 $\mu g/m^3$ during the spring, 50 $\mu g/m^3$ during the summer, and 12 $\mu g/m^3$ during the fall. From this continuous air sampling data, a trajectory analysis was performed to outline the maximum ambient PM concentration versus prevailing wind direction. Based on these findings, source origins contributing to PM concentration maxima did not appear to be associated with the wood waste burner operation. In addition, a source to site trajectory analysis was performed on the continuous sampling data, which identified the wood waste burner as the source, and the sampling locations as the sites. This analysis resulted in relatively low levels of PM originating from the wood waste burner direction compared to the maximum concentration trajectory analysis performed. Based on these findings, the obvious presence of combustion source originating from the direction of the wood waste burner was not indicated. The final analysis performed with the continuous data was a comparison of the mass concentrations to other locations. For High Level, the overall median 24-hour $PM_{10}$ concentration was 13 $\mu g/m^3$ (for all

four seasons of sampling), which is less than the median 24-hour $PM_{10}$ concentration reported for Edmonton and Calgary (27 $\mu g/m^3$ and 23 $\mu g/m^3$ respectively).

Particulate matter collected from the low volume samplers were analyzed by Scanning Electron Microscopy - Energy Dispersive X-ray analysis (SEM-EDX), and the results statistically analyzed using a principal component analysis (PCA) receptor modeling technique. Results of the PCA suggested that six primary sources accounted for approximately 79 percent of the variance between element concentrations. These six primary sources included crustal material (26%), road dust (13%), road salts (12%), vehicles (11%), residual oil (10%), and sulfates (7%). Based upon these findings, an obvious relationship was not found between the wood waste burner operation in High Level and airborne particulate concentration fluctuations observed at any of the sites monitored. Instead, the primary sources contributing to measured PM levels at these sites appeared to be crustal soil, road dust and vehicle re-suspension.

## ACKNOWLEDGEMENTS

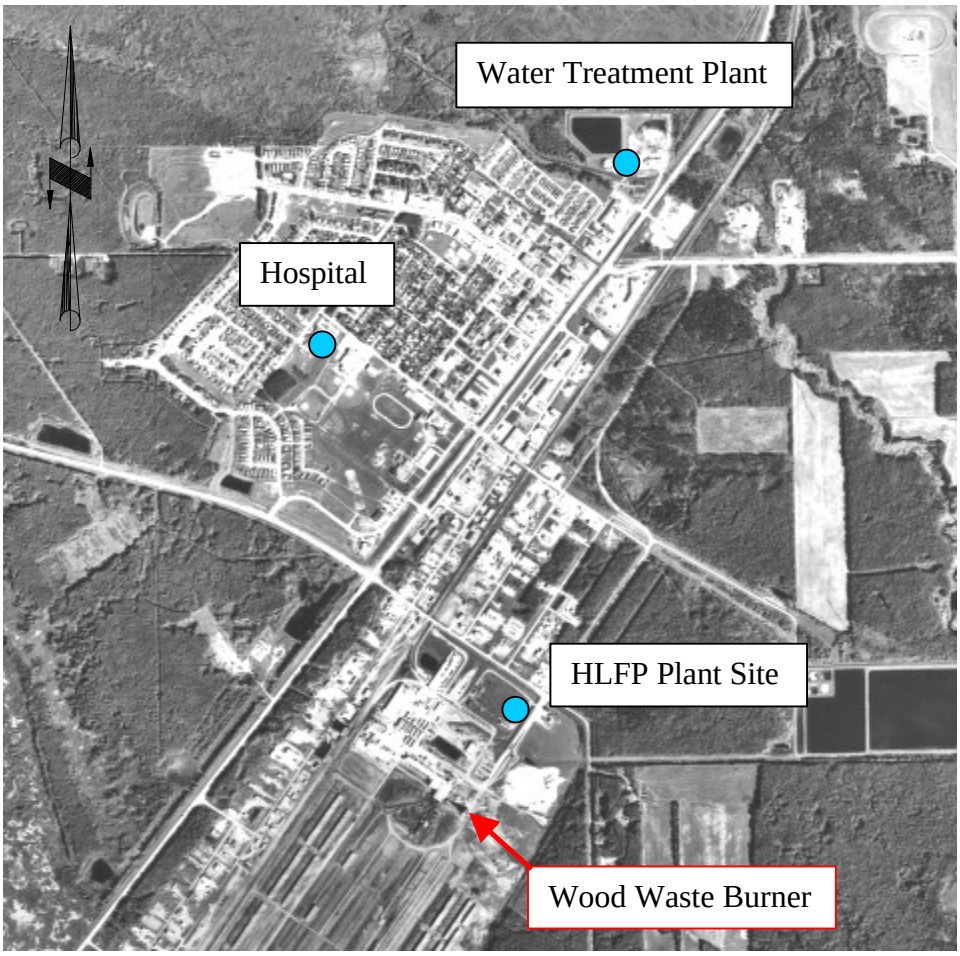
The author would like to thank the Sustainable Forest Management Network and High Level Forest Products Ltd. (Tolko Industries) for funding of this project. The author would also like to thank Nick Chernuka and Stefan Szabo for their assistance during field sampling in High Level and Dr. Warren Kindzierski for his advice and support during the field research.

Additional acknowledgements would like to be extended to the town staff of High Level and the utility staff in High Level for their assistance throughout the sampling period.

# INTRODUCTION

Particulate matter (PM) is a concern to regulatory bodies due to potential adverse health effects of exposure. Thus a study was undertaken to characterize source contributions of PM to the airshed in High Level, Alberta. High Level is a community located in the northwestern corner of Alberta, approximately 58°30' latitude by 117°08' longitude, with an elevation of 325 m (Figure 1). High Level is surrounded by marsh (north, south, southwest, west and northwest of town) and agricultural land (to the northeast, east and southeast of town). Based on the industrial activities in High Level, the main emission sources of PM identified include, oil and gas (industrial), agricultural (including grain storage and handling), vehicle exhaust (diesel and gasoline), road dust (vehicle re-suspension and street cleaning), gravel road dust, wood burning (residential fire place or fire pits), and wood waste burning (beehive burner). Of primary interest for this study was a wood waste burner, operated by High Level Forest Products Ltd., Tolko Industries (formally Daishowa-Marubeni International Ltd.). Wood wastes such as sawdust, bark, paper, cut ends and yard wood waste are directed into this burner from the sawmill. The wood waste burner (beehive burner) is cylindrical in shape, with a height of 30 m and an exit diameter of 10 m. This burner typically operates twenty-four hours a day, from Monday to Friday. On Friday at midnight the burner is shut down, to allow for ash removal and on Sunday at midnight the burner is typically restarted, reaching its operating temperature (≥370°C) in about five hours. The particulate emission is related to the temperature of combustion, the operation of the burner, maintenance, and feed rate of the wastes. The particulates emitted from a typical beehive burner range in size from <5 μm to >100 μm (1 mm = 1000 μm), with the larger particles settling out typically within a few 100 m from the burner (Kindzierski and Jackson 1999). Depending upon the prevailing wind conditions and local meteorology, the finer PM may be transported over a larger distances. It is this fine fraction that is of interest to regulatory and health agencies, for it is in this fraction where health related issues have been identified. Wood waste burners have increased focus from environment agencies; in particular, item 35 of British Columbia's Greenhouse Gas Action Plan has called for phase-out of highly inefficient wood residue burners ("beehive burners") by 2004 (BC Environment 1995; Rolfe 1996). The BC Ministry of Environment is phasing out the simple incineration of wood waste and pushing for a utilization of the wood combustion energy from the wood products industry (Rolfe 1996; Rolfe and Currie 1998).

In order to identify the effects of the wood waste burner in High Level, a detailed air-sampling program was carried out during the winter, spring, summer and fall of 1999. This four-season study entailed a sampling plan for the collection of ambient air samples over one month each season. For each of the seasons, the air sampling equipment was situated at three separate locations (two elevated and one ground level) around the community of High Level. The first elevated site was on the hospital roof, the second elevated site was on the old water treatment plant reservoir, and the ground level site was located at the High Level Forest Products Ltd. (HLFP) plant site (refer to Figure 1).




Indicates a sample site

**Figure 1. Air sampling locations in High Level, Alberta**

The scope of this research was to study and evaluate new methodologies pertaining to low volume air samplers and micro-analytical analysis in order to optimize receptor-model techniques. The receptor sampling approach involved collecting and analyzing ambient air samples at a given site, and inferring the contribution of sources to the total (PM) mass measured. The low volume sampling technique is more portable and more cost effective for industry, compared to the use of large and costly mid to high volume samplers. In addition to evaluating new methodologies, the objective was to identify the potential source effect of the wood waste burner on the community of High Level. Thus along with the receptor model a tracer analysis and trajectory analysis were also utilized to characterize the source to site effects. In addition, ambient levels of PM collected were analyzed and compared to levels observed in other communities of Alberta to demonstrate similarities in ambient air PM concentration without wood waste burners.

## Particulate Matter Issues

Impacts of the air pollutant "particulate matter" have become an important air quality issue in Alberta and across Canada. Particulate matter refers to all airborne particles, in both the solid and liquid phase (except pure water) ranging in size from approximately 0.005 μm to 100 μm aerodynamic diameter (AD - diameter of a spherical particle with equal settling velocity and unit density) (CEPA and FPAC 1999). From this vast size range, there are two primary size ranges of particulate matter that are of most interest to regulatory and health agencies. The first, $PM_{10}$, refers to particulate matter less than 10 μm in aerodynamic diameter, the second, $PM_{2.5}$, refers to particulate matter less than 2.5 μm in aerodynamic diameter (Health Canada and Ontario Ministry of Health 1997). The Provincial Health Officer, John Millar, British Columbia Ministry of Health, issued a statement declaring that the particulate matter emitted from wood waste combustion sources are the single greatest source of air pollution in British Columbia (BC Ministry of Health 1994). This drew wood waste burners into focus, for particulate matter has the ability to decrease levels of pulmonary lung function in children and adults with obstructive airways disease; increase in daily prevalence of respiratory symptoms in children and adults; increase in physician and emergency room visits for asthma and other respiratory conditions; increase in hospitalizations for respiratory and cardiac conditions; increase in cardiac and respiratory mortality on days after those with high particulate levels (Rhebergen et al. 1999; Johnson 1999). In addition to the health effects, the fine PM has a secondary effects of visibility impairment through a regional haze, and a "soiling" effect, when the particles accumulate on cars, laundry (outside), and homes. This results in a "nuisance impact" on the environment in addition to the health impact (Pacific Environmental Services, Inc. 1999; Rhebergen et at. 1999).

## Source to receptor studies

Receptor modeling techniques have become an important tool for identifying source influences on potential receptor locations. By using receptor modeling, the approach is to start from a measurement site and work back to the source(s) (Friedlander 1981, Blanchard 1999). Then using a multivariate (or statistical) approach such as a principal component analysis (PCA) to unravel the seemingly unrelated data into "source fingerprints" or source profiles (Henry and Hidy 1979; Cooper and Watson 1980; Thurston and Spengler 1985; Harrison et al. 1996; Harrison et al. 1997; Biegalski et al. 1998).

## Sampling methods and techniques

In performing the air-sampling survey in High Level, a variety of equipment, both field and laboratory was required. A brief summary of the equipment is outlined below (more detail of tests and protocols will be included in the co-author's Ph.D. Thesis).

### *Field Equipment*

A Tapered Element Oscillating Microbalance (TEOM) Series 1400a Ambient Particulate Monitor was used to collect real time $PM_{10}$ (Rupprecht & Patashnick Co., Inc. 1996). The

Minivol $PM_{2.5}$ and Minivol $PM_{10}$ low volume portable air samplers were used to collect a multitude of time-integrated samples (Airmetrics 1998; Jones et al. 1998; Tropp et al. 1998). The meteorological measurements were collected using a Campbell Scientific CR-10X datalogger, in conjunction with a Met-One Wind direction sensor (model 023A), and a Met-One Wind Speed Sensor (model 013A) (Campbell Scientific, Inc. 1990; Campbell Scientific, Inc. 1986). The anemometer and wind vane were mounted to a cross arm assembly on a 3 m tall CM10 tripod, while the Minivols were mounted to the shaft of the tripod (Campbell Scientific, Inc. 1998).

