CHARACTERIZATION AND SOURCE APPORTIONMENT OF PARTICULATE MATTER LESS THAN 10 MICRONS IN DIAMETER IN THE PRINCE GEORGE AIRSHED

by

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BSc.(Agr)., The University of Guelph, 1994

THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

ENVIRONMENTAL SCIENCE

THE UNIVERSITY OF NORTHERN BRITISH COLUMBIA

September 1998

ABSTRACT

The susceptibility of the Prince George airshed to high concentrations of particulate matter less than 10 microns in diameter (PM_{10}) have raised considerable concern because of the possible health impacts attributed to this air pollutant. This study examined the chemical and morphological characteristics of samples collected from two main PM_{10} sources and selected ambient samples from the archive of the Ministry of Environment to determine the contributions from these PM_{10} sources to the PM_{10} composition during Episodic and Non-Episodic events. The sources sampled included road dust taken from street sweepings, snow removed from city streets and unpaved roads and a beehive burner sample. PM_{10} samples from three Episodic events with 24 hour PM_{10} levels $>50\mu g/m^3$ and three Non-Episodic events with 24 hour PM_{10} levels $<50\mu g/m^3$ were examined in the bowl area of Prince George (represented by three sampling sites: Plaza, Van Bien, and Lakewood) using a Scanning Electron microscope with Energy Dispersive system and Inductively Coupled Plasma Emission Spectroscopy. Episodes and Non-Episodes were also examined in the BCR industrial site.

Results show that rounded, spherical and oval shaped particles were diagnostic of combustion sources, while amorphous shaped particles were dominant in all samples. The particle size distributions indicated that combustion sources contributed more to the fine fraction of PM_{10} ($<2.5\mu m$) than road dust. The presence of a substantial amount of PM_{10} with a diameter of $3\text{-}4\mu m$ is diagnostic for significant contributions of the road dust source to ambient PM_{10}. The qualitative chemical analysis suggested that high concentrations of aluminum, silicon and magnesium were indicative of road dust while high concentrations of carbon, sodium and sulphur were indicative of combustion and industrial sources.

Principal Component Analysis (PCA) was performed on the qualitative chemical data and four discernable sources were identified as contributing to the ambient PM_{10} in all locations: road dust,

industrial, combustion, and salt. Most of the episodes examined were dominated by road dust while the non-episodes were influenced by industrial, combustion and road dust.

The presence of sulphur in the ambient PM_{10} sampled is a cause for concern due to the possible health implications. The methodology developed in this study can be applied to future source apportionment for the Prince George Airshed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

Many thanks to the following people for their invaluable help during the preparation of this thesis.

Jennifer Wilson
David & Colette Purcell-Chung
Rumon Carter
David Sutherland
Steve Lamble
Dennis Fudge
Guy Plourde
Peter Jackson
David Dick
Peter McEwan
Jill Craig
Frank Blues
Mark Logan
Richard Crombie
Joselito Arocena
Bruno Zumbo
Paul Broda
Jane Hohenadel

This thesis is dedicated to my family
whose love and support mean everything

Roger, Yvonna, & Allen Breed
Charles & Marletta Gabriele
Leslie & Gertrude Breed
Wayne, D'arcy & Terry Gabriele

INTRODUCTION

Particulate Matter is a collective term for the complex and varying mixture of air pollutants found in minute solid and liquid form. Particulate Matter contains both organic and inorganic compounds and varies in size, composition, origin and health hazards (Dockery & Pope,1994). Examples of particulate matter include fine dusts which are formed from the mechanical breakdown of rocks (*i.e.* winter sanding materials) and smoke which is formed from combustion activities (*i.e.* fireplaces, vehicles, industry). Particulate Matter is considered to be a serious health concern for a considerable portion of the population. The World Health Organization concluded that there are over one billion people exposed to excessive levels of particulates and the advent and expansion of industrialization and urbanization continue to expose a greater portion of the population to these unacceptable conditions (French,1990). Particulates, especially PM_{10} or the fraction less than 10 micrometres (μm) in diameter, pose the most significant health hazard because they can be inhaled into lung tissues and may interfere with lung functions.

Prince George is highly susceptible to the accumulation of PM_{10} due to local geography and meteorology, industrial activities in the city, and the severe winters which require significant application of sand to roads. To date, there is a lack of detailed information with respect to the characteristics and distribution of PM_{10} in the Prince George airshed. Management of PM_{10} has been identified by the Prince George Airshed Technical Management Committee as the first air quality management priority due to the high frequencies of unacceptable ambient air quality levels and current epidemiological studies indicating serious health impacts of PM_{10} (PGATMC,1996). The Northern Interior Health Unit (which includes Prince George) ranks nineteenth out of the twenty regions in B.C. for death rates, respiratory disease, and socioeconomic characteristics (PGATMC,1996). The only air pollution health study to date in Prince George was a two part study completed in 1986 and 1991 and examined links

between total reduced sulphur (TRS), total suspended particulate (TSP) and respiratory disease. To date, no studies have focussed on the characterization and effects of PM_{10} on health in the Prince George region.

The 1996 Draft Air Quality Management Plan for Prince George recommends studies to would identify the composition and sources of PM_{10} to aid in prioritizing reduction strategies. Comparisons of annual average ambient PM_{10} levels between 1992 and 1996 show monitoring sites in Prince George rank third (Plaza 26$\mu g/m^3$), fourth (Van Bien 25$\mu g/m^3$), and tenth (Gladstone 19$\mu g/m^3$) out of sixteen Canadian centers (Sutherland,1998). In 1995, at the British Columbia Railroad (BCR) site, the level B - 24 hour objective of 50 $\mu g/m^3$ was exceeded over 30% of the time (mean 41$\mu g/m^3$); at the Plaza it was exceeded 10% of the time (mean 26$\mu g/m^3$) and in College Heights it was exceeded 3% of the time (mean 17$\mu g/m^3$) (MELP,1997). The BCR site is an industrial park with extensive road system (paved and unpaved), beehive burners, sawmills, train tracks / traffic and various other industries. Between 1993-1995 the level A objective was exceeded an average of more than five weeks per year in Prince George (MELP,1997; MELP,1995). The PM_{10} concentrations in the interior of the province corresponded to more than 5 weeks of poor to very poor air during 1993-1995 (MELP,1997). Knowledge of both the sources, and effects of meteorology are also crucial in characterizing the local air pollution problem. The health impacts and high concentrations of PM_{10} have been shown to be significant enough to warrant a study of this nature in the Prince George airshed. Source apportionment of the PM_{10} in the ambient air will rectify the current lack of knowledge about the sources in the Prince George Airshed.

This thesis is intended to provide knowledge of the morphology and composition of PM_{10} in the Prince George airshed. Objectives of this study are to a) determine the physical (*e.g.*, particle size distribution) and chemical (*e.g.*, elemental contents) composition of the major PM_{10} sources in the

Prince George Airshed, and b) to determine the contribution from these major sources to PM_{10} concentrations during episodic and non-episodic events in the bowl and the British Columbia Railroad (BCR) areas in Prince George. The BCR site was examined separately due to the high frequency of non-compliance of the Level B Objective at this location.

CHAPTER 1: LITERATURE REVIEW

Sources, Types and Composition of PM_{10}

Natural sources of PM_{10} include geological, oceanic, forest fire, volcanic, and biological emanations (See Table 1). Primary geological materials (soil) are largely contributed during summer and fall (Chow *et al.*,1992). The composition of these crustal materials varies due to the distinctive elements found in different locations (Chow *et al.*,1992;Schroeder *et al.*,1987). Oceanic or marine sources can form aerosols with trace amounts of metals and sulphur (Bridgman,1990;Schroeder *et al.*,1987). Forest fires can be large contributors during the summertime while volcanoes tend to be an irregular and unpredictable (although quite large) source (Chow *et al.*,1992;Schroeder *et al.*,1987). Biological emanations from leaves, peas, coniferous trees, soils, and pollen also contribute to PM_{10} in the environment (Schroeder *et al.*,1987).

Most natural sources produce PM_{10} in the coarse particle size fraction from 2.5μm to10μm diameter (Chow *et al.*,1992). Coarse particulate often has basic pH, and is formed by the mechanical breakup of materials (Dockery & Pope,1994). This is especially true of soil and crustal PM_{10} (Chow *et al.*,1992). It is believed that due to size and chemical composition, natural sources do not have the same adverse health effects as anthropogenic sources (Vedal,1996). The chemical constituents found in the natural sources mentioned in the literature are summarized in Table 1. The elements found in natural sources vary not only between different sources, for example crustal sources contain aluminum and silicon while marine sources contain sodium, but also between similar sources, for example soil from two areas in Prince George may have quite different compositions (Table 1).

TABLE 1 : Composition of Natural and Anthropogenic Sources of Particulates

NATURAL SOURCE	ELEMENTS/COMPOUNDS
Biological emanations	Zn, Hg, V, Ni, Cu, Cr, As, Pb, Mn, Fe, Co, Cd, Sb, volatile exudates, alkyl arsenic (Schroeder *et al.*,1987)
Crustal	Al, Ca, Fe, Si (Karue *et al.*,1992)
Forest fires	Cd (Schroeder *et al.*,1987)
Ocean/marine	Na, Fe, Mn, Pb, V, Zn, Cu, Ba, La, NO_3^-, Organic C/Elemental C, Cl, Ti, Ni, Sr, Zr,Pd, Ag, Sn, Sb, Al, Si, K, Ca, SO_4^{2-} (Bridgman,1990;Kowalczyk *et al.*,1982;Schroeder *et al.*, 1987;Chow,1995)
Soil dust	Al, Si, S, K, Ca, Fe, Ti, Cr, Mn, Ni, Zn, Li, Mg, P, Sc, Sn, Zr, Nb, Cs, As, Ba, Cl, Na, OC/EC (Kowalczyk *et al.*,1982;Xhoffer *et al.*,1991;Pierson & Brachaczek,1983;Chow,1995)
ANTHOPOGENIC SOURCE	
Agriculture	fugitive dust, secondary ammonium nitrates, ammonia, limestone, NO_3^-, NH_4^+, Cr, Zn, Sr,SO_4^{2-}, Na, K, S, Cl, Mn, Ba, Ti, Al, Ca, Fe, Si, Organic C (Chow, *et al.*,1992;Kowalczyk *et al.*,1982; Chow,1995)
Anthropogenic	Cd, Cu, Mn, Ni, Pb, Zn (Karue *et al.*,1992)
Asphalt production	Ti (Xhoffer *et al.*,1991)
Cement plants	Ca, Mg (Kowalcyzk *et al.*,1982;Alpert & Hopke,1981)
Coal fired boilers	Ti, As, Mn, Fe, Zn, Pb, V, Cl, Ga, Se, Br, Rb, Cr, Zr, Cu, Ni, Co, P, K, Sr, Cd, Ba, Sb, Hg, OC/EC, Al, S, Ca, Si, NH_4^+, NO_3^-, SO_4^{2-} (Kowalcyzk *et al.*,1982;Xhoffer *et al.*,1991; Schroeder *et al.*,1987;Chow,1995)
Construction projects	fugitive soil, limestone, Cr, Mn, Zn, Sr, Ba, SO_4^{2-}, K, S, Ti, Al, Ca, Fe,Organic C, Si (Kowalcyzk *et al.*,1982; Chow,1995)
Crude/residual oil combustion	S, V, Ni, Cr, K, Organic C/Elemental C, Cl, Ti, Co, Ga, Zn, Se, Na, Fe, Si, SO_2, NH_4^+, NO_3^-, SO_4^{2-} (Kowalcyzk *et al.*,1982;Lowenthal & Rahn,1987; Kartal *et al.*,1993;Pierson & Brachaczek,1983; Chow *et al.*, 1992;Xhoffer *et al.*,1991;Chow,1995)

TABLE 1: Composition of Natural and Anthropogenic Sources of Particulates continued

ANTHROPOGENIC SOURCE	ELEMENTS/COMPOUNDS
Ferrous metallurgy	Fe (Xhoffer *et al.*,1991)
Fireplaces/wood smoke	K, organic carbon, retene, Zn (Chow *et al.*,1992;Lewis *et al.*,1988)
Fly ash	Major: Al, Ca, Fe, K, S, Si Minor: As, Cr, Mn, Ni, Ti, Zn (Xhoffer *et al.*,1991;Alpert & Hopke,1981)
High temperature combustion	As, Cd, Cr, Pb, V, Zn (Schroeder *et al.*,1987)
Incineration	Zn, Cl, K, Ni, Ag, Sb, Fe, Hg, Pb, Ti, As, Cd, Co, Cu, Mn, V, Sn, Al, NO_3, Na, EC, Si, S, Ca, Br, La, SO_4^{2-}, NH_4^+, Organic C (Schroeder *et al.*,1987;Alpert & Hopke,1981;Kowalczyk *et al.*,1982;Chow,1995)
Open hearth furnaces	Fe, Zn, Cr, Cu, Mn, Ni, Pb (Schroeder *et al.*,1987)
Non-ferrous smelters	Cu, V, Mn, Sb, Cr, Ti, Cd, Zn, Mg, Na, SO_2, Ca, K, Se, As, Pb, S (Kartal *et al.*,1993;Harley *et al.*,1989;Chow,1995)
Paved road dust	Al, Si, K, Ca, Ti, Mn, Fe (Chow *et al.*,1992;Chow,1995)
Pigment spray	Ti (Xhoffer *et al.*,1991;Alpert & Hopke,1981)
Power plants	Ti, S, Ca, Fe, Zn, Pb, V, Mn, Cr, Cu, Ni, As, Co, Cd, Sb, Hg, Se, Br, Ba, Al, Si, P, K, NH_4^+, OC/EC, Ag, SO_4^{2-} (Xhoffer *et al.*,1991;Schroeder *et al.*,1987;Kartal *et al.*,1993; Chow,1995)
Soil/sewage sludge	alkyl selenides (Lowenthal & Rahn,1987)
Vegetative burning	P, Ca, Mn, Fe, Zn, Rb, Pb, NH_4^+, Na, soluble potassium, Organic C/Elemental C, SO_4^{2-}, NO_3^{2-}, Br, Cl (Chow *et al.*,1992;Xhoffer *et al.*,1991;Chow,1995)
Vehicle emissions	Pb, B, Mg, P, Br, Sr, Co, Ba, Ni, Zn, Fe, As, Al,Cr, Y, Si, Ca, S, Mn, NH_4^+, NO_3^-, SO_4^{2-}, methyl cyclopentadienyl manganese tricarbonyl, alkanes, unburned/oxygenated hydrocarbons, PAH, benzo(a)pyrene, Cl, 1,2dichloroethane, N-nitrosomorpholine (Chow *et al.*,1992 ;OECD,1995; Greenburg *et al.*,1993;Pierson & Brachaczek,1983;Hamilton *et al.*,1994; Williams *et al.*,1989b; Lowenthal & Rahn,1987;Chow,1995;Kowalczyk *et al.*,1982)

Anthropogenic or "man-made" sources can account for a significant portion of the PM_{10} produced (See Table 1). Such sources include stationary fuel combustion (agriculture, oil & gas production, refining, manufacturing, industrial, electric utilities, residential); waste burning (agricultural debris, range/forest management, incineration); petroleum processing (storage/transfer, oil & gas extraction, petroleum refining); industrial processes (chemical, food, agricultural, mineral/metal processing, wood and paper industries, cement plants); miscellaneous processes (farming, construction, demolition, road dust, unplanned fires); mobile sources (passenger vehicles, heavy duty gas & diesel trucks, motorcycles, buses, trains, ships, aircraft) (Alpert & Hopke,1981;Chow *et al.*,1992).

Anthropogenic sources tend to contribute finer PM_{10} (2.5μm or less) than natural sources. These smaller particles tend to be acidic, for example soot particles or acid condensate aerosols (Dockery & Pope,1994). Due to size and composition, this portion of PM_{10} is the most hazardous to health (Vedal,1996). One example of this is vehicle exhaust. Eighty six percent of the particles emitted from diesel engines have an aerodynamic diameter of less than 1μm (Williams *et al.*,1989a;1989b).

There are two types of particles emitted from PM_{10} sources: primary and secondary particles. Primary particles undergo few changes in the atmosphere between sources and receptors (monitors) and the ambient concentration tends to be proportional to the quantities emitted (Chow *et al.*,1992). Secondary particles are formed through chemical conversions (gases to aerosols) in the environment and tend to produce fine aerosols (less than 0.1μm - 2μm) (Bridgman,1990;Chow *et al.*,1992). Aerosols are defined as small solid and liquid material that remains suspended for a period of time (Bridgman,1990). Secondary aerosols can be transported over long distances affecting air quality and climate outside of the local (generating) area (Bridgman,1990). As the aerosols are transported, they often undergo interactions and coagulation to form particulates unique to the original source (Post & Buseck,1984). It is believed that sulphates, nitrates, organic carbon compounds and acid aerosols make

up a majority of fine particulates (Vedal,1996). It is important to consider these differences in order to understand the total PM_{10} being formed.

Health Impacts of PM_{10}

Exposure to particulate matter occurs through the extensive interface provided by the respiratory tract which contains a thin tissue barrier that can be penetrated by PM_{10} (Schlesinger,1990). Epidemiological studies have concluded that for every 10% increase in PM_{10} there is a 1% increase in daily mortality; a 1.4% increase in cardiovascular disease; a 3.4% increase in respiratory disease; and a 3% increase in asthmatic attacks (Dockery & Pope,1994). Recent epidemiological studies have reported increases in human mortality associated with significantly lower levels of PM_{10} than previously believed to be important (Kao & Friedlander,1995). This may be related to the presence of short lived biochemically active species that are not collected or considered within routine sampling (Kao & Friedlander,1995). Animal studies have found that the greatest injury is caused by particulates less than 1.7 μm in diameter which tend to have high sulphate, transition metal and acid content (Vedal,1996). Sensitive members of the population such as asthmatics, elderly/young, and people suffering from cardiovascular and respiratory diseases are more likely to be affected by even lower levels of PM_{10} (Vedal,1995; Hileman,1981).

The respiratory tract has defenses or clearance mechanisms to remove insoluble nonviable deposited particles (Schlesinger,1990). In the upper respiratory tract the main clearance mechanism is mucociliary transport (Dockery & Pope,1994; Schlesinger,1990). Most of this area is lined with a continuous sheet of ciliated epithelium which removes particles trapped by the epiphase (a fluid layer) which covers the epithelium (Schelsinger,1990). Particles are normally removed from the upper respiratory tract within 24-48 hours; however, some studies suggest that 1% of the particles deposited

are retained for longer periods of time (Schlesinger,1990). Once particulates reach the alveolar region of the lung, it is believed they are not removed for weeks to years (Hileman,1981).

In the respiratory (alveolar) region the main clearance mechanisms are the pulmonary macrophages. Alveolar macrophages (located in the air spaces) are phagocytic and mobile; they ingest particles and are then removed via the mucociliary transport or through the lymphatic system (Schlesinger,1990). Interstitial macrophages (located within connective tissue) ingest particles entering the interstitial spaces and also removed by the above mechanisms (Schlesinger,1990). The particles which are deposited in this region remain for weeks to months (Schlesinger,1990).

It appears that inhaled toxic substances such as PM_{10} can alter the efficiency of clearance mechanisms which may cause disease (Schlesinger,1990). Carcinoma (due to smoking) and chronic bronchitis are instances where the mucociliary transport no longer functions properly (Schlesinger,1990). When the clearance mechanisms are disrupted, the residence time of particles increases, enhancing the probability of injury to the respiratory tract. Lung burden of particulates affects the macrophages by depression in mobility due to ingestion of large amounts of particles (Schlesinger,1990). Particulates can aggravate chronic respiratory disease such as asthma, bronchitis, and emphysema by disturbing normal ventilation and causing inflammation (Hileman,1981).

There is also a recent theory that links PM_{10} to cardiovascular mortality (Economist,1995). While the PM10 resides in the lungs, it is believed that they inflame the tissue and alter the body's defense mechanisms (EPA,1984;Hileman,1981). This inflammation may stimulate the bodies' cells to produce fibrinogen and factor vii, both of which are responsible for blood-clotting (Economist,1995). This would explain why people with heart disease are so sensitive to pollution levels. This theory is supported by the trends of increased cardiovascular deaths in highly polluted cities, and the seasonal

variations of lower PM_{10} concentrations and blood-clotting factors during the summer and higher PM_{10} levels and blood-clotting factors during the winter (Economist,1995).

Vehicle exhaust consists of organic PM_{10} and is believed to be a major contributor to cancer risk (OECD, 1995). The International Agency for Research on Cancer (IARC) has concluded that diesel and gasoline exhaust is carcinogenic: diesel is linked to a 15.1% increase in cancer and gasoline is linked to a 12.9% increase (OECD, 1995).

There is believed to be an important difference between the effects of the coarse and fine portions of particulate matter. Total suspended particulate matter is no longer considered an adequate measure for health related studies because only particulates less than 15μm in diameter will penetrate the tracheobronchial and alveolar regions of the body (Hileman,1981). Any particulates larger than 15μm are either not inhaled or are deposited in the upper respiratory tract and expelled within minutes by the mucus membranes.(Hileman,1981; Swift & Proctor,1982). Health effects, such as respiratory problems of PM_{10} are seen in the absence of both acidic and other air pollutants indicating the importance of PM_{10} levels in the air (Vedal,1995). More emphasis is now being placed on $PM_{2.5}$ because this size portion is believed to dominate the penetration into the gas exchange portion of the lungs (Dockery & Pope,1994). Vedal found that the particulates ranging between 0.5 - 5 micrometers are the most important for health (Vedal,1996).