***Laboratory Equipment***

A Mettler semi-microbalance (±10 μg) and Sartorius microbalance (±1 μg) were used for the low volume gravimetric analysis. In addition, the elemental concentrations were analyzed using a Scanning Electron Microscopy (SEM) - JEOL 6301F (Field Emission SEM) with a Light Element Energy Dispersive X-ray Analysis (EDX) attachment.

***Site locations***

When locating sites for the sampling equipment, the wood waste burners potential zone of influence and meteorology played an important role. In order for the burner to directly affect the community of High Level the winds would have to be blowing from the southeast. However, data collected by Bovar Environmental (1997a, b) indicated that wind blew from the south less than 5% while north winds predominated occurring 45% during 1996. Equipment was therefore located based on background knowledge of source emissions, sensitive receptor locations, and historic meteorological conditions. From this information, three locations were chosen for sampling in High Level (Figure 1). A primary concern for the location of the equipment was an electricity supply and security of the equipment. The first site chosen was at the hospital (Figure 2), which is located near the centre of town. The equipment was situated on the roof of the hospital, approximately 3.5 m from the ground (Figure 3). The hospital was a valid location for the potential impact of receptors and for the monitoring history, of which High Level Forest Products Ltd. operates a $PM_{10}$ and TSP sampler on the hospital roof. The second site chosen was at the water treatment plant (Figure 4), which is located at the north end of High Level. The equipment was situated on the top of the old reservoir approximately 4.5 m from the ground (Figure 5). This site was ideal for evaluation of ambient particulate background levels based on the wind blowing from the north. The third site was on the property of HLFP (Figure 6), which is located in the southeast industrial section of High Level. The equipment was placed on ground level, within a fenced compound (Figure 7). There was a shed that supplied power 30 m to the southwest, with a service road (unpaved) located approximately 3 m to the east, and a main road (unpaved) 40 m to the east (and 100 m to the north). The equipment setup including appropriate spacing, vertical and horizontal probe placement was strictly adhered to (as per ASTM 1997; ASTM 1998; EPA 1996; EPA 1997).


**Figure 2. Hospital sampling site**

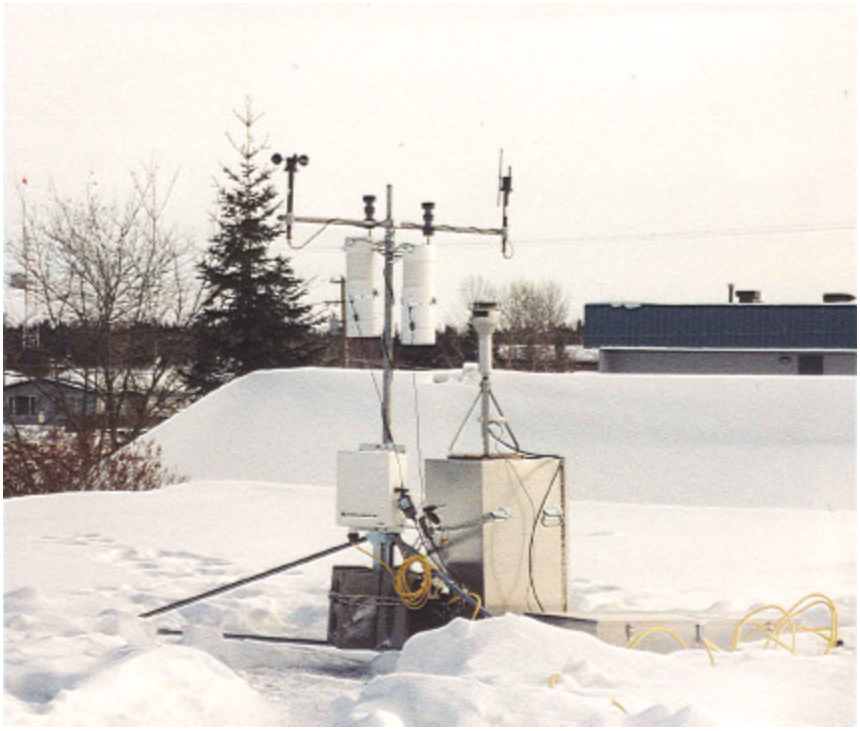


**Figure 3. Winter - hospital sampling site**

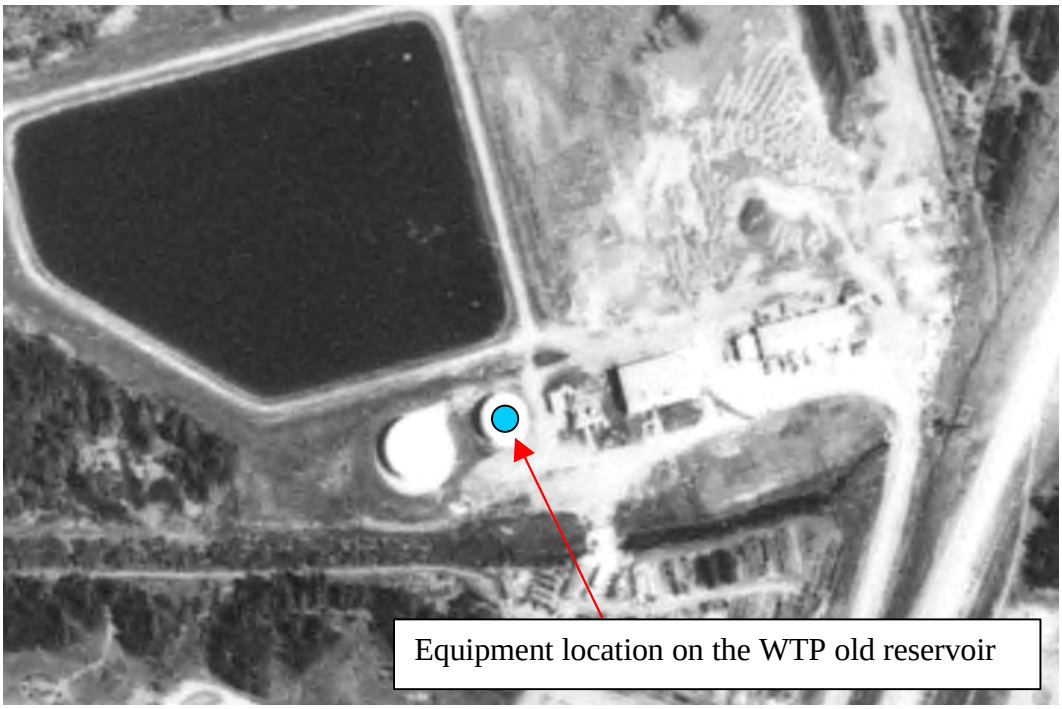



**Figure 4. Water treatment plant sampling site**

**Figure 5. Fall – water treatment plant old reservoir roof sampling site**


**Figure 6. High Level Forest Products Ltd. ground level sampling site**

**Figure 7. Summer - HLFP ground level sampling site**

# ANALYSIS OF DATA

A full air-sampling survey was conducted throughout four seasons in 1999, staring with winter, spring, summer, and fall. Each of the sampling seasons included three individual sampling runs which involved ambient air sampling at the three identified sites.

**Winter Sampling**

The winter sampling survey was performed during the month of March 1999. During this sampling period the winds prevailed from an easterly direction, approximately 55% of the time. The average temperature during the winter sampling survey was -3$^{o}$C, with an average atmospheric pressure of 1.001 atm. The precipitation during the winter sampling was recorded at 4.6 mm (7.8 cm snow). The first sampling run was performed on the hospital roof from March 1, 1999 to March 10, 1999. The second sampling run was on the old water treatment plant reservoir (WTP roof) from March 11, 1999 to March 19, 1999. The third sampling run was on the ground level property of High Level Forest Products Ltd. (HLFP ground) from March 19, 1999 to March 28, 1999.

During these sampling periods, the continuous sampling for 24-hour $PM_{10}$ concentrations resulted in an average of 9 $\mu g/m^3$ at the hospital, 14 $\mu g/m^3$ at the water treatment plant, and 29 $\mu g/m^3$ at the High Level Forest Products site. The results of the continuous 30-minute $PM_{10}$ average sampling, along with the precipitation data during the sampling period, are displayed in Figure 8. In addition a concentration rose (Figure 9) shows the bulk of the $PM_{10}$ source (30-minute averages) was in the 0-37 $\mu g/m^3$ range, and was being transported primarily from the east of the sampling sites.

In addition to the continuous sampling, the low volume samplers were used to collect a total of forty-six filters. Of these filters collected, twenty-eight were sampled for $PM_{10}$, with samples collected over six, twelve and twenty four hours. Based on the gravimetric analysis there appeared to be no significant differences between the nighttime and daytime tests, with the average concentration measured at 30 $\mu g/m^3$ for both periods. The remaining eighteen filters were sampled for $PM_{2.5}$, with samples collected over six, twelve, and twenty-four hours. From these tests, there also appeared to be no significant differences between the nighttime and daytime tests, with the average concentrations at the same level of 15 $\mu g/m^3$. The SEM-EDX micro-quantification analysis was then performed on both the $PM_{10}$ and $PM_{2.5}$ filters. The abundant elements seen in the analysis appeared to be directly associated with crustal sources which include silica, calcium, iron, and aluminum for the course fraction ($PM_{10}$) and fine fraction ($PM_{2.5}$) (EPA 1999). In addition, there is evidence of elements associated with road de-icing activities, which include sodium and chlorine for the course fraction ($PM_{10}$) and fine fraction ($PM_{2.5}$) (EPA 1999). Examples of the SEM photos are presented in Appendix A.

**$PM_{10}$ - 30 Minute Mass Concentration Air Sampling Results**
**Winter Sampling, High Level, Alberta**
**March 1, 1999 to March 28, 1999**

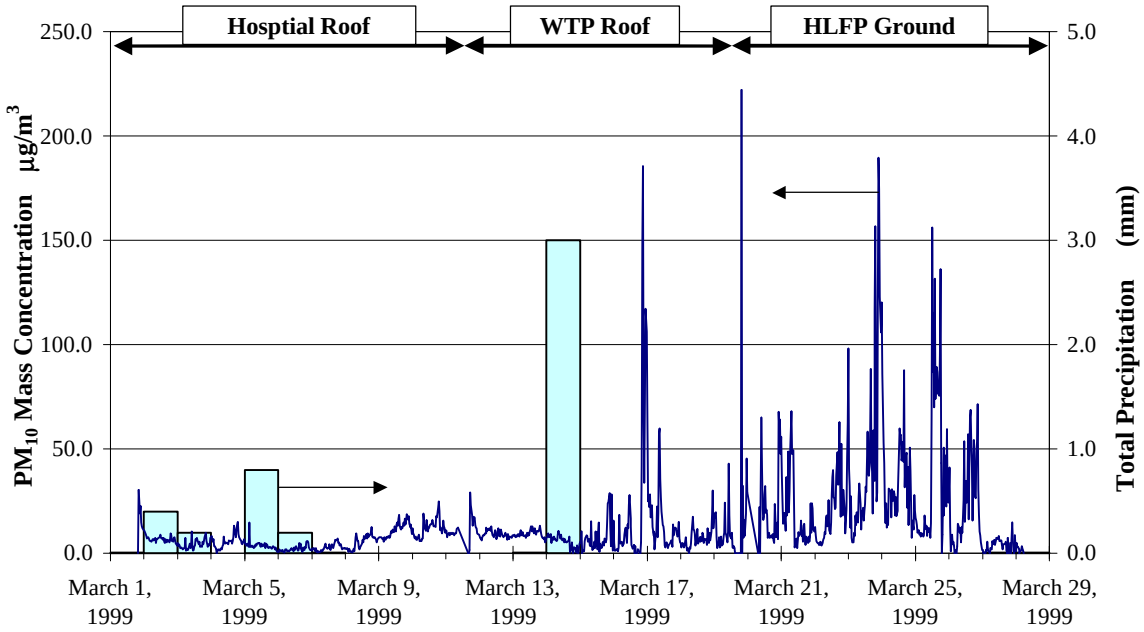



**Figure 8. Summary of the TEOM winter sampling results**

**$PM_{10}$ - 30 Minute Mass Concentration Rose**
**Winter Sampling, High Level, Alberta**
**March 1, 1999 to March 28, 1999**

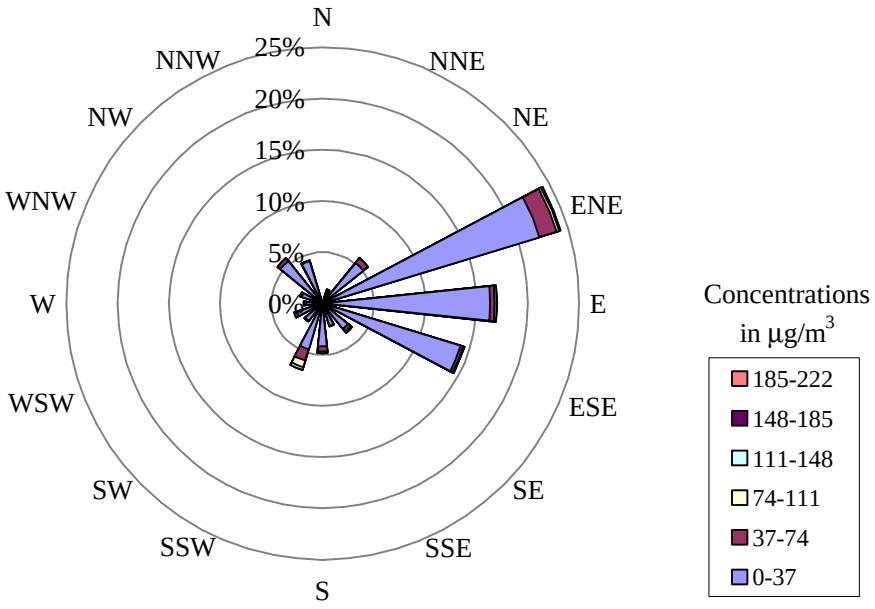



**Figure 9. Winter concentration rose from the TEOM sampling results**

Throughout the winter monitoring period there appeared to be no significant differences in the $PM_{10}$ concentrations recorded on the weekday or weekend by the continuous sampling. This was verified by the low volume samples collected and analyzed gravimetrically. The continuous data did indicate an abundant increase in $PM_{10}$ at the ground level site on the HLFP property. An increase that could be attributed to rapid snow cover loss, allowing for re-suspension of soil particles. With the overall wind for this sampling survey prevailing from an easterly direction sources were likely from roadway activities. This would include local traffic, as well as traffic along the Mackenzie Highway. In addition, there was no relationship found that could tie the wood waste burner as a predominate cause to increasing or decreasing levels of PM collected at any of the winter sites.

**Spring Sampling**

The spring sampling survey was performed during the month of May 1999. During this sampling period the winds were still predominate from an easterly direction approximately 38% of the time, with occurrences of extended wind gusts from a southeasterly (18%) and northwesterly (12%) direction. The average temperature during the spring sampling period was $8^{o}C$, with an average atmospheric pressure of 0.967 atm. The precipitation during the spring sampling was recorded at 31.7 mm (of rainfall). The first sampling run during the spring survey was performed on the ground level at HLFP from May 3, 1999 to May 12, 1999. The second sampling run was on the hospital roof (as near to the original location as possible) from May 12, 1999 to May 21, 1999. The third sampling run was on the old water treatment plant reservoir from May 21, 1999 to May 31, 1999.

During these sampling periods, the continuous sampling for 24-hour $PM_{10}$ concentrations resulted in an average of 38 $\mu g/m^3$ at the HLFP site, an average of 9 $\mu g/m^3$ at the hospital site, and an average of 13 $\mu g/m^3$ at the water treatment plant. The results of the continuous 30-minute $PM_{10}$ average sampling, along with the precipitation data during the sampling period are displayed in Figure 10. In addition a concentration rose (Figure 11) shows the bulk of the $PM_{10}$ source was in the 0-65 $\mu g/m^3$ range, and was being transported primarily from the east of the sampling sites, with periods of southeasterly and northwesterly contributions.

In addition to the continuous sampling, the low volume samplers were used to collect a total of thirty-five filters. Of these filters collected, twenty were sampled for $PM_{10}$, with samples collected over twelve and twenty four hours. Based on the gravimetric analysis there appeared to be little difference between the nighttime and daytime tests for $PM_{10}$, with an average of 10 $\mu g/m^3$ (night) and $<1$ $\mu g/m^3$ (day). The remaining fifteen filters were sampled for $PM_{2.5}$, with samples collected over twelve and twenty-four hours. From these tests, there appeared to be no significant difference between the nighttime and daytime tests, with the average concentrations at the same level of 10 $\mu g/m^3$. The SEM-EDX micro-quantification analysis was then performed on both the $PM_{10}$ and $PM_{2.5}$ filters. Based on the course fraction ($PM_{10}$) elemental analysis the most abundant elements found were directly related to crustal sources and include silica, calcium, iron, and aluminum. During the spring run, minor trace elements are found to be more

**$PM_{10}$ - 30 Minute Mass Concentration Air Sampling Results**
**Spring Sampling, High Level, Alberta**
**May 3, 1999 to May 31, 1999**

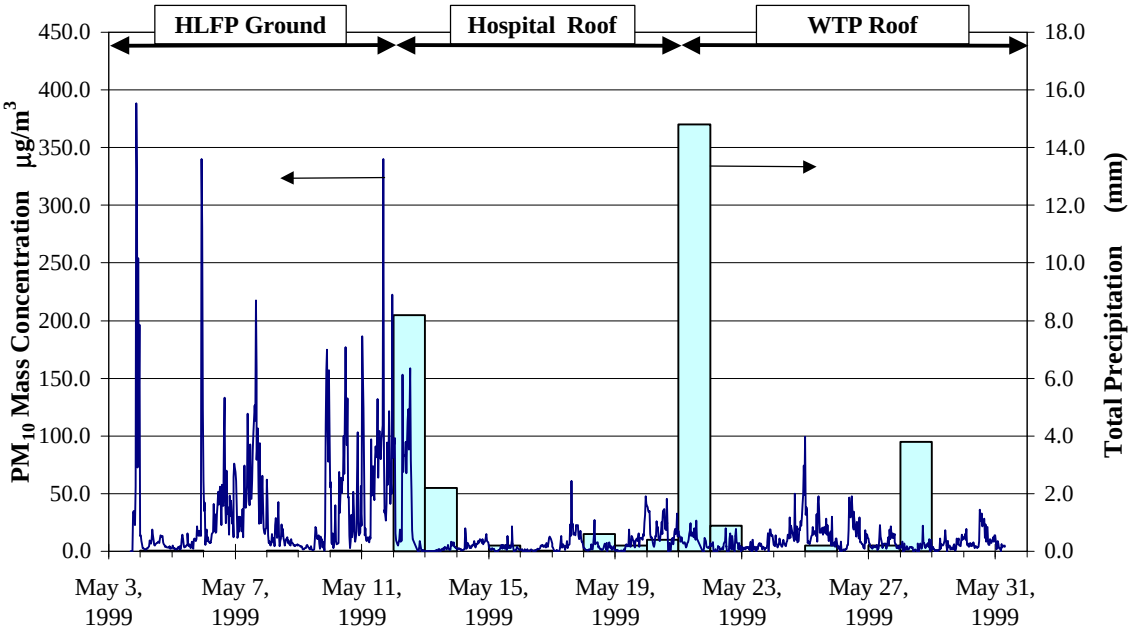



**Figure 10. Summary of the TEOM spring sampling results**

**$PM_{10}$ - 30 Minute Mass Concentration Rose**
**Spring Sampling, High Level, Alberta**
**May 3, 1999 to May 31, 1999**

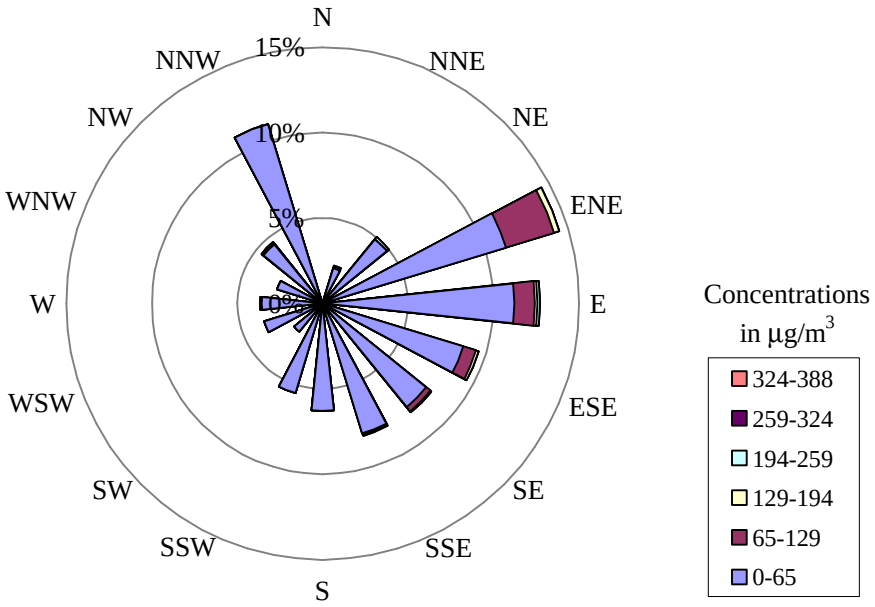



**Figure 11. Winter concentration rose from the TEOM sampling results**

prevalent compared to the earlier winter run. This would be expected because the snow cover of winter had melted, exposing more ground base material for re-suspension.

Throughout the spring monitoring period there appeared to be no significant differences in the $PM_{10}$ concentrations recorded on the weekday or weekend by continuous sampling. In addition, the low volume samples had very low concentrations, with the results essentially at the detection limit of the scale. Based on the nature of the elements analyzed and the potential sources from wind trajectories, these sources would include agricultural and roadways. Similar to the winter analysis, there was no relationship to tie the wood waste burner as a predominate cause to increasing or decreasing levels of airborne particulates collected at each of the sites. The results did indicate an increase in airborne PM compared to the winter analysis which was expected due to the loss of snow cover.

**Summer Sampling**

The summer sampling survey was performed during the months of July and August of 1999. During this sampling period the winds prevailed from a southerly direction approximately 28% of the time, and an easterly direction approximately 27% of the time. There were additional occurrences of sustained wind gusts from a southeasterly (8%) and northwesterly (13%) direction. The average temperature during the summer sampling survey was 15$^{o}$C, with an average atmospheric pressure of 0.969 atm. The precipitation during the summer sampling was recorded at 90.2 mm, of which 39.4 mm fell over a twenty-four hour period. The first sampling run was on the old water treatment plant reservoir from July 14, 1999 to July 23, 1999. The second sampling run was on the hospital roof from July 23, 1999 to August 1, 1999. The third sampling run was located at HLFP plant site from August 1, 1999 to August 9, 1999.

During these sampling periods the continuous sampling for 24-hour $PM_{10}$ concentrations resulted in an average of 18 $\mu g/m^3$ at the water treatment plant, 9 $\mu g/m^3$ at the hospital, and 130 $\mu g/m^3$ at HLFP plant site. The higher 24-hour $PM_{10}$ average at the HLFP plant site is strongly due to an extended dry period, from July 31, 1999 to August 7, 1999. The results of the continuous 30-minute $PM_{10}$ average sampling, along with the precipitation data during the sampling period, are displayed in Figure 12. In addition a concentration rose (Figure 13) shows the bulk of the $PM_{10}$ source was in the 0-262 $\mu g/m^3$ range, and was being transported primarily from an easterly and southeasterly direction.