When determination of personal exposure is a priority, the measured outdoor ambient concentrations can only be considered a very rough estimate of personal exposure. Ambient concentrations are monitored in the outdoor environment while personal exposures are determined by "the microenvironments that are continuously surrounding the individual". The majority of these microenvironments are of an enclosed nature, and the three most important microenvironments are occupational, vehicular, and residential (Spengler *et al.*,1985; Valtink & Liegmahl,1989; Li *et al.*,1993;

Mage,1985). While ambient concentration indicates the level of personal exposure when the individual is outside, it is a very poor indicator of total personal exposure since much of the individuals' time (up to 80%) is spent indoors within the microenvironments discussed above (Li *et al.*, 1993). Indeed, there have been correlation found between personal exposure and indoor levels, but not personal exposure and ambient levels, or indoor levels and ambient levels (Spengler *et al.*, 1985). On average indoor personal exposure is 25ug/m^3 higher than outdoor concentrations (Spengler *et al.*, 1985). The outdoor ambient concentrations only represent the minimum exposure for individuals as it will likely be the lowest particulate matter concentration of all the environments the individual occupies.

PM_{10} Accumulation

Meteorology is an extremely important factor to consider when studying air pollution. Specific meteorological conditions such as wind, turbulence, and temperature stratification can contribute to or disperse air pollution such as PM_{10} (Oke,1987). Air pollutants also often undergo physical and chemical transformations which are related to relative humidity, temperature, intensity of solar radiation, and the presence or absence of other substances (Oke,1987). In general the atmosphere has the capacity to disperse pollution hence the slogan the solution to pollution is dilution. However, specific conditions must be present for this to occur. The best conditions for pollutant dispersal involve a strong instability and deep mixing layer which removes the pollutant from the local area (Oke,1987). Often the opposite conditions occur which contribute to "pollution event" by arresting air dispersion.

The main meteorological condition which contributes to a "pollution event" is the inversion of temperature, where a warm air mass overlays a cold air mass producing a stable boundary layer (Oke,1987). Pollutants are trapped within this stable layer and will often accumulate to such an extent that a pollution episode will occur. Local circulation systems such as

land to sea breezes, mountain/valley winds, and city winds tend to contribute to increasing levels of pollution because they are closed circulation systems with slow wind speeds and have diurnal reversal in the direction of flow (Oke,1987). These characteristics contribute to increasing levels of pollutants because the air mass surrounding the area is simply re-circulated, not exchanged for less polluted air.

Precipitation is one removal process for air pollutants such as PM_{10} whether by "wash out" the sweeping up of materials during precipitation events or the formation of precipitation surrounding pollution particles (Oke,1987). Gravitational settling is often responsible for the removal of PM_{10}, however only the larger particulates settle quickly; smaller fine particulates can remain suspended for longer periods of time (Oke,1987).

PM_{10} in the Prince George Airshed

The PM_{10} in the Prince George airshed is considered the top management concern for the airshed (PGATMC,1996). The Prince George airshed is defined as "the mass of air contained within the municipal boundaries of Prince George and the immediate surrounding communities of the Regional District, and particularly that air mass contained and affected by the natural topographical features at the confluence of the Nechako and Fraser Rivers" (PGATMC,1996).There are two main sources of PM_{10} in Prince George: industrial (beehive burners contribute approximately 30% of the non-dust (permitted) sources or 4000 tonnes per year) and road dust contributes 100% of the dust sources (paved/unpaved roads contribute 10,580 tonnes per year; winter sanding contributes 10,550 tonnes per year) (MELP,1997). The Ministry of the Environment has developed an Air Quality Index which is a scale that relates actual concentrations of PM_{10} to the PM_{10} objective and is used to determine air quality (MELP,1997). The Air Quality Index for PM_{10} uses the following descriptives; good $<25\mu g/m^3$; fair $26\text{-}50\mu g/m^3$; poor $51\text{-}100\mu g/m^3$; and very poor $>100\mu g/m^3$ (MELP,1997). The

annual mean concentrations of PM_{10} in the province of British Columbia range from 15$\mu g/m^3$ to greater than 50$\mu g/m^3$ (MELP,1997)

The pollutants produced in the Prince George airshed are often concentrated and re-circulated. The city contains numerous sources of PM_{10} which produce and emit particulates within the river valley. The particulates are often re-circulated in the "bowl area" contributing to the buildup of particulates. Often inversions occur covering the bowl area, generally caused by a warm air mass overlying cold or denser air. This decreases diffusion of the cold air containing PM_{10} and forces it to remain stagnant. The longer the air is trapped, the higher the particulate levels become as the sources continue to produce and emit more PM_{10}. When inversions occur for extended periods of time, the likelihood that pollution advisories will occur increases.

CHAPTER 2: MATERIALS & METHODS

PM_{10} Source Samples

The three types of road dust sources included in the study were street sweepings, snow removal particulates, and unpaved road dust. Street sweepings were collected from a large pile next to the City works yard on 4th avenue, 2 hours after deposition in March 1997. Three 75-litre plastic pails full of materials were removed from five locations in the pile for chemical and physical analyses. All plastic pails used in this and subsequent procedures had been washed with distilled water and Liquinox™, and acid washed with 10% Hydrochloric acid previous to sampling. The street sweepings samples provided information on the contribution of the paved road dust to the composition of PM_{10}. Snow removal samples were collected at Carrie Jane Grey Park to provide information on the contribution of winter sands to the composition of PM_{10}. Materials were removed from several sections of one pile of melting snow containing winter sanding materials into three 75 litre plastic pails. Three 75 litre plastic pails, full of unpaved road samples were collected from several locations on Northern Crescent and Willowcale Forest roads in the BCR site using a shovel to study the contribution from unpaved road dust to the composition of PM_{10}.

Other sources of PM_{10} in the Prince George airshed are pulp mill emissions and beehive burners. A sample of Total Suspended Particulates (TSP) was provided by Canadian Forest Products Prince George Pulp mills. This sample was removed from the power boiler stack which produces the majority of the particulate matter emitted by the pulp mill. The beehive burner sample was obtained from an undisclosed site in the Central Interior of British Columbia.

PM_{10} from Ambient Samples

The ambient PM_{10} samples from three locations in the bowl area and from the BCR site were provided by B.C. Ministry of the Environment Prince George Region (MELP) (Table 2). The three sampling locations in the bowl area were Plaza 400, Lakewood, and Van Bien (Figure 1). As discussed in the introduction, the BCR site was analyzed separately to determine the sources responsible for the frequent non-compliance of the 24 hour level A objective of PM_{10} present at this location. The samples were collected on teflon coated borosilicate glass fiber filters which are used by the MELP for routine total particulate - PM_{10} Hi-volume monitoring (BC Environment,1997). The ambient PM_{10} concentrations reported are based on the weight of PM_{10} sampled in micrograms divided by the volume of air passed through the filter during the 24 hour sampling period in cubic meters. Three episodes (with average 24 hour ambient PM_{10} concentrations above $50\mu g/m^3$) and three non-episodes (with average 24 hour ambient PM_{10} concentrations below $50\mu g/m^3$) were chosen to represent unacceptable and acceptable PM_{10} levels, respectively (Table 2). The three episodes were the three highest PM_{10} episodes occurring between 1994 and 1997. The three non-episodes were chosen to represent good and fair air quality according to established criteria. Filter samples taken before 1994 were unavailable for analysis as they had been destroyed. The meteorological conditions on each date examined are summarized in Appendix A.

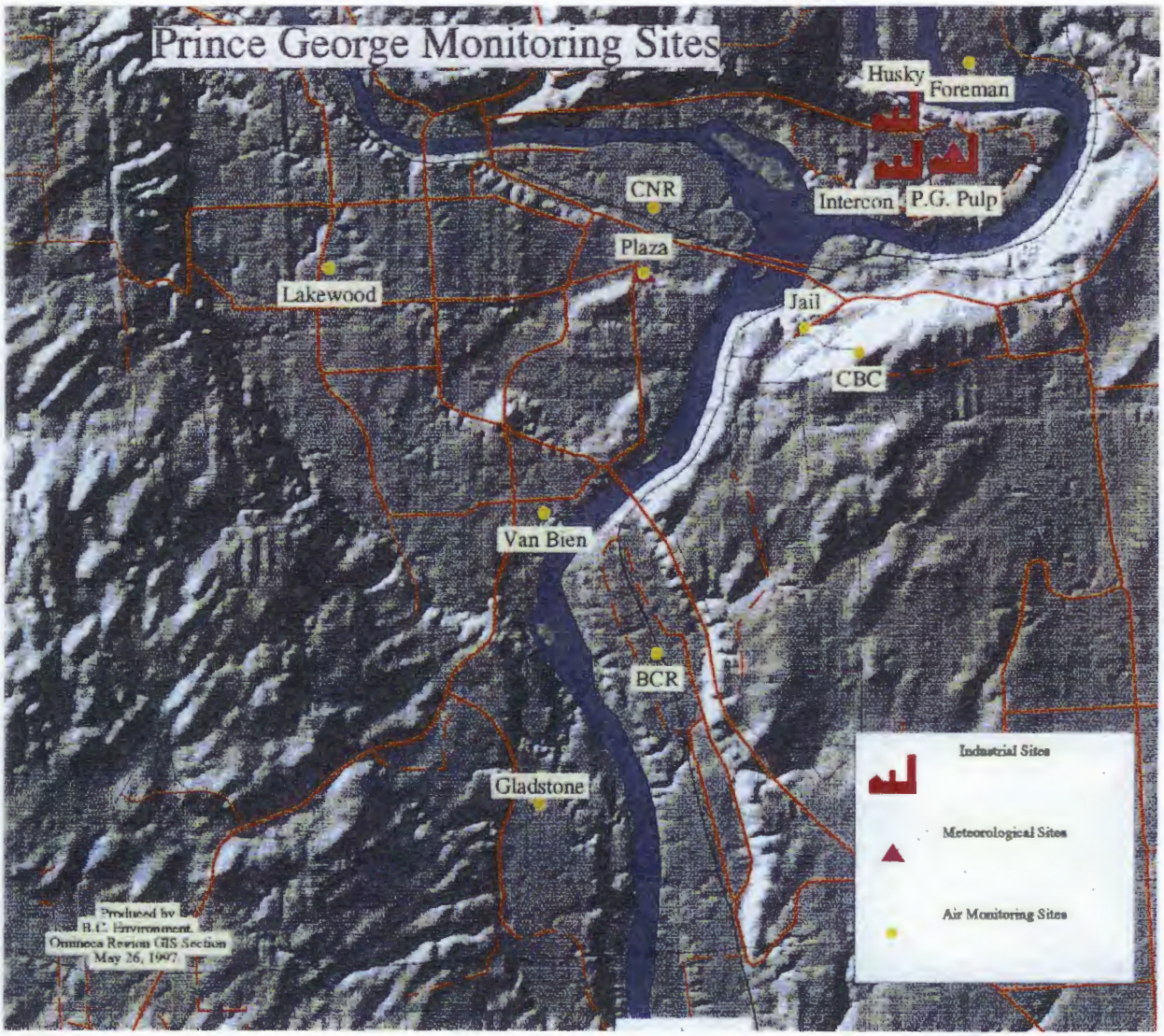
Seven episodes and two non-episodes were chosen to represent the BCR sampling site. The episodes represented poor and very poor air quality and the non-episodes represented fair air quality.