In addition to the continuous sampling, the low volume samplers were used to collect a total of thirty filters. Of these, eighteen were sampled for $PM_{10}$, with samples collected over twelve and twenty four hours. Based on the gravimetric analysis there appeared to be little significant differences between the nighttime and daytime tests, with the average concentration measured at 30 $\mu g/m^3$ (daytime) and 20 $\mu g/m^3$ (nighttime). There was one set of samples taken during a 24-hour period with a concentration of 110 $\mu g/m^3$ which was collected during a dry dusty period. The remaining twelve filters were sampled for $PM_{2.5}$, with all the samples collected over twenty-four hours. From these tests the average concentration was in the range of

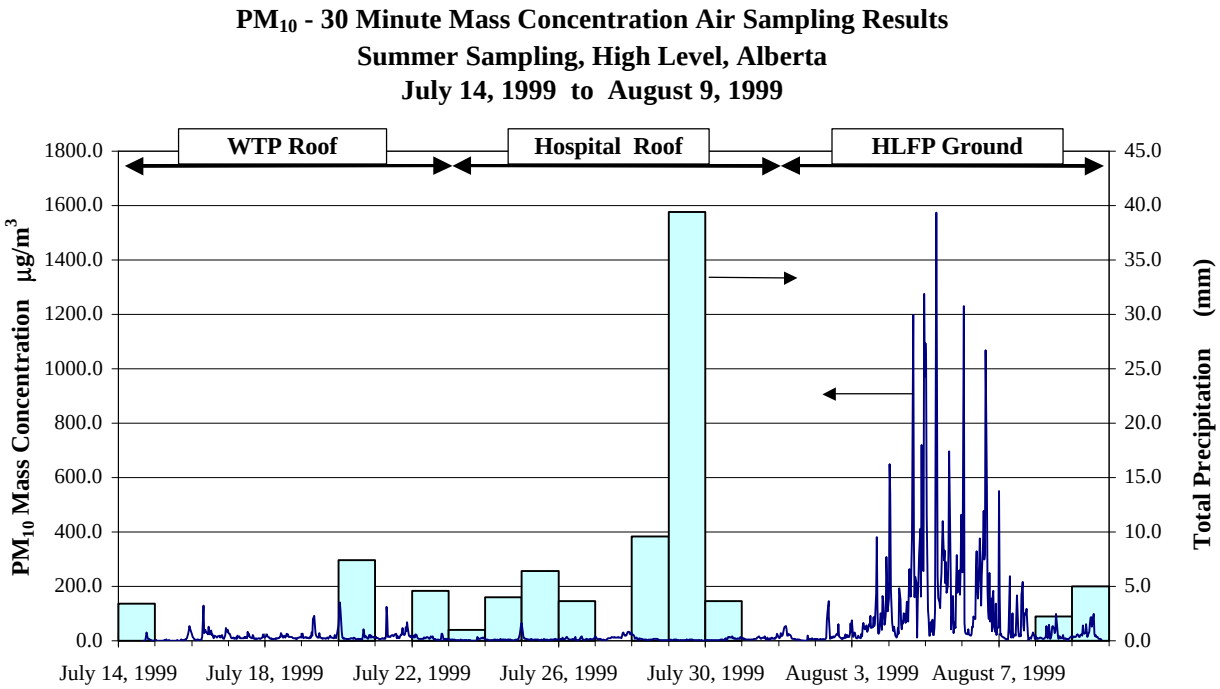



**Figure 12. Summary of the TEOM summer sampling results**

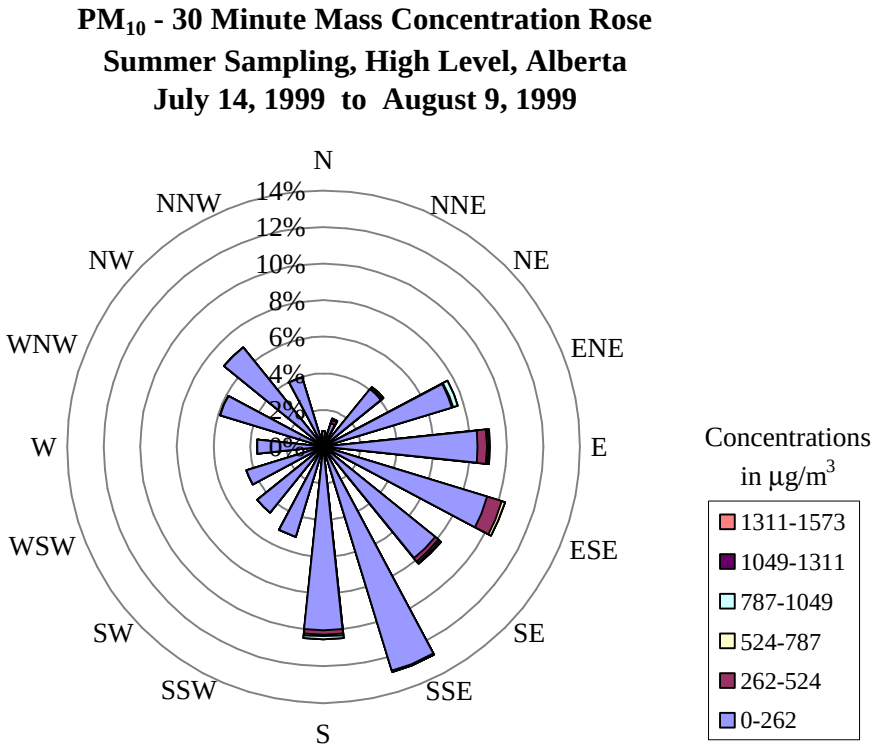



**Figure 13. Summer concentration rose from the TEOM sampling results**

10 $\mu g/m^3$. The SEM-EDX micro-quantification analysis was then performed on both the $PM_{10}$ and $PM_{2.5}$ filters. The abundant elements seen in the analysis appeared to be directly associated with crustal sources which include silica, calcium, iron, aluminum and trace magnesium for the course fraction ($PM_{10}$) and fine fraction ($PM_{2.5}$) (EPA 1999). In addition, there is evidence of elements associated with biomass burning, which include calcium, potassium, and rubidium for the fine fraction ($PM_{2.5}$) (EPA 1999). During the summer sampling survey there were occasions of high levels of PM, which were primarily due to re-suspended material in the absence of precipitation. There was also evidence on several filters of organic fungal spores (refer to Appendix A for SEM photos).

Throughout the summer monitoring period there appeared to be slight differences in the $PM_{10}$ concentrations recorded during the weekdays and weekend by the TEOM. The differences may be attributed to vehicle movement during the weekdays, and activity decreasing during the weekend. With the wind directions during the summer period prevailing from a southerly direction, and an easterly direction, the potential PM sources are again spread over a vast area. However, based on the nature of the elements analyzed and the potential sources from the areas in which the wind prevailed, the majority of the PM sources indicate agricultural and roadways. In particular, the increased air filter loads taken near the beginning of August (1999) appear to be strongly associated with road dust from vehicle movement. There was no relationship found to tie the wood waste burner as a cause of airborne PM collected at any of the sites. The sampling data did however show high levels of $PM_{10}$ during dry, dusty periods.

**Fall Sampling**

The fall sampling survey was performed during the months of September and October of 1999. During this sampling period the winds prevailed from an easterly direction approximately 32% of the time, and a westerly direction approximately 21% of the time. There were additional periods of extended wind gusts from a southeasterly (7%), southwesterly (8%), and northwesterly (7%) direction. The average temperature during the fall sampling run was $1^oC$, with an average atmospheric pressure of 0.968 atm. The precipitation during the fall sampling was recorded at 15.9 mm, of which 5.6 mm fell as rain and 13.6 cm fell as snow. The first sampling run was on the old water treatment plant reservoir from September 24, 1999 to October 3, 1999. The second sampling run was at HLFP plant site from October 3, 1999 to October 12, 1999. The third sampling run was on the hospital roof from October 12, 1999 to October 20, 1999.

During these sampling periods the continuous sampling for 24-hour $PM_{10}$ concentrations resulted in an average of 10 $\mu g/m^3$ at the water treatment plant, 15 $\mu g/m^3$ at HLFP plant site, and 13 $\mu g/m^3$ at the hospital site. The results of the continuous 30-minute $PM_{10}$ average sampling, along with the precipitation data during the sampling period are displayed in Figure 14. In addition, a concentration rose (figure 15) shows the bulk of the $PM_{10}$ source in the 0-28 $\mu g/m^3$ range and was being transported primarily from a southerly and southeasterly direction, with additional loading transported from the west.

**$PM_{10}$ - 30 Minute Mass Concentration Air Sampling Results**
**Fall Sampling, High Level, Alberta**
**September 24, 1999 to October 20, 1999**

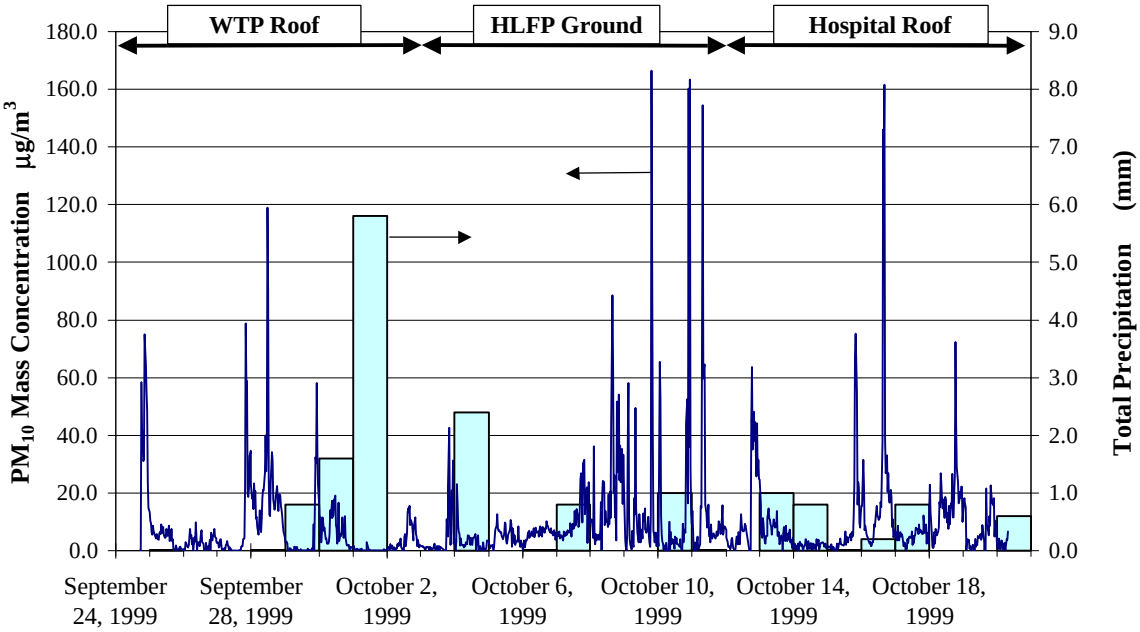



**Figure 14. Summary of the TEOM fall sampling results**

**$PM_{10}$ - 30 Minute Mass Concentration Rose**
**Fall Sampling, High Level, Alberta**
**September 24, 1999 to October 20, 1999**

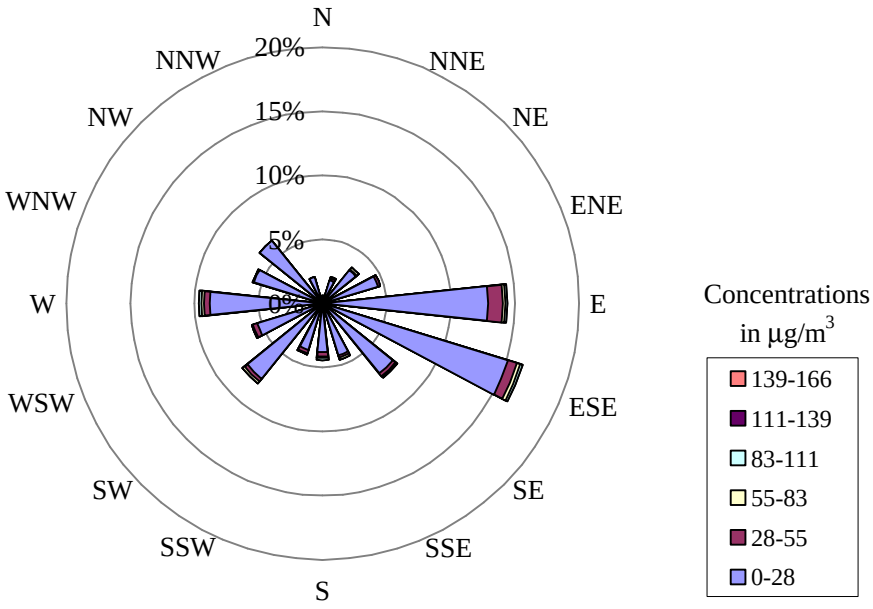



**Figure 15. Fall concentration rose from the TEOM sampling results**

In addition to the continuous sampling, the low volume samplers were used to collect a total of thirty-six filters. Of these filters collected, twenty were sampled for $PM_{10}$, with samples collected over twelve and twenty four hours. Based on the gravimetric analysis there appeared to be no significant differences between the nighttime and daytime tests, with the average concentration measured at 10 $\mu g/m^3$ (daytime) and 10 $\mu g/m^3$ (nighttime). The remaining sixteen filters were sampled for $PM_{2.5}$ over twenty-four hours with an average concentration of 5 $\mu g/m^3$. The SEM-EDX micro-quantification analysis was then performed on both the $PM_{10}$ and $PM_{2.5}$ filters. The abundant elements seen in the analysis appeared to be directly associated with crustal sources which include silica, calcium, iron, aluminum potassium, magnesium and trace titanium for the course fraction ($PM_{10}$) and fine fraction ($PM_{2.5}$) (EPA 1999). There was also evidence of elements associated with biomass burning; calcium, potassium, and rubidium and road de-icing activities; sodium and chlorine for both the course and fine fraction ($PM_{10}$ and $PM_{2.5}$) (EPA 1999). During the fall sampling period there appeared to be evidence of wood combustion and with the dropping temperatures, an increase in wood combustion fireplaces may have occurred. In addition, there were some minor snowfalls which may have prompted de-icing agents to be used thus resulting in the salt found primarily in the fine fraction ($PM_{2.5}$). However with the lack of snow cover for this entire period, the most abundant elements found appeared to be related to crustal sources.

Throughout the fall monitoring period there appeared to be no statistical differences in the $PM_{10}$ concentrations recorded during the weekdays and weekend by the TEOM. With the wind directions during the fall period prevailing from an easterly direction and westerly direction the potential sources of airborne particulate are again spread over a vast area. Based on the nature of the elements analyzed and the potential sources from the areas in which the wind prevailed, the majority of the sources would once again indicate agricultural and roadways. In addition, there was evidence from the elemental analysis that wood burning was likely taking place. This wood burning may have been the result of cooler temperatures and increased fireplace usage. This was observed when the wind was blowing from the west (over the community), indicating the samplers may have picked up local effects of burning. Hence, there was no relationship found to tie the wood waste burner as a cause to levels of airborne PM collected at any of the sites.

**Tracer analysis – Source apportionment analysis**

A principal component analysis (PCA) was performed using the coarse particulate matter collected ($PM_{10}$) and analyzed by the SEM-EDX. In addition, PAH concentration data was also included in the analysis to help identify potential sources. The concentration data for the elements and PAH data was first standardized, then analyzed using SYSTAT® 9.0 for the PCA with a Varimax rotation. This resulted in a total of six eigenvalues greater than one (where eigenvalues less than one, are presumably dominated by error variance (Thurston and Spengler 1985)), thus resulting in six principal components accounting for 79 percent of the variance in the data set.

The first principal component was identified as a crustal source, due to the strong association with the crustal elements silica, iron, aluminum, potassium, and magnesium. The second principal component was loosely identified as road dust, due to the strong association with road dust trace elements of phosphorus, strontium, and manganese (EPA 1999). The third principal component was identifiable as road salts. The main source of sodium and chlorine are from marine sources, however in areas that use de-icing material in the winter both of these elements can be used as a tracer for the de-icing activity (Chow and Watson 1998). The fourth principal component was strongly associated with PAH and calcium, with a negative association to rubidium. Wood burning and vehicle emissions are both associated with PAH and calcium, however wood burning is also associated with rubidium. With PAH and rubidium having an opposite effect for this component, it was believed that the fourth component would be related to vehicle emissions. This was verified by Benner et al. (1989) and Harrision et al. (1996) who believe PAH should be used as a tracer for vehicle emissions. The fifth principal component is strongly associated with vanadium and copper, of which vanadium is highly recognized as a residual oil component, with copper being a trace element in residual oil (Cooper and Watson 1980). The sixth and final principal component is highly associated with sulfur, which has been identified as a sulfate source. This was verified by Cheng et al. (1998) when they reported that Alberta has higher levels of $SO_2$, $NO_x$ and VOC compared to all bordering provinces and states, and that for Edmonton and Calgary the largest mass fraction in fine particles is sulfate.

**Trajectory analysis - maximum concentrations versus wind direction**

In order to assess the contribution the wood waste burner has on the community of High Level, the continuous 30-minute average mass concentrations were compared to wind directions. This was done to ascertain the potential sources of recorded maximum concentrations. The maximum level of mass concentrations were calculated as the average mass concentration (of 25 $\mu g/m^3$) plus one standard deviation (of 70 $\mu g/m^3$) of the sampled data, thus a reading was considered a maximum if it was greater than 95 $\mu g/m^3$. The resulting 30-minute maximums were compared to the wind direction for each occurred incident (Figure 16). Based on the results, the bulk of the $PM_{10}$ appeared to prevail from the east approximately 56%, while there were minor episodes from the south, southeast, and northeast approximately 23%, 8%, and 8% respectively. Additionally, 92% of the maximum 30-minute concentrations were sampled at the HLFP plant site. While the water treatment plant and hospital only comprised 7% and 1% of the 30-minute maximums respectively. The sources of these maximum concentrations recorded are believed to be originating from re-suspended soils and from vehicle sources (road dust, and vehicle movement) based on this trajectory analysis.

**Source to site trajectory analysis**

To further scrutinize the wood waste burner as a potential source, a source to site trajectory evaluation was performed. Thus assuming the wood waste burner was the only source of airborne particulate and the three sampling locations were analyzed during prevailing winds from the “source”. Based on the trajectory from the wood waste burner to the hospital, this

occurred 314 times during the continuous 30-minute sampling. The equipment was set up on the hospital site for a total of 61 of these occurrences throughout all four seasons of sampling. During these episodes in which the wind was prevailing from the direction of the wood waste burner, the average concentration at the hospital was 15 μg/m$^3$, with a maximum of 81 μg/m$^3$.

**Maximum Occurances of 30 minute $PM_{10}$ TEOM Results**
**Mass Concentration Rose - March 1, 1999 to October 20, 1999**

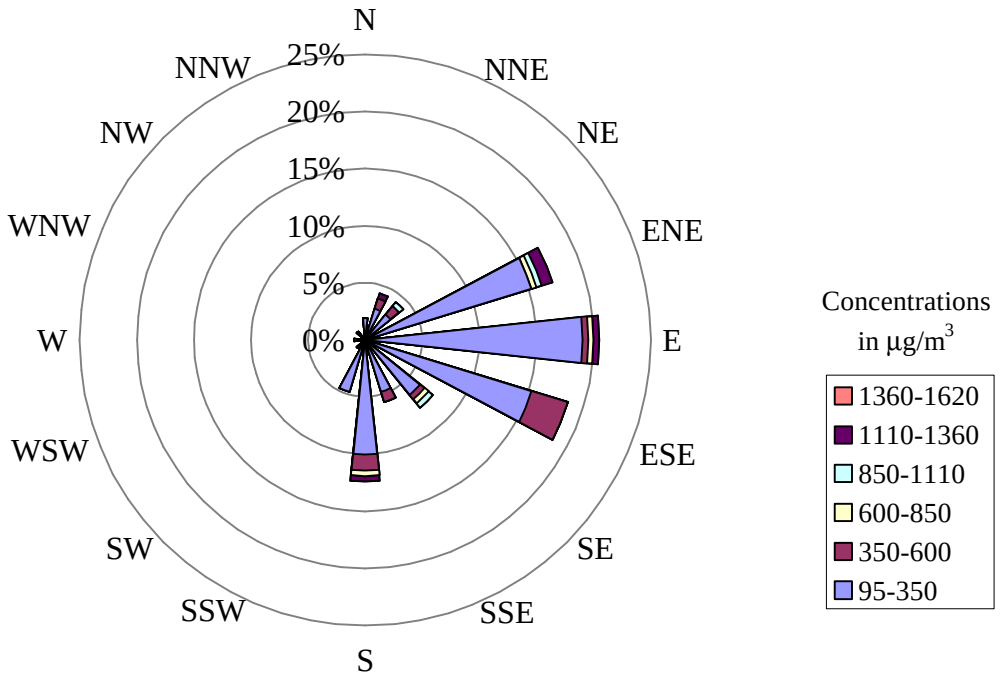



**Figure 16. Maximum $PM_{10}$ occurrences**

For the source to site analysis of the wood waste burner to the water treatment plant, this occurred a total of 319 times during the continuous 30-minute sampling. The equipment was set up at the water treatment plant for a total of 154 of these occurrences throughout all four seasons of sampling. During the episodes in which the wind was prevailing from the direction of the burner, the average concentration at the water treatment plant was 17 μg/m$^3$, with a maximum of 150 μg/m$^3$.

For the source to site analysis of the wood waste burner to the HLFP plant site, this occurred a total of 241 times during the continuous 30-minute sampling. The equipment was set up at the HLFP plant site for a total of 62 of these occurrences throughout all four seasons of sampling. During the episodes in which the wind was prevailing from the direction of the burner, the average concentration at the HLFP plant site was 30 μg/m$^3$, with a maximum of 140 μg/m$^3$.

In general the concentrations found from this trajectory analysis indicates the levels potentially responsible from the wood waste burner are much lower than the sources responsible for the high levels found in the maximum concentration trajectory analysis.

**Site comparison**

Finally a site comparison was done to ascertain the air quality in High Level compared to historic data and other locations in Alberta. The historic sampling was performed at the High Level hospital (Kindzierski and Jackson 1999), a residential site in St. Albert, Alberta (Kindzierski and Jackson 1999), and two roadside sites (residential and freeway) in Edmonton, Alberta. For this comparison, the same TEOM equipment setup was used to sample at the High Level hospital during the winter of 1997, in St. Albert during the winter in 1997, and for the roadsides in Edmonton during the summer of 1999.

A comparison was made using the average 24-hour $PM_{10}$ continuous sampling data from each of the sampling sites showing the minimums, maximums, average (arithmetic), geometric average, $50^{th}$ percentile (median), and $95^{th}$ percentile. The average 24-hour $PM_{10}$ data from the hospital site in High Level, both historic (1997) and recent (1999) had an average of 10 $\mu g/m^3$ (9 $\mu g/m^3$ based on geometric averages), which is well below even the most stringent 24-hour $PM_{10}$ guideline of 50 $\mu g/m^3$ (based on geometric averages) in California, USA (State of California 2000). For the sampling at the water treatment plant, the range throughout the year was from 10 $\mu g/m^3$ to 18 $\mu g/m^3$, with an average for the entire period of 14 $\mu g/m^3$ (a geometric average of 13 $\mu g/m^3$). There was little difference between the average 24-hour concentrations recorded at the two elevated sites in High Level. With respect to the ground level sampling, the average 24-hour levels recorded at the HLFP plant site ranged from 15 $\mu g/m^3$ to 130 $\mu g/m^3$, with an average for the entire period of 50 $\mu g/m^3$ (39 $\mu g/m^3$ geometric averages). In comparing the ground level sites, for the winter sampling period, the 24-hour average was 29 $\mu g/m^3$ at the HLFP plant site, while the average ground level sampling in St. Albert was 24 $\mu g/m^3$ during the winter. The low 24-hour concentrations at each site are indicative of winter sampling, due to a cover of snow hindering the re-suspension of particulates. The spring and summer sampling averages of 38 $\mu g/m^3$ and 130 $\mu g/m^3$ at the HLFP plant site are again compared to the roadside sampling performed in Edmonton. The average concentrations recorded in Edmonton were 28 $\mu g/m^3$ and 43 $\mu g/m^3$ for a residential roadway and freeway respectively. The difference between the gravel road and paved road is noted in the higher concentration found during the High Level summer sampling run. The high loading of particulate during the summer run was found to be mainly due to lack of precipitation and the re-suspension of the dry surface material.