TABLE 2: Location and Description of Ambient & Source Samples

Ambient	Plaza 400	Van Bien	Lakewood
Bowl Episodic	#1 - January 21,1995*		
	54 μg/m³**	60 μg/m³	57 μg/m³
	#2 - March 28,1995		
	85 μg/m³	106 μg/m³	51 μg/m³
	#3 - February 27,1996		
	61 μg/m³	63 μg/m³	35 μg/m³
Bowl Non - episodic	#1 - January 22,1996		
	43 μg/m³	40 μg/m³	50 μg/m³
	#2 - March 4,1996		
	32 μg/m³	44 μg/m³	13 μg/m³
	#3 - May 9,1996		
	17 μg/m³	15 μg/m³	11 μg/m³
BCR site Episodic	#1 - April 8,1994 143 μg/m³	#2 - September 23,1994 110 μg/m³	#3 - February 16,1995 139 μg/m³
	#4 - March 28,1995 181 μg/m³	#5 - August 31,1995 104 μg/m³	#6 - August 13,1996 101 μg/m³
	#7 - March 4,1996 85 μg/m³		
BCR site Non - episodic	#1 - January 22,1996 47 μg/m³	#2 - May 9,1996 32 μg/m³	
Sources			
Road Dust	(1) Street Sweepings (2) Snow Removed from City Streets (3) Unpaved Roads in BCR site		
Beehive Burner	Undisclosed Site		
Pulp Mill	Canadian Forest Products - Prince George		

Dates: * Date of collection by MELP; **Concentration of PM_{10} collected over that 24 hour period. Advisories occurred March 29 - April 1, 1995 & February 28 - March 2,1996.

Figure 1. Sampling Locations for PM_{10} in the Prince George Airshed.



PM_{10} Collection from Source samples

PM_{10} from road dust samples were extracted using particle size analyses. The road dust samples were placed in a 2mm sieve and washed with de-ionized water to separate the materials into coarse fragments (>2mm) and the sand/silt/clay portion (<2mm). Materials smaller than 2mm were then passed through a 53μm sieve to separate the sand (>0.05mm) from the silt/clay (<0.05mm). The clay and silt portion was placed in 2L glass beakers and dried in an oven at 105°C overnight in order to concentrate the sample. The concentrated sample was gradually transferred to one 2L beaker which was topped up with de-ionized water. In order to separate the inhalable particulates (<PM_{15}), Stoke's Law was applied.

Stoke's Law $$v = \frac{D^2 g (\rho s - \rho l)}{18n}$$

Where : D^2 = Diameter squared; ρs = Particle Density defined as $2.65 gcm^{-3}$;

ρl = Density of the liquid media (water) defined as $1.0 gcm^{-3}$;

n = poise defined as $0.01 gcms^{-1}$; g = acceleration due to gravity defined as $980 cms^{-2}$;

v = velocity of the particle in cms^{-1}

Inhalable particulates PM_{15} (<15μm) settle 10cm in water in 8.25 minutes. The sample was agitated using a hand mixer. In order to ensure no contamination with particles greater than 15μm in diameter, the sample was removed at 7cm below the water surface, after 8.25 minutes, using a 10mL glass pipette and transferred to a new 600mL beaker. This procedure was repeated a considerable number of times until enough sample was collected. The PM_{15} sample was then air dried in a plastic container and transferred to a 500mL amber glass bottle for permanent storage. This procedure was conducted for all three road dust samples.

The PM_{10} from the inhalable particulate extracted from the road dust samples were transferred to teflon coated borosilicate glass fiber filters using an Anderson PM_{10} High Volume sampler. To avoid contamination with other PM_{10} sources a small containment building was constructed with a wood frame covered with 6mm construction poly plastic (the floor was also covered with plastic) in the Buckhorn area. The Anderson sampler was set up in the center of the building and cleaned with Kimwipes™ and de-ionized water before and after each sampling period. The samples were gently broken apart into a fine powder and placed in a plastic bag. Once the sampler was operating, the sample was introduced into the air surrounding the sampler by agitating the bag. Due to the concentration of sample, the sampler deposited an adequate amount of PM_{10} on the filter within 20 minutes.

The beehive burner sample was obtained using an Anderson PM_{10} sampler by placing it at ground level within 100 feet of the beehive burner. The plume from the burner intersected the location of the sampler providing a sample of the PM_{10}. Two samples were obtained each taking approximately four hours.

The PM_{10} from the pulp mill TSP samples was collected using Stoke's law after repeated washing with nanopure water, in order to remove the high amounts (19%) of calcium in the TSP. Calcium was removed to lower the ionic strength of the suspension and ensure adequate dispersion of the samples.

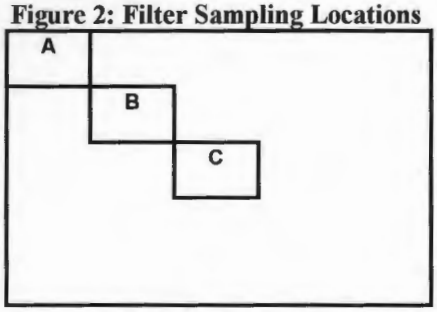
Morphology and *in-situ* Chemical Composition

The Scanning Electron Microscope (SEM) is a very powerful technique that can be used for descriptive purposes such as particle size and morphology. In addition, Energy Dispersive X-Ray analysis (EDAX) system provides the ability to perform qualitative analysis of the chemical

composition of particles. Microanalytical studies on individual particles can be used to classify their source of origin (Linton *et al.*,1980).

From each PM_{10} filter, three sub-samples of approximately $1cm^2$ each were taken and analyzed using SEM/EDAX in order to get an adequate representation of the PM_{10} on the filter (See Figure 2). Each sub-sample was glued to an aluminum stub using a two-sided adhesive tab and gold coated for 45-60 seconds. Thicker gold coatings were required for the filters with greater numbers of particulates to reduce charging.

Figure 2: Filter Sampling Locations



One hundred particles were examined in each sub-sample for two-dimensional particle size (the X and Y diameters), morphology (the nine general shapes observed {amorphous, oval, round, spherical, flat, flat-smooth, rectangular, rod, cube}; illustrated in Appendix B), and chemical composition. Once the stub was placed in the SEM, one edge of the filter was located and the X and Y co-ordinates of the stage were noted. The particle in the center of the screen (found using the bull's eye feature) was located and measured. A spot scan was placed on the center of the particle (9KeVolts,5/6 scan) for a period of 100 sec (defined as the spectrum acquisition time expressed in live seconds) (EDAX,1995). To optimize the spectrum acquisition , the count rate used was between 1000 and 5000 CPS (Counts per second) (EDAX,1995). The quantification of the intensities was performed using a ZAF (Z= atomic #; A= absorption; F=

fluorescence) correction method which calculated the %weight for each element present in the particle. ZAF corrects for the matrix effects such as surface roughness, angle of particulate and fluorescence. Each particle was assigned a unique identification and the spectrum was saved on disk.

Gold coating may have interfered with the sulphur analysis because the gold peak is very close to the sulphur peak in the EDAX quantitative analysis. To determine if the sulphur peak was in fact real, a sample was carbon coated and 100 particles were examined using the EDAX chemical analysis (Appendix C). This analysis confirmed the presence of sulphur in the sample.

The SEM/EDAX analysis has several limitations. Quantitative analysis of chemical composition is extremely difficult due to uncertainty and the inability to measure exact volume or mass (Keyser *et al.*,1978). Chemical composition determined by SEM/EDAX is qualitative and has confidence intervals of ±10% for all elements (Post & Buseck,1985). Elements which make up less than 2% of the bulk of a single particle will routinely not be detected (Lichtman & Mroczkowski,1985). The detection of trace elements is limited due to this feature. Since the technique involves bombardment with charged particles there is a possibility of changing the sample due to chemical reactions/volatilization (Keyser *et al.*,1978). The confidence intervals applied to this study had to include the possible contributions from the teflon coated borosilicate glass fiber filters. To accomplish this, a blank filter was sampled at 100 locations using the EDAX chemical analysis (Appendix D). This analysis showed that the average content of the following elements are: aluminum 1.62%, carbon 2.41%, potassium 0.38%, sodium 9.19%, and silicon 10.48%. These averages were combined with the confidence intervals found in the literature for the EDAX/SEM to be representative of the best estimates for confidence intervals in the study.

The EDAX chemical means for the particulates were presented as percentages of detected elements and then compared for differences using ANOVA. It is possible that this representation of the data may help to mask the actual amount of each element making it harder to determine source apportionment.

The ambient samples and four source samples (road dusts and beehive burner) were examined using this technique. There was insufficient PM_{10} from the pulp mill sample for this analysis.

Total Chemical Composition

Inductively Coupled Plasma Emission Spectroscopy (ICP) is a widely accepted analytical method to determine the quantitative elemental composition of a sample. The sample is dissociated into its atomic components and excited to high energy levels within an argon plasma (Harman,1989). Excited species present within the sample emit characteristic radiation as they return to ionic ground states which are detected and measured against specific calibration curves (Harman,1989). The method is capable of determining most elements at parts per billion (ppb) levels and can measure 100 parts per million (ppm) at ±1% (Harman,1989). The disadvantages of ICP are the significant calibration time due to spectral interferences and high capital costs (Harman,1989).

A Milestone Microwave Digestor was used to digest the sample from the teflon coated glass fiber filters following the modified method of Warren *et al.*(1990). One quarter of each filter ($130cm^2$) chosen from the edge of the filter was placed in a teflon bomb. Strong acids (4mL HNO_3, 7mL HF, 1mL HCl, 2mL H_2O_2) were added to the bombs to facilitate digestion of the material. The ten bomb container was then placed in the microwave digestor and subjected to 5 minutes at 250 Watts, 5 minutes at 450 Watts, and 10 minutes at 650 Watts. The bombs are used

to enhance the digestion process as the samples are subjected to high temperatures under pressure in addition to the corrosive effects of the acid mixture. Once the bombs had been vented for 15 minutes and cooled for 30 minutes in a water bath, approximately 4.5g of boric acid and 30mL of nanopure water was added. The boric acid is used to prevent volatilization of silicon. The bombs were then placed back into the microwave digestor for the identical treatment as previously described. In order to ensure complete digestion of the PM_{10} on the filter, the samples were vented, cooled, and placed in the microwave digestor for another 30 minutes at 750 Watts. Due to the nature of the filter (the presence of Teflon) a portion of the filter could not be digested. Any solid remnants of this Teflon portion were removed by centrifuging the materials for 10 minutes at 15,000rpm at 4°C. The supernatant was transferred using a disposable glass pipette to a 100mL volumetric flask. The sample was made up to 100mL using nanopure water and transferred to 125mL Nalgene containers for permanent storage. The Nalgene containers had been soaked in Alconox™ and acid washed with 10% HCl. The samples were then analyzed for aluminum, barium, cadmium, calcium, chromium, copper, iron, lithium, magnesium, manganese, nickel, potassium, phosphorus, silicon, sodium, strontium, tin, titanium, vanadium, zinc, and zirconium. Four standard soil samples were analyzed using identical methods as above. Elemental recoveries for the extraction method are reported in Appendix E.