The comparison data is displayed graphically in Figure 17, which shows a total comparison of all the sampling sites. On the chart, the lower tail of the box represents the $5^{th}$ percentile, the bottom of the box and top of the box is the $25^{th}$ to $75^{th}$ percentile, and the top of the tail represents the $95^{th}$ percentile. In addition, the arithmetic average has been plotted as a circle on the chart, while the $50^{th}$ percentile appears as a thick line near the center of the box.

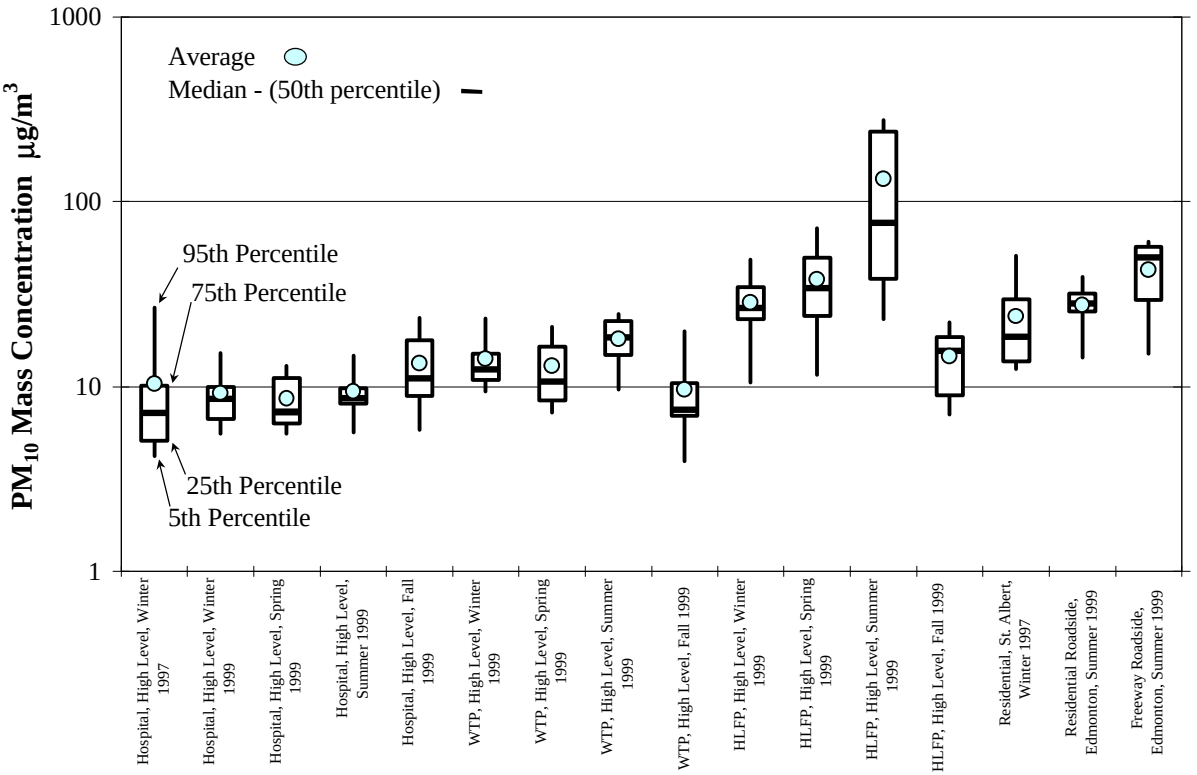



**Figure 17. $PM_{10}$ 24-hour average concentration - site comparison**

The median annual $PM_{10}$ concentrations have been reported for Edmonton and Calgary at 27 $\mu g/m^3$ and 23 $\mu g/m^3$ respectively (Cheng et al. 1998). Thus for the entire four seasons of sampling, an average of all the sample sites in High Level resulted in 25 $\mu g/m^3$ (median value of 13 $\mu g/m^3$). Cheng (et al. 1998) also reports the cross-Canada range of $PM_{10}$ as 18 $\mu g/m^3$ to 46 $\mu g/m^3$. Thus placing High Level well within the cross-Canada range, and below the City of Edmonton and City of Calgary ambient $PM_{10}$ levels.

## MANAGEMENT APPLICATIONS

This project involved the development of new methodologies for low volume ambient air sampling in conjunction with microanalysis for receptor modeling techniques. These methodologies have the potential to help identify potential air quality impacts the pulp and paper or wood products industries have on the surrounding community. The use of low volume samplers to analyze the surrounding ambient air quality has been both cost effective and informative to identify potential sources affecting the community air. The low volume samplers

are smaller, lightweight, portable, and cost effective compared to the mid to high volume samplers.

This form of detailed air sampling program can be used to evaluate emissions based on a source to site analysis. The results of such studies can identify the potential impacts from the industrial airborne emissions to the surrounding community in a cost effective and reliable manner. Hence this type of community air study has the potential to identify any adverse effects from the pulp and paper or wood products industries on the air quality of the surrounding environment.

With industries required to monitor for particulate emissions in the community airshed, it was also found advantageous to monitor for meteorology at the same location. The meteorological station can be used to record wind speed and wind direction, thus identifying potential trajectories during high loadings recorded by the particulate samplers. By using the more cost effective low volume samplers, the industry can utilize more than one sample for collection of fine and coarse fractions of airborne particulates during the same time intervals. In addition, during extended dry periods and high dust loading the use of battery operated low volume samplers can be deployed to identify background levels around the facility and in remote locations.

## CONCLUSIONS

In general, there was variability of particulate matter ($PM_{10}$) levels on both temporal and spatial scales in High Level during four seasons of sampling in 1999. The primary reduction mechanism in airborne $PM_{10}$ levels occurred during periods of precipitation (snowfall and rainfall) and not during the wood waste burner shutdown. Wind speed and wind direction were found to strongly affect the spatial distribution of airborne $PM_{10}$ measured.

From receptor modeling analysis at all three sampling sites in High Level, the following elements were found: Si, Ca, Fe, Al, K, Na, Mg, Cl, Rb (>1% relative abundance) [Ti, Mn, P, S Cu, V, Cr, Ce, Sr (<1% relative abundance)]. Based on the principal component analysis (PCA), six main sources were determined to account for approximately 79 percent of the variance between elemental concentrations measured. The six sources included: crustal material (26%), road dust (13%), road salts (12%), vehicles (11%), residual oil (10%), and sulfates (7%). In addition, from a trajectory analysis of 30-minute maximum $PM_{10}$ values (>95 $\mu g/m^3$), sources were originating from the east of High Level approximately 56% of the time. A trajectory analysis using the wood waste burner as a source resulted in a total average $PM_{10}$ level of 19 $\mu g/m^3$ with the wind direction prevailing from the burner to the sampling sites. This is less than the average $PM_{10}$ level observed at all three sites monitored for all four seasons (25 $\mu g/m^3$).

The low volume samples collected had an average 24-hour $PM_{10}$ level of 20 $\mu g/m^3$ and an average 24-hour $PM_{2.5}$ level of 10 $\mu g/m^3$ for all four seasons. The continuous and integrated

samples resulted in similar low concentrations of particulate matter. Typically, ground level sampling at the High Level Forest Products Ltd. plant site had the highest concentration of $PM_{10}$ while the elevated sites, located on the hospital roof and water treatment reservoir, typically had higher concentrations of $PM_{2.5}$.

Re-suspension sources of particulate matter emissions and local meteorology were the two most important factors affecting local air quality. The primary sources contributing to measured particulate matter levels at sites monitored appeared to be crustal soil, road dust and vehicle re-suspension. Based upon these findings, a relationship was not found between wood waste burner operation and airborne particulate matter concentration fluctuations observed at any of the three sites in High Level during the 1999 sampling period.

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# Appendix A SEM Photos from Low Volume-Ambient Air Sampling Filters in High Level, Alberta

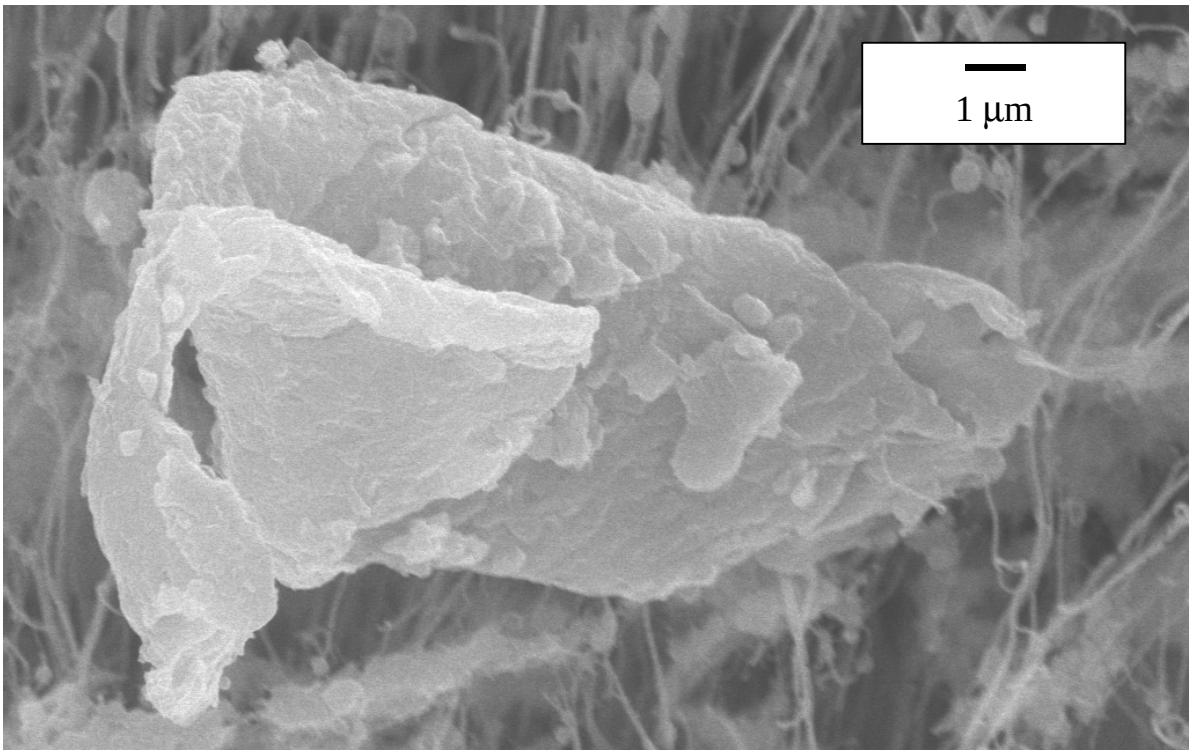


Figure A1. Winter sample – $PM_{10}$ - Collected at the Water Treatment Plant, Primary elements - Ca, Cl, Fe, K