The percentage of each element in the ambient samples was calculated by determining 25% of the total mass (grams) collected on the filter using the following equations:

Weight of sample (grams) = $X\mu gm^{-3}$ x $1627.2m^3$ air in 24 hours x $1g/10^6\mu g$ x 25% (1)

where, $X\mu gm^{-3}$ = PM_{10} weight calculated by MELP

% Element = ppm of element (μg/mL) x 100mL x 1/weight of sample (grams) x 10^{-4} (2)

One quarter of a filter from each source sample was weighed and the weight of an identically sized blank was subtracted to provide the approximate weight of the sample in grams. The percentage for each element was then calculated using equation 2. This was repeated for the BCR ambient samples.

In this study, the most limiting factor was the filter type. Although the teflon portion of the filter was not digested, the glass fiber caused considerable problems due to the high levels of silicon, aluminum, and other metals that the filter contained. (Harman,1989). The averaged blank values for each element was subtracted from each sample to provide a true measure of the elements (Appendix F). Unfortunately, the variability of several key elements caused some difficulties in interpretation of samples with smaller particulates loadings. Due to these problems the comparison between episodes and non-episodes for the bowl area was considered unreliable and was not discussed in the final result section of the study. Comparison of the results are summarized in Table 3 and indicate that there was larger concentrations (which sum to over 100%) of most elements on the filters with smaller particulate loadings which is not logical. Higher concentrations of elements would be expected on filters with substantially more particulate matter. The silicon determined by the ICP was also deemed inaccurate and removed from the results due to the presence of large quantities of silicon in the filter, the large variations found in the blank filter, and the poor method recoveries (50%) determined using the standard samples.

Other Analyses

The Coulter counter is an analytical instrument used to determine particle size distribution. A sample is thoroughly mixed in a liquid media (generally a 1-3% sodium chloride/ nanopure water solution). Analysis of different size ranges require tubes made with different aperture sizes. The sample is drawn through the aperture for a specified amount of time or volume. Each time a

particle passes through the aperture it breaks the light beam that runs from the machine through the aperture. The size of the particle is measured and recorded, providing a particle size distribution for the sample.

TABLE 3: Comparison of Elemental Analysis (ICP) between Episodes and Non-Episodes

Element	Episode		Non-Episode		ANOVA Results
	Total Mean %	SD	Total Mean %	SD	
Aluminum	6.67[a]	17.630	54.49[b]	33.450	H(1,n=18)=7.23, p=0.0072
Barium	0.86[a]	2.570	10.5[b]	11.240	H(1,n=18)=5.57, p=0.0183
Calcium	13.53[a]	30.530	68.47[b]	39.900	H(1,n=18)=5.90, p=0.0152
Chromium	0.000	0.000	0.017	0.035	H(1,n=18)=4.65, p=0.0311
Copper	0.022	0.061	0.025	0.064	H(1,n=18)=0.25, p=0.6150
Iron	3.390	3.680	3.920	6.010	H(1,n=18)=0.002, p=0.9646
Lithium	0.0023[a]	0.007	0.023[b]	0.016	H(1,n=18)=7.11, p=0.0077
Magnesium	0.67[a]	1.250	13.35[b]	8.290	H(1,n=18)=6.93, p=0.0085
Manganese	0.070	0.098	0.064	0.150	H(1,n=18)=0.69, p=0.4057
Nickel	0.017	0.012	0.016	0.014	H(1,n=18)=0.16, p=0.6905
Phosphorus	0.110	0.210	0.210	0.290	H(1,n=18)=1.03, p=0.3095
Potassium	2.46[a]	3.890	9.08[b]	7.170	H(1,n=18)=4.19, p=0.0407
Sodium	30.330	19.780	45.800	25.450	H(1,n=18)=1.87, p=0.1711
Strontium	0.043	0.130	0.130	0.190	H(1,n=18)=1.95, p=0.1625
Titanium	0.760	0.770	1.450	1.000	H(1,n=18)=2.13, p=0.1443
Vanadium	0.008	0.011	0.028	0.027	H(1,n=18)=4.19, p=0.0407
Zinc	3.450	6.410	7.020	5.630	H(1,n=18)=1.91, p=0.1667

Episodes (n=3); Superscript across columns indicates significant differences between means ($p<0.05$); For example the Aluminum is significantly different between the Episodes and Non-Episodes as indicated by the different letters in superscript

A portion of the filter (30.6cm^2) was placed in an acid washed 50mL centrifuge tube and 50mL of a 0.45μm filtered 1% Liquinox™ detergent solution in nanopure water was added. The samples were shaken using a horizontal shaker for 72 hours in order to remove the PM_{10} from the filter. The samples were measured with two aperture tubes to determine an accurate curve; the 200μm aperture tube which is more accurate for large particles and the 30μm aperture tube which is more accurate for smaller particles.

There were many difficulties discovered while performing the analyses on the filter samples. In addition to larger particles blocking the aperture (which then had to be unblocked before the analysis could be restarted), the blank filter contained more particles than sample filters. It appears that the PM_{10} adsorbed to the filter actually protected a portion of the filter from the removal process making the preparation of a true blank impossible. Because removal of PM_{10} by shaking was the most successful method tried for removing particulates while maintaining filter integrity, it was concluded that the analysis of particulate size using the Coulter Counter was not practicable.

The amounts of carbon, nitrogen, and sulphur were determined using a C,N,S analyzer. The elemental analyzer method is based on the complete and instantaneous oxidation of the sample by flash combustion (CHU,1994). All organic and inorganic substances are converted into combustion products, and are then passed through a reduction furnace (CHU,1994). The gases are separated in the column and detected by the thermal conductivity detector (CHU,1994). The signal that is detected is proportional to the concentration of the element (CHU,1994).

A portion of the filter ($30.6cm^2$) was placed in an acid washed 50mL centrifuge tube and 50mL of a 0.45μm filtered 1% Liquinox™ detergent solution in nanopure water. The samples were shaken using a horizontal shaker for 72 hours in order to remove the PM_{10} from the filter. In order to concentrate the PM_{10} the samples were transferred to 50mL acid washed Nalgene centrifuge tubes and spun at 15,000 rpm for 20 minutes at 4°C. The samples were then concentrated and transferred to 25mL polypropylene scintillation vials. To remove all water the samples were freeze dried.

Freeze drying removes the water more gently than regular drying, so that the end sample is not extremely hard. The freeze drying process was completed in 72 hours. When the samples

were analyzed, the blank filter samples contained a substantial portion of carbon. The carbon removed from the filter itself overwhelmed any contributions from the PM_{10} samples making the results unreliable. The inability to produce an acceptable blank eliminated the usefulness of the procedure.

Statistical Analysis

The three main statistical methods used in the analysis of the data in this study were One-way ANOVA, Non-parametric Kruskal-Wallis ANOVA, and Principal Component Analysis (PCA) using Statistica™.

One- way ANOVA was used to compare the morphological properties between episodes/non-episodes in the bowl area. The particle size distribution data was transformed using a log transformation. Tukey's post hoc with $\alpha = 0.05$ was used to determine significant differences between the means.

Non-parametric Kruskal-Wallis ANOVA was used for most of the comparisons between episodes/non-episodes in the BCR site data set for morphology and particulate size because the data violated the two main requirements for ANOVA: normality and equality of variance. These violations would not be so serious if not compounded by the unbalanced nature of the design in this case (Non-Episodes=599 versus Episodes=2100) (Zumbo & Coulombe,1997). The Least Square Difference test was used to determine significant differences between the means.

The elemental composition and average particle diameter were analyzed to determine whether there were significant correlation between specific elements and particle sizes. The elemental composition and morphology were also analyzed to determine whether there were significant differences between the morphological shapes. Non-parametric Kruskal-Wallis ANOVA was used for this analysis.

Principal Component Analysis (PCA) is a mathematical model used to explain the variation present in a sample by forming principal components which show the relationships between variables. PCA was used to reduce the number of variables (in this case elements) into a much smaller number of Principal Components or Factors (in this case source signatures) that is expected to indicate the amount of pollutant contributed by specific sources (Tabachnick & Fidell,1996). Principal Components or Factors with eigenvalues (which represent variance) of greater than one were analyzed because they represent the amount of variance introduced by one variable and are deemed significant (Tabachnick & Fidell,1996). Only factors with more than one variable having high loadings were included in the analysis to enhance the interpretability of the final result (Tabachnick & Fidell,1996). None of the PCA performed had significant correlation between factors so a normalized Varimax rotation was chosen to enhance interpretability of the solution (Tabachnick & Fidell,1996). The values in the loading matrix of the factor (those represented in this study) illustrate the correlation between variables and factors (Tabachnick & Fidell,1996). The amount of the loading and pattern of loadings (positive and negative relationships) are used to interpret the factor. Loadings of more than 0.71 (50% overlapping variance) are excellent, above 0.63 (40% overlapping variance) are very good, above 0.55 (30% overlapping variance) are good, above 0.45 (20% overlapping variance) are fair and above 0.32 (10% overlapping variance) are poor (Comrey & Lee,1992). PCA was performed on the EDAX qualitative chemical composition data in an attempt to identify the presence of factors, which for the sources would be considered the most commonly found particulate types / or elemental relationships.

The EDAX chemical analysis was used to perform the PCA because the sample size was large and any influence the filter had on the analysis was incorporated into the confidence

intervals. The ICP/AES quantitative analysis would have required substantially more samples which would have been impossible to obtain due to the archival nature of the samples. The filter type is also not conducive to ICP/AES analysis.

CHAPTER 3: RESULTS & DISCUSSION

Morphological and Chemical Properties of PM_{10} Sources

Road Dust

The three road dust samples analyzed have two dominant morphological shapes: amorphous and flat (Table 4 & Appendix B). Amorphous soil / dust particles have been identified by many researchers (Van Borm & Adams,1988; Xhoffer *et al.*,1991; Fisher *et al.*,1978). The presence of flat particles have not been reported in the literature. The flat shape most likely represents clay minerals which can account for 40 - 50% of the soil dust fraction in ambient particulate materials (Post & Buseck,1984). There were a few spherical particulates present in the snow removal and unpaved road dust samples, however, it is possible that they were contaminants present in the air, contributed by other particulate sources.

The mean particle size range of the road dust is between 3.78 - 4.67μm which also agrees with the literature (Chow,1995)(Table 5). The literature suggests that particles from road dusts and soil particles are mainly coarse particles which is consistent with the trend seen in the particle size distributions (Figure 3-5) (Chow,1995).

The quantitative chemical composition of the road dusts samples indicate that aluminum, calcium, magnesium, potassium, sodium, and barium are major components and chromium, copper, lithium, manganese, nickel, phosphorus, strontium, tin, titanium, vanadium, zinc, and zirconium are minor components in all the samples (Table 6). The only noticeable difference between the road dusts was the larger percentage of iron in the street sweepings, however, this was not statistically significantly different from the other road dust samples. The quantitative chemical composition of the three road dust samples is consistent with the reported literature for most elements (Chow *et al.*,1992; Chow,1995) (Table 6).

TABLE 4: Distribution of Morphological shapes in PM10 sources

Morphological Type	Street Sweepings %	Snow Removal %	Unpaved Roads %	Beehive Burner %
Amorphous	79.00	61.00	53.21	32.00
Oval	0.00	0.00	0.00	18.00
Round	0.00	0.00	0.00	1.00
Sphere	0.00	4.00	1.84	1.00
Flat	21.00	35.00	44.95	48.00

Sources (n=100); except Unpaved Roads (n=103)

TABLE 5:Comparison of Average Particle Size for Sources

Sources	Mean (μm)	SD	ANOVA Results
Street Sweepings	4.67[a]	2.53	
Snow Removal	4.11[ab]	2.58	
Unpaved Roads	3.78[b]	2.55	
Beehive Burner	3.19[c]	3.02	F(3,398)= 10.94,p=0.00001

Columns means superscripted with different letters are significantly different ($p<0.05$);
SD = Standard Deviation; (street sweeping & snow removal n=100; unpaved roads n=103; beehive burner:n=99)

TABLE 6: Quantitative Chemical Composition of PM10 Sources (ICP)

Element	Street Sweepings		Snow Removal		Unpaved Roads		Beehive Burner	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
Aluminum	6.04[ab]	0.920	7.58[a]	1.200	10.85[a]	3.130	9.56[a]	6.140
Barium	1.96[a]	0.080	1.12[a]	0.440	2.19[a]	0.540	4.92[b]	2.920
Calcium	4.400	0.950	2.670	0.260	1.190	2.070	7.470	12.950
Cadmium	nd[a]	nd	nd[a]	nd	nd[a]	nd	nd[a]	nd
Chromium	0.011[a]	0.003	0.002[a]	0.001	0.001[a]	0.002	0.01[a]	0.022
Copper	0.016[a]	0.001	0.01[b]	0.000	0.019[a]	0.002	0.004[c]	0.004
Iron	3.590	1.940	0.063	0.032	0.016	0.028	2.190	3.790
Lithium	0.004[ac]	0.000	0.004[ac]	0.001	0.0066[a]	0.001	0.0121[b]	0.005
Magnesium	1.22[a]	0.181	1.33[a]	0.260	2.07[ab]	0.587	2.40[b]	0.977
Manganese	0.037[a]	0.008	0.108[b]	0.016	0.587[b]	0.030	0.977[c]	0.000
Nickel	0.0049[a]	0.001	0.007[a]	0.001	0.0085[a]	0.002	0.0057[a]	0.001
Phosphorus	0.073[a]	0.018	0.138[b]	0.019	0.135[b]	0.030	0.074[a]	0.039
Potassium	1.73[a]	0.167	1.49[a]	0.705	2.09[a]	0.960	4.05[b]	1.050
Sodium	3.59[a]	0.233	3.36[a]	0.446	4.84[b]	0.723	12.62[c]	0.682
Strontium	0.092	0.004	0.070	0.017	0.114	0.035	0.212	0.184
Tin	0.0032[a]	0.001	0.0028[a]	0.002	0.00497[a]	0.004	0.0136[b]	0.005
Titanium	0.219[a]	0.026	0.457[b]	0.056	0.48[b]	0.110	0.283[a]	0.065
Vanadium	0.0058[a]	0.001	0.011[b]	0.002	0.0135[b]	0.003	0.005[a]	0.003
Zinc	0.841[a]	0.049	0.458[b]	0.184	1.01[a]	0.142	3.68[c]	0.061
Zirconium	0.018	0.002	0.018	0.003	0.024	0.006	0.036	0.031

Row means superscripted with different letters are significantly different ($p<0.05$); Each source (n=3)
SD = Standard Deviation; nd = not detected

TABLE 6: Quantitative Chemical Composition of PM_{10} Sources cont.

Element	Pulp Mill TSP		Pulp Mill PM10		ANOVA Results
	Mean %	SD	Mean %	SD	
Aluminum	1.12^{b}	0.021	2.12^{b}	0.020	H(5,n=18)=13.35, p=0.0203
Barium	0.033^{a}	0.001	0.144^{a}	0.019	H(5,n=18)=14.99, p=0.0104
Calcium	18.698	0.455	12.830	0.295	H(5,n=18)=9.95, p=0.0768
Cadmium	nd^{a}	nd	0.00025^{b}	0.000	H(5,n=18)=14.39, p=0.0133
Chromium	0.035^{b}	0.005	0.246^{c}	0.003	H(5,n=18)=12.78, p=0.0255
Copper	0.012^{b}	0.000	0.026^{d}	0.000	H(5,n=18)=16.39, p=0.0058
Iron	1.300	0.056	3.170	0.030	H(5,n=18)=10.23, p=0.0690
Lithium	0.0016^{c}	0.000	0.0016^{c}	0.000	H(5,n=18)=15.36, p=0.0089
Magnesium	1.99^{ab}	0.033	4.57^{c}	0.056	H(5,n=18)=11.95, p=0.0355
Manganese	0.99^{d}	0.020	2.20^{e}	0.020	H(5,n=18)=16.23, p=0.0062
Nickel	0.016^{b}	0.001	0.169^{c}	0.004	H(5,n=18)=15.13, p=0.0098
Phosphorus	0.714^{c}	0.009	1.46^{d}	0.015	H(5,n=18)=15.27, p=0.0093
Potassium	3.50^{b}	0.230	1.06^{a}	0.027	H(5,n=18)=13.09, p=0.0225
Sodium	2.51^{d}	0.043	0.35^{e}	0.021	H(5,n=18)=16.25, p=0.0062
Strontium	0.044	0.001	0.038	0.001	H(5,n=18)=9.52, p=0.0902
Tin	0.0076^{a}	0.002	0.0169^{b}	0.001	H(5,n=18)=13.63, p=0.0181
Titanium	0.065^{c}	0.001	0.089^{c}	0.001	H(5,n=18)=15.83, p=0.0074
Vanadium	0.0034^{a}	0.003	0.0057^{a}	0.000	H(5,n=18)=13.23, p=0.0213
Zinc	0.077^{d}	0.001	0.222^{d}	0.003	H(5,n=18)=16.39, p=0.0058
Zirconium	nd	nd	0.001	0.000	H(5,n=18)=9.75, p=0.0827

Rows mean superscripted with different letters are significantly different ($p<0.05$); Each source (n=3)
SD = Standard Deviation; nd = not detected