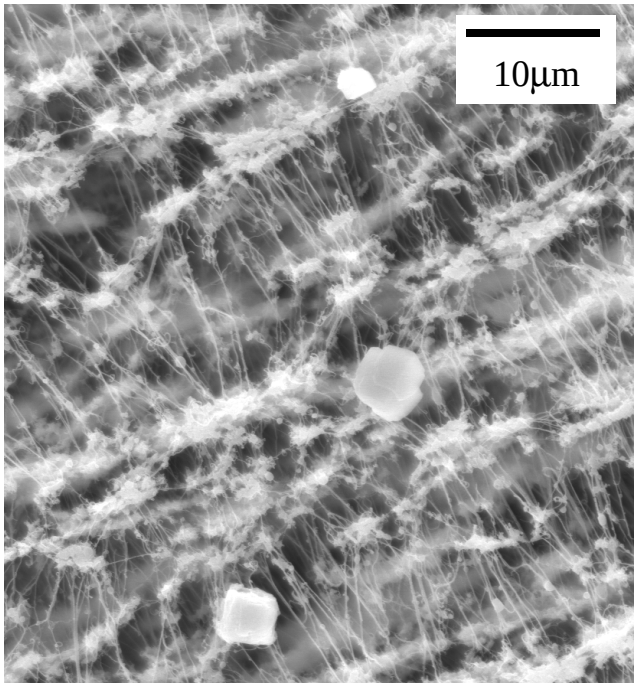


Figure A2. Winter sample – $PM_{2.5}$ - Collected at the hospital site, Primary elements - Na, Cl

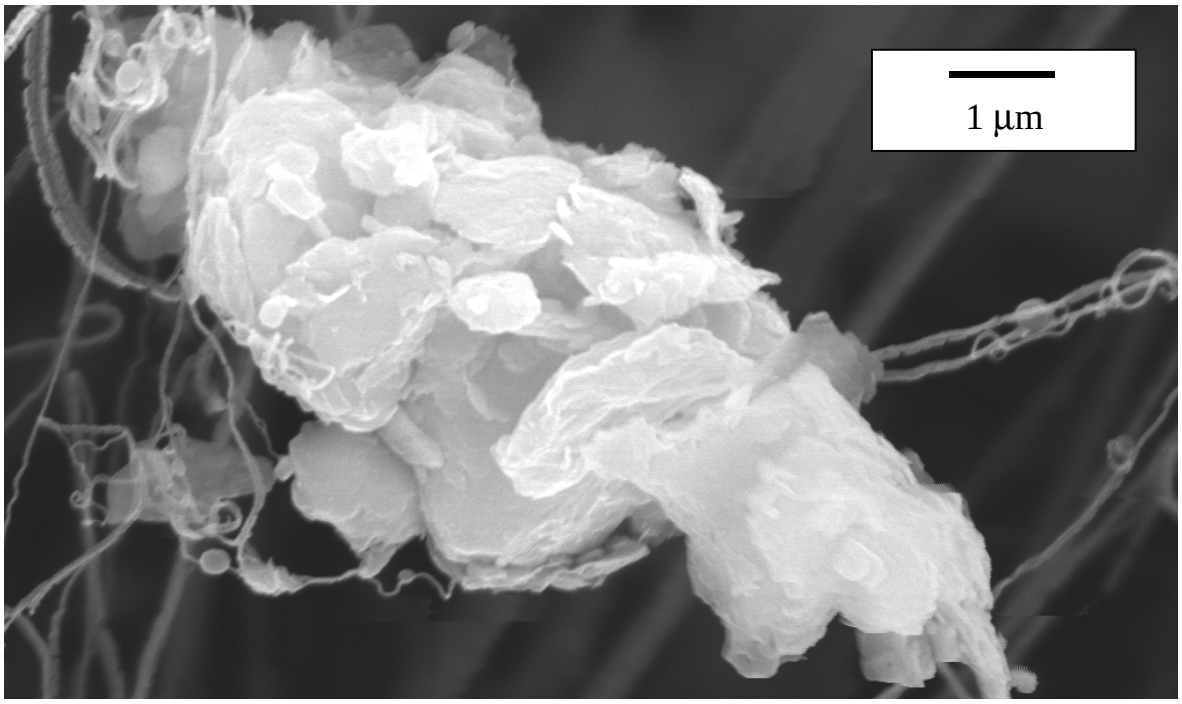


Figure A3. Spring sample – $PM_{10}$ - Collected at the High Level Forest Products Ltd. (HLFP) Site, Primary elements - Si, Al, Ca, Fe

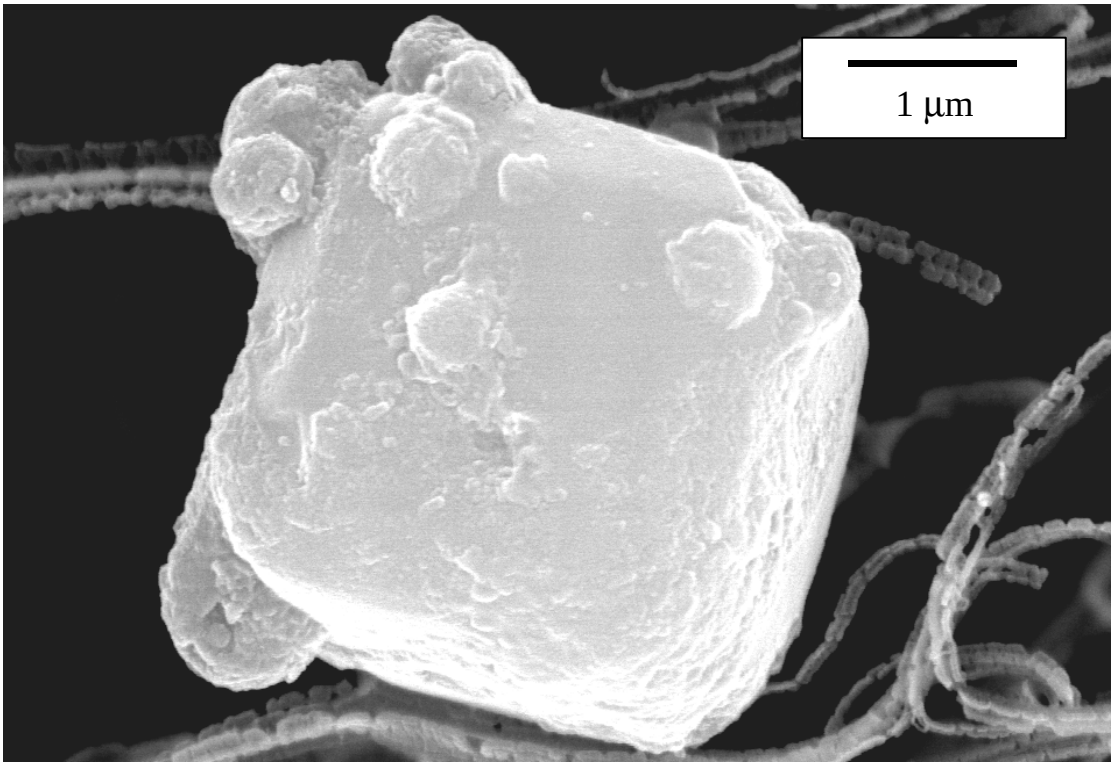


Figure A4. Spring sample – $PM_{10}$ - Collected at the hospital site, Primary elements - Si, Al, Ca, Na

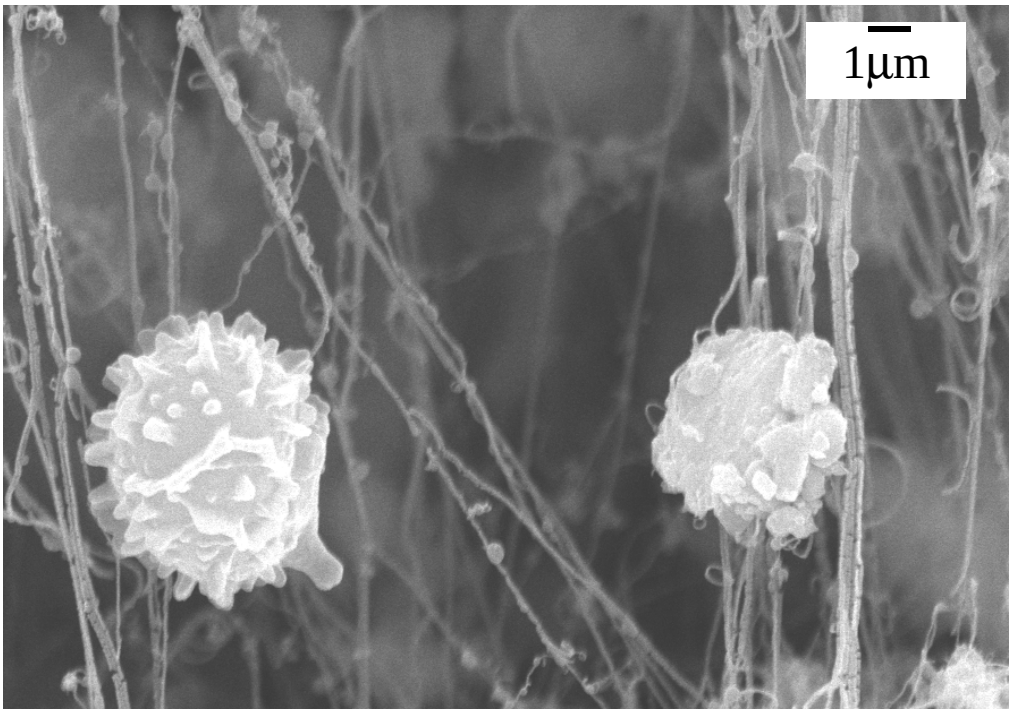


Figure A5. Summer sample – $PM_{10}$ - Collected at the hospital site,
Primary elements - Si, Al, Ca, with a fungal spore

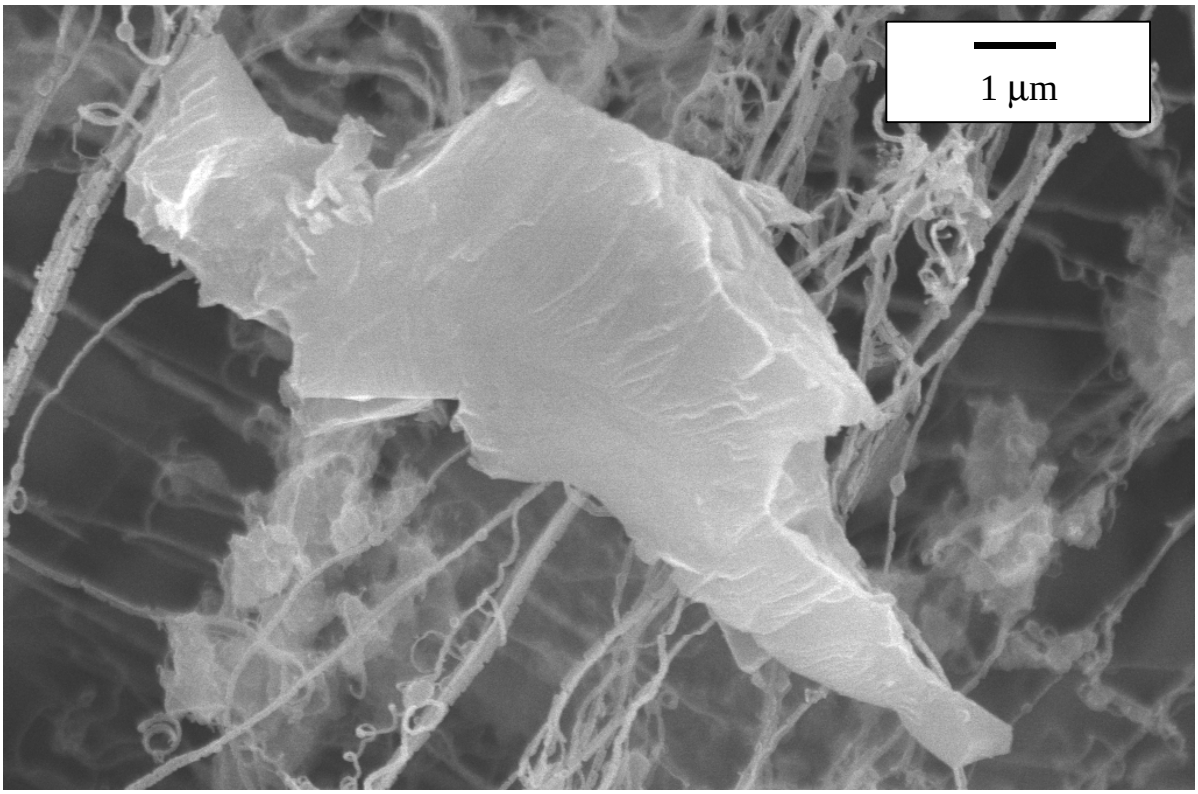


Figure A6. Summer sample – $PM_{2.5}$ - Collected at the hospital site,
Primary elements - Ca, Mg, and trace Al, Na