Figure 3: Particle Size Distribution: Street Sweepings

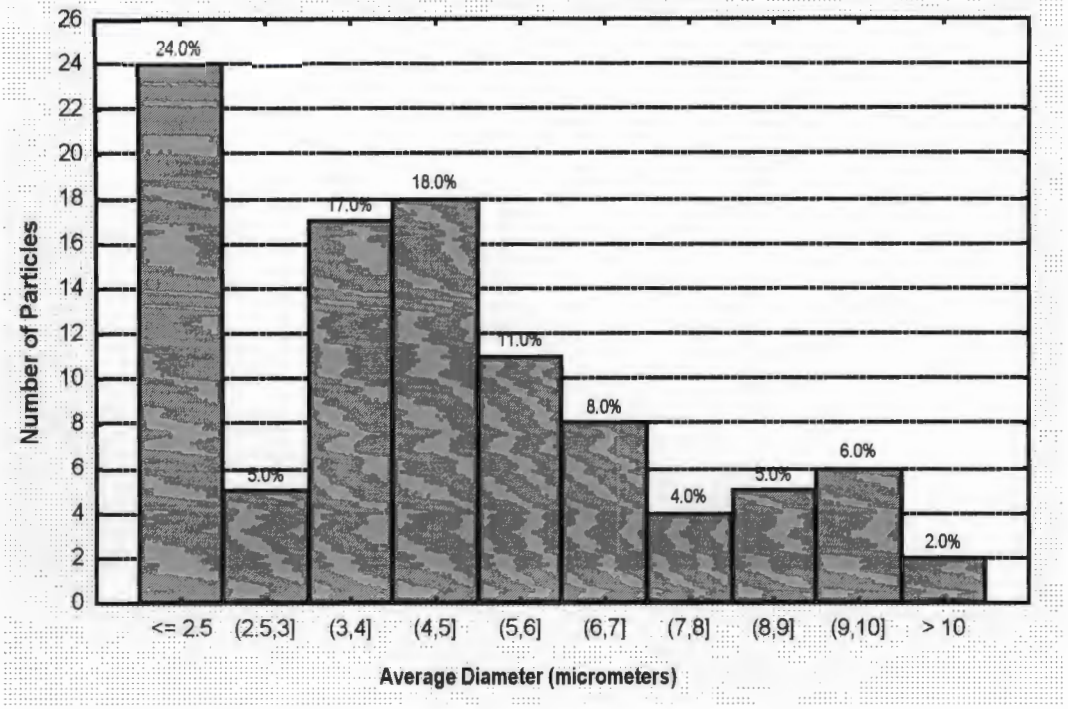
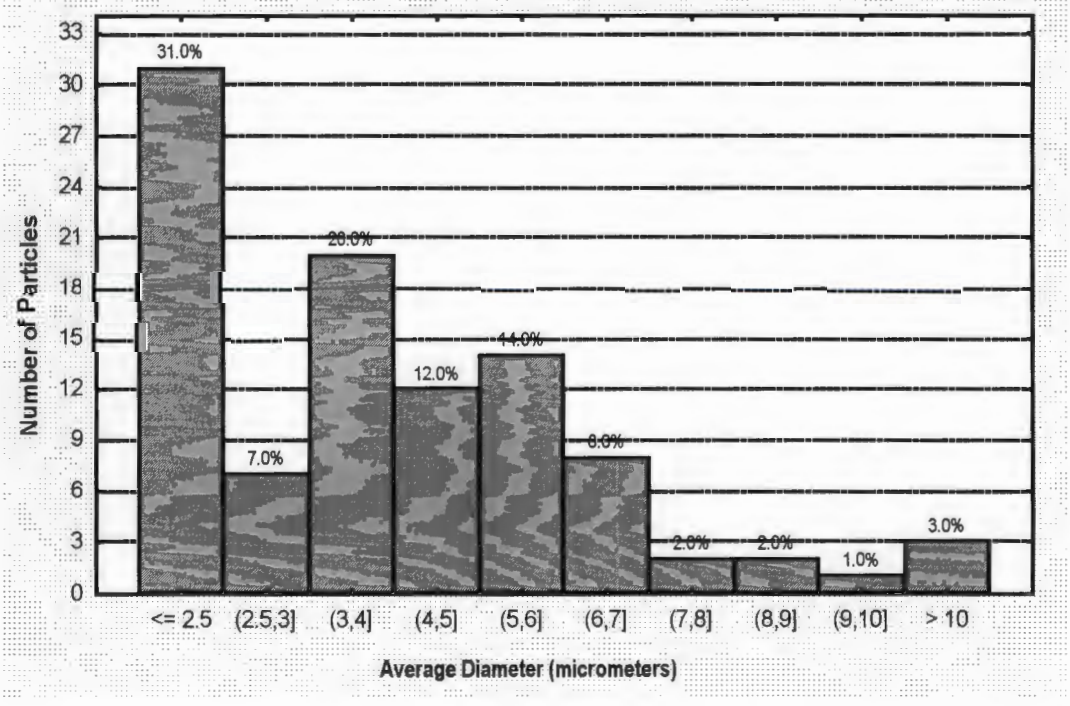
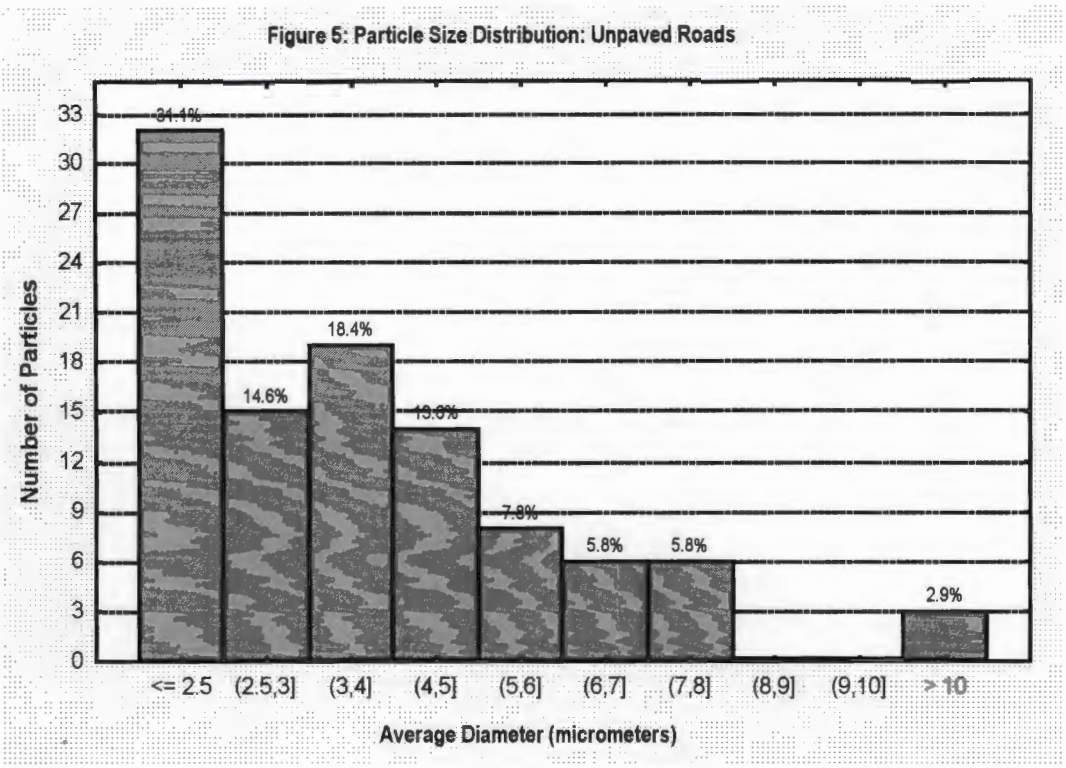


Figure 4: Particle Size Distribution: Snow Removal





The quantitative values of barium, zinc, and sodium are higher and the iron is lower in the Prince George PM_{10} samples compared to those in the literature (Chow *et al.*,1992; Chow,1995). This may be a result of variations in the amounts of these elements present in the crustal materials in Prince George. There is some uncertainty with these results due to problems with the filter blank (see Methods section). The qualitative chemical compositions (±10%) are consistent with the reported literature for carbon, chlorine, potassium, magnesium, and titanium (Chow *et al.*,1992; Chow,1995)(Table 7). There is however, more aluminum, sodium and silicon, and less calcium and iron than found in the reported literature (Chow *et al.*,1992; Chow,1995). This could again be a result of natural variation or the large confidence intervals of the EDAX analysis.

TABLE 7: EDAX Qualitative Chemical Characterization of PM_{10} Sources

Sources	Al		C		Ca		Cl		Fe	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
Street Sweepings	18.72[a]	8.37	10.31[a]	8.73	0.42[a]	1.05	0.02	0.18	nd	nd
Snow Removal	21.16[a]	10.20	5.64[b]	4.72	0.31[a]	0.87	nd	nd	0.27	1.25
Unpaved	20.97[a]	9.36	5.68[b]	6.08	0.61[a]	1.32	nd	nd	0.12	0.69
Beehive Burner	12.98[b]	9.59	19.93[c]	16.11	1.92[b]	8.02	nd	nd	0.69	6.72
Teflon Blank	1.62	0.55	2.41	1.37	nd	nd	nd	nd	nd	nd
	K		**Mg**		**Na**		**Si**		**Ti**	
	Mean %	**SD**	**Mean %**	**SD**	**Mean %**	**SD**	**Mean %**	**SD**	**Mean %**	**SD**
Street Sweepings	1.68[a]	2.02	4.01	7.30	16.42[a]	11.38	48.28[a]	13.98	0.15	1.02
Snow Removal	1.41[ab]	2.24	3.45	6.35	11.37[b]	11.77	56.26[b]	16.77	0.14	1.10
Unpaved	1.73[a]	2.33	4.46	6.16	12.28[b]	11.45	54.10[b]	13.51	0.06	0.42
Beehive Burner	0.95[b]	1.21	2.96	5.42	15.76[a]	11.91	44.40[a]	19.77	0.43	2.71
Teflon Blank	0.38	0.22	nd	nd	9.19	2.12	10..48	3.69	nd	nd

Across rows, means superscripted with different letters are significantly different ($p<0.05$); Each source (n=100)
Confidence Intervals for EDAX (±10%); ANOVA Results in Appendix I
SD = Standard Deviation; nd = not detected

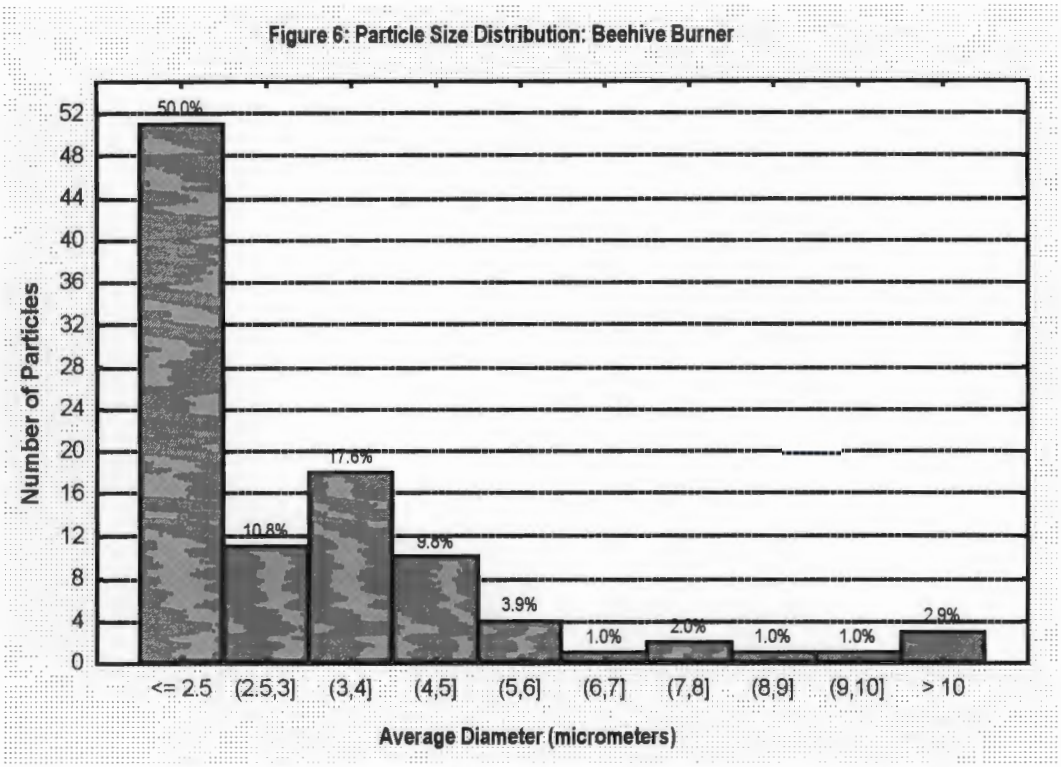
The quantity of road dust produced should be considered between the different types of road dusts. A distance of 1.6 kilometers (1mile) of travel on a paved road produced 0.0045kg (0.01 pounds) of dust while 1.6 kilometers (1 mile) of travel on an unpaved road generated 4.5kg (10 pounds) of dust (1000 times the dust) (Evans & Copper,1980).

Beehive Burner

The beehive burner sample analyzed contained three main morphological shapes: amorphous, oval, and flat (Table 4 & Appendix B). Amorphous or irregular shaped particles are often the result of combustion processes (*ie* fly ash) (Kaufherr & Lichtman,1984). The oval shape morphology identified has not been reported in the literature, however distinctive rounded or spherical shape particulates are produced by anthropogenic or combustion sources as a result of formation at high temperatures (Kaufherr & Lichtman,1984; Purghart *et al.*, 1990; Xhoffer *et al.*,1991). Spherical particles in combustion products such as fly ash indicate a complete melting of silicate materials (Fisher *et al.*,1978). The unique oval shaped particulates are most probably a result of the high temperature combustion which forms fine particulates (many are probably secondary particulates) through chemical conversions and condensation, however, this shape is not mentioned in the literature. The flat shaped morphology may either be a result of incomplete wood combustion or dust contamination, it is unclear which is responsible.