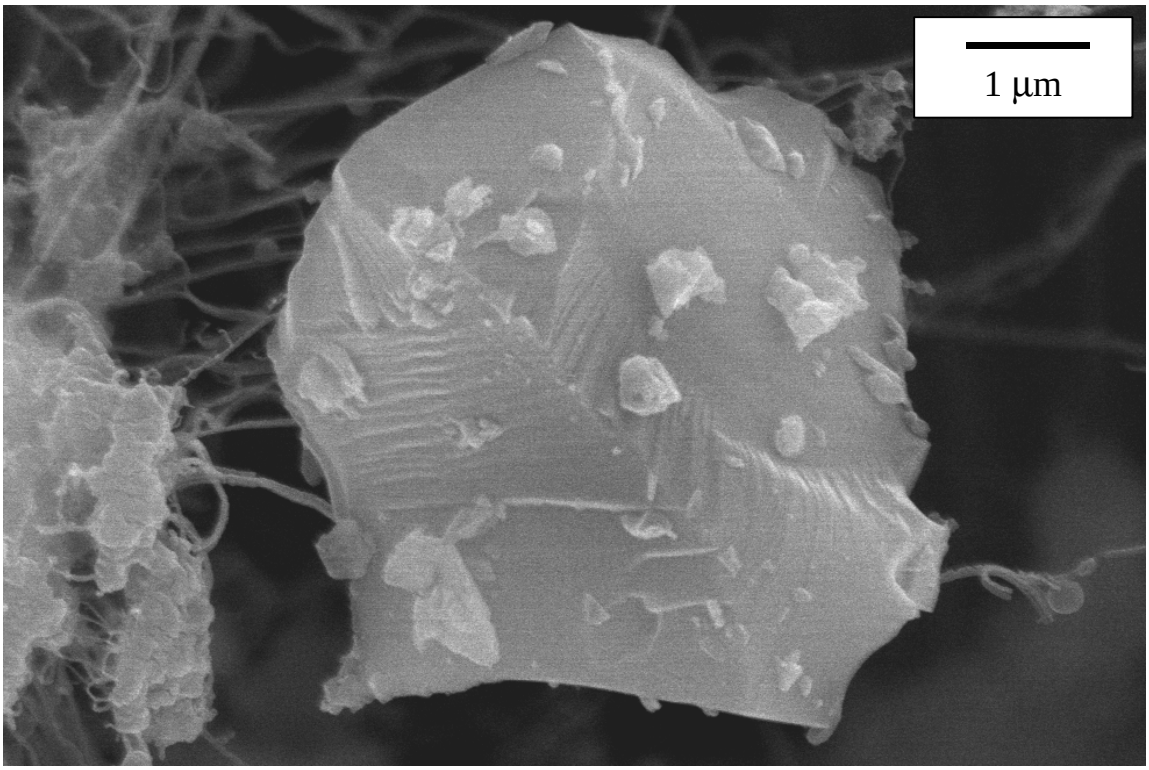


Figure A7. Fall Sample – $PM_{10}$ - Collected at the High Level Forest Products Ltd. (HLFP) site, Primary elements - Si, and trace Ca, Al, Ti

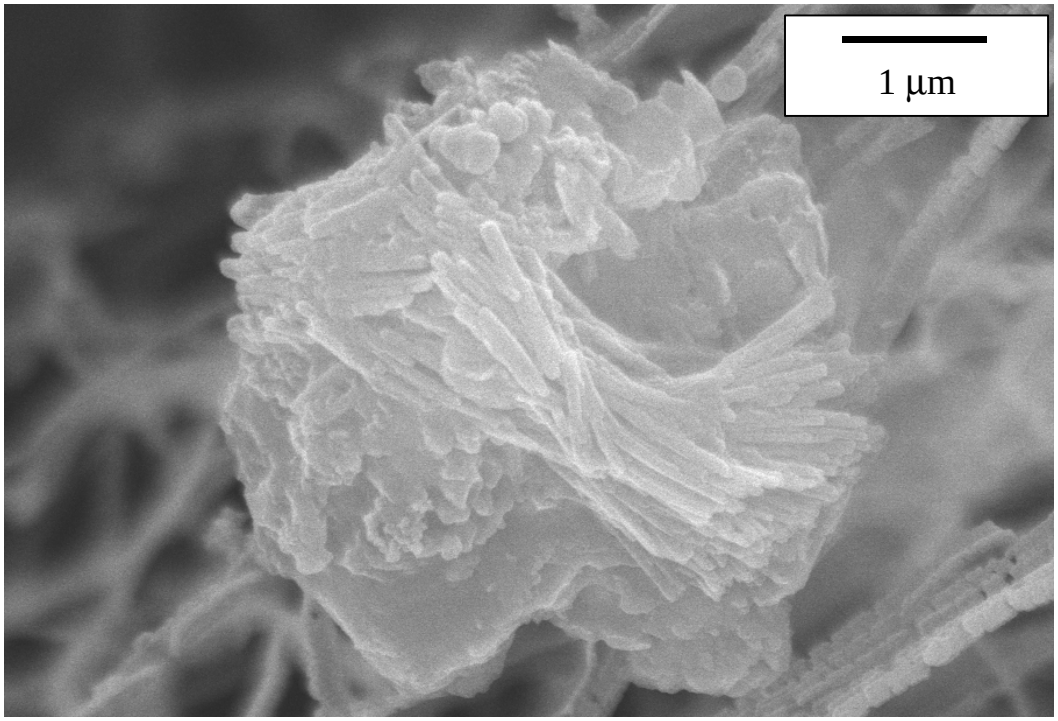


Figure A8. Fall sample – $PM_{10}$ - Collected at the hospital site, Primary elements - Si, Fe, S, Al, Ca

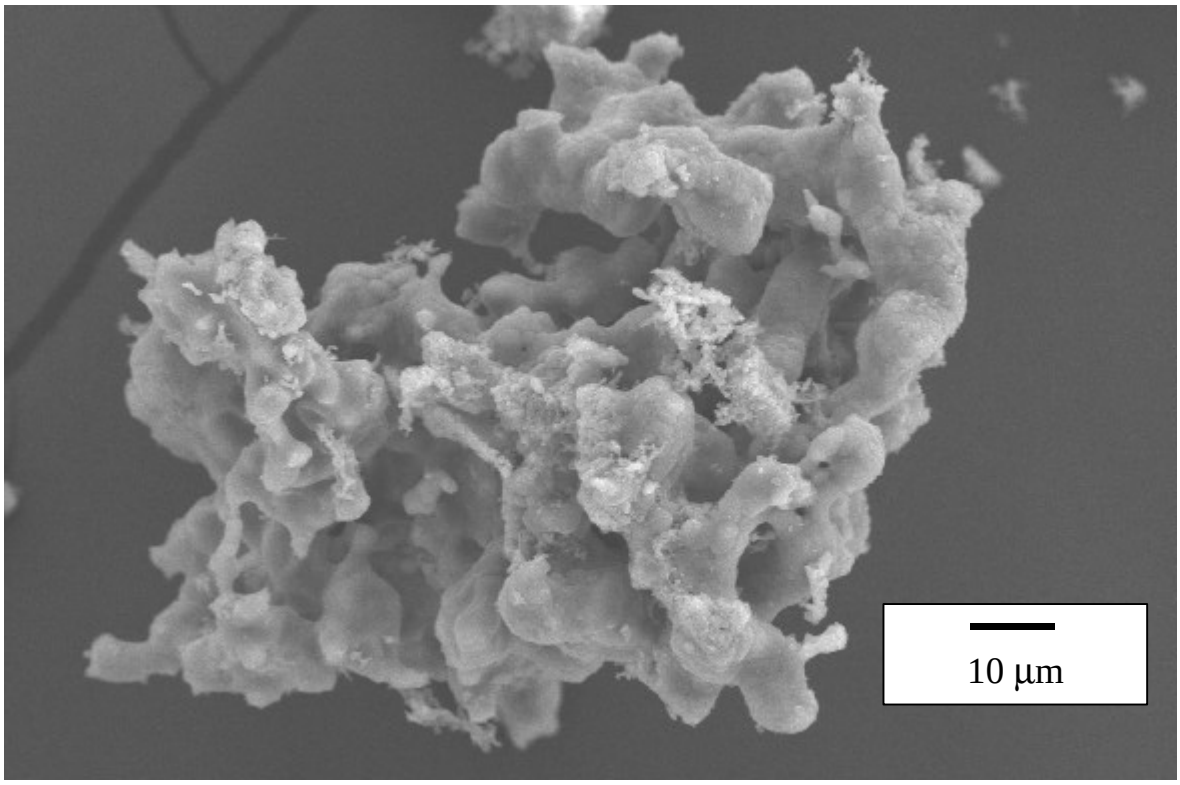


Figure A9. Example of a combustion product from the wood waste burner ash, Primary elements - Ca, with trace Si, Fe, Al, Mg, Cu, Zn

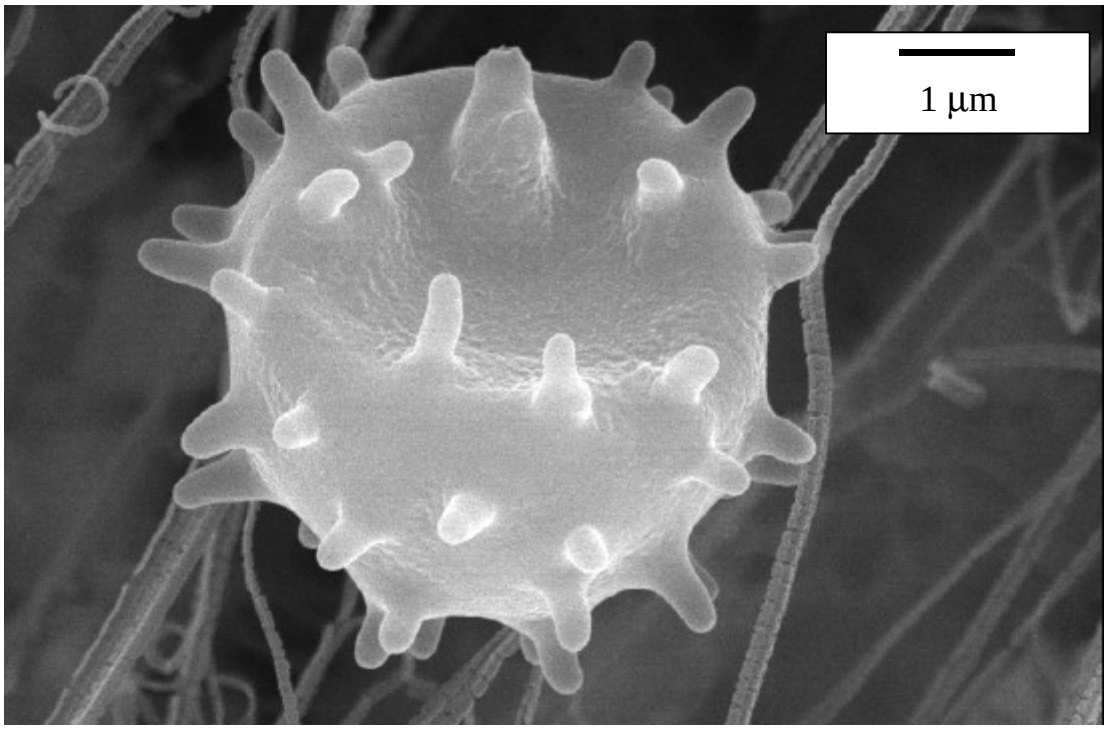


Figure A10. Example of an organic particle – $PM_{10}$ - collected at the Water Treatment Plant