The literature indicates that 50 - 80% of total wood burning particulates are fine particulates which is consistent with the results (Figure 6) (Stevens,1985;CHU,1994). The larger particulates present in this sample may be the result of incomplete combustion or dust contamination (Dockery & Pope,1994). The mean particle size varies significantly between burners depending on conditions and type of materials being burned (Boubel,1968). One study

found a mean particle size of 3.28μm which is consistent with the results in this study (Table 5) (Boubel,1968).



The quantitative and qualitative chemical compositions of the beehive burner sample was compared to vegetative burning as there was no published information on beehive burners in the literature. All the elements in the quantitative analysis except potassium were found in higher concentrations which could be a result of higher combustion temperatures or difference in material type (Table 6). The qualitative chemical compositions were also larger for most elements (Table 7) (Chow,1995). The amount of carbon and iron were consistent with the published literature while chlorine and potassium were lower than expected (Table 7) (Chow,1995).

Pulp Mill

The literature search conducted found no published literature on either chemical or physical characteristics of pulp mill particulates. Many of the elements were concentrated in the

PM_{10} fraction of the sample including aluminum, barium, cadmium, chromium, copper, iron, magnesium, manganese, nickel, phosphorus, tin, vanadium, and zinc (Table 6). This concentration of elements seems to be consistent with the theory that trace metals tend to condense on the surfaces of fine particulates (Keyser *et al.*,1978).

Comparison of Source Samples

Morphological and Particle Size Characteristics

Examination of morphological characteristics confirm that the three types of road dust are different. The unpaved road dust sample contained more particulates with a flat morphology (47% compared to 21% in street sweepings and 35% in snow removal) which suggests a greater concentration of clay particulates in unpaved roads (Table 4). This is understandable considering the area sampled (BCR site) contains a high (60-70%) clay content (Pineview Clay) deposited while most of Prince George was under a glacial lake (Dawson,1989). The snow removal materials also contained a larger proportion of particulates with flat morphology (35% compared to 21% in street sweepings) suggesting that materials removed from the roads during the winter may have contained more clays (Table 4). Amorphous morphology was more evident in the street sweeping sample (79% compared to 61% in snow removal and 54% in unpaved road dust) suggesting that mechanical breakdown of larger materials is more important on paved city streets in the spring (Table 4).

The morphological characteristics indicate a significant difference between the beehive burner sample and the road dust samples. The appearance of the oval type accounts for 18% of the particulates from the beehive burner (Table 4). This sample also contains fewer amorphous type particulates (32%) compared to 79%, 61%, 54% in the street sweeping, snow removal, and

unpaved road dust samples respectively (Table 4). The larger percentage of flat particulates (48%) in the beehive burner compared to 21%, 35% in the road dust is possibly a result of incomplete combustion processes rather than clay particulates. However, the unpaved road dust contained a comparable amount of flat particulates suggesting that this shape would not necessarily be useful in distinguishing between road dust and beehive burner sources.

The mean particle size and particle size distribution also illustrate that the road dust samples differ. The unpaved road dust is significantly smaller compared to the street sweepings (Table 5). There is no significant difference between the street sweepings and snow removal road dusts (Table 5). The unpaved road dust appears to contain more clay particles than the other road dusts which have smaller particle size and are flat shaped. Comparison of the particle size distributions in Figures 3-5 show a 6% increase in the fine particulate (<2.5μm) in the unpaved road dust compared to the street sweepings. The less positively skewed distribution in the road dust samples illustrates the presence of the larger "amorphous" particulates formed through mechanical breakdown of larger particles (Chow,1995).

The mean particle size indicates a significant decrease between the beehive burner sample and any of the road dust samples (Table 5). This trend is illustrated in the particle size distribution (Figures 3-6) which indicate an increase of almost 20% in fine particulates in the beehive burner sample. This trend was expected due to the combustion nature of the beehive burner source.

Chemical Composition

There are significant correlation between elemental concentrations and average particle diameter (Table 8). However, it should be noted that the correlation coefficient values are indicating a very weak correlation (Mendenhall & Beaver,1991). In the street sweepings, aluminum (r=0.22) is found to increase in concentration as particle size increases and sodium (r=-

0.21) is found to decrease in concentration as particle size increases (Table 8). In the snow removal sample, carbon (r=-0.25) seemed to be found in higher concentrations in the smaller particulates (Table 8). In the beehive burner sample, there are elements which have higher concentrations in smaller particulates *ie* carbon (r=-0.28) and sodium (r=-0.44) and elements that have higher concentrations in larger particulates *ie* magnesium (r=0.56), aluminum (r=0.20) and calcium (r=0.27) (Table 8). The carbon and sodium concentration in smaller particulates may represent small "secondary" carbon particulates (Chow,1995). The magnesium, aluminum, and calcium concentration in larger particulates may be representative of dust particulates or perhaps incomplete combustion products (Chow,1995).

TABLE 8: Significant Correlation between Elemental Composition and Average Particle Diameter in PM_{10} Sources

Source	Element	R	Correlation Equation
Street Sweepings	Aluminum	0.22	Al (%)= 15.375 + 0.71473*Mean Diameter
	Sodium	-0.21	Na (%)= 20.864 - 0.9510* Mean Diameter
Snow Removal	Carbon	-0.25	C (%)= 7.5427 - 0.4630* Mean Diameter
Beehive Burners	Aluminum	0.2	Al (%)= 11.138 + 0.63456*Mean Diameter
	Calcium	0.27	Ca (%)= -0.3471 + 0.72281* Mean Diameter
	Carbon	-0.28	C (%)= 23.908 - 1.451* Mean Diameter
	Magnesium	0.56	Mg (%)= -0.2228 + 1.0175* Mean Diameter
	Sodium	-0.44	Na (%)= 21.348 - 1.766*Mean Diameter

There were significant differences between the contents of several elements in the three road dust samples (Table 6). There was significantly more manganese, phosphorus, and titanium, in the snow removal road dust than in the street sweepings (Table 6). These results suggest that these elements are most likely found in much greater concentrations in the winter sanding materials used by the city. The street sweepings did have significantly more zinc than the snow removal road dust, however, the concentrations of many other elements were consistent as was expected. The unpaved road dust had significantly more manganese and sodium than the other road dust samples suggesting that these elements are naturally present in higher concentrations in

the unpaved roads (Table 6). The literature suggests that the dominant elements composing road dust are aluminum, silicon, calcium, potassium, titanium, and iron which are also dominant in soil (See Table 1) (Chow,1995). These elements were found in the road dust samples, however, iron and titanium were not found in the quantities expected. Many researchers use aluminum and silicon as tracer elements for dust sources, however the results for silicon could not be compared due to problems with the filter type, methodology and the percentage of aluminum was not significantly different between the road dust samples and the beehive burner samples (Table 6) (Chow,1995).

The beehive burner sample contained significantly more barium, lithium, manganese, potassium, sodium, tin, and zinc and significantly less copper than any of the road dust samples (Table 6). The higher levels of potassium are consistent with other studies which often use soluble potassium as a tracer element for wood combustion sources (Table 1) (Stevens,1985; Chow,1995). The dominance of organic and elemental carbon in vegetative burning PM_{10} can be used as an indication of combustion sources such as beehive burners. However, the ICP-AES is not able to analyze for this element (Chow,1995). Compared to the road dust and beehive burner samples, the pulp mill PM_{10} samples contained significantly more cadmium, chromium, copper, magnesium, manganese, and phosphorus suggesting that these elements are concentrated in the pulp mill processes. These elements may be useful in determining the pulp mill contribution to the PM_{10}, however, the lack of information in the literature makes any comparisons impossible. The uncertainty caused by the problems with the blanks may be masking differences between the road dusts, beehive burner, and pulp mill samples and this uncertainty was considered when conclusions were drawn with this data.

The qualitative EDAX chemical composition means (±10%) showed some significant differences between the road dust samples (Table 7). The street sweepings contained significantly more carbon and sodium and significantly less silicon than the other two types of road dusts (Table 7). This could be due to addition of carbon by vehicle exhaust or deposits on the pavement and the addition of sodium by salt applied to paved roads. The beehive burner sample contained significantly more carbon and calcium and significantly less aluminum which would be expected from a combustion source (Tables 1&7) (Chow,1995). Although fewer elements were analyzed and the method was qualitative with this technique, the results were considered more reliable than the quantitative analysis. The teflon blank contributions were included in Table 7 to indicate additional possible contributions to the recognized confidence intervals of ±10%.

The results of PCA for each of the three road dust samples indicated four factors or particle types present. The first factor in the street sweepings (accounting for 22.24% of the variance) and the second factor in the snow removal sample (17.62%) showed large loadings on silicon with corresponding negative loadings on aluminum and sodium (Table 9). The high loading on silicon suggests that this factor most likely represents "Quartz" or silicon dioxide. The second factor in the street sweeping (17.59%) and the first factor in the snow removal sample (22.62%) contained large loadings on aluminum and potassium with corresponding negative loadings on sodium which are elements present in minerals called "K-Feldspars"(Table 9&10) (Brady,1996). The third factor on the street sweeping (15.35%) and the unpaved road dust (17.82%) also contained loadings on calcium and magnesium and corresponding negative loadings on sodium which are present in "Ca-Feldspars" (Table 9 &11) (Brady,1996). The fourth factor in the street sweepings (11.31%) contained loadings on calcium and chlorine which represents calcium chloride (Table 9). The third factor on the snow removal sample (15.49%) containing loadings on

calcium, carbon, and magnesium could represent either "Ca-Feldspar or Calcium Carbonate" it is unclear which, and the four factor on the snow removal (12.45%) containing high loadings on iron and titanium represents a "Clay mineral or Iron oxide"(Table 10) (Brady,1996). The first factor on the unpaved road dust (26.35%) has high loadings on calcium, iron, potassium, and titanium representing "K-Feldspars or Iron oxide" and the second factor (18.63%) with high loadings on silicon and corresponding negative loadings on carbon and sodium represents "Quartz" (Table 11) (Brady,1996). The last factor (13.22%) on the unpaved road dust contains high loadings on aluminum and potassium and corresponding negative loadings on silicon and probably represents "K-Feldspars"(Table 11) (Brady,1996).

The PCA analysis completed on the beehive burner determined three factors or three type of particulates present in the sample. The first factor (accounting for 25.77% of the variance) contained high loadings on carbon and sodium and a corresponding negative loading on silicon and represents the expected organic carbon particulate (Table 12). The second factor (18.69%) contains high loadings on calcium and magnesium and corresponding negative loadings on sodium as well as the third factor (14.57%) containing loadings on aluminum, magnesium, potassium and negative loadings on carbon could be dust contaminants and could not be interpreted (Table 12).

The factors determined using the PCA were used as examples of possible relationships between the different variables/elements which may be characteristic of specific sources. There were several relationships seen in the road dust samples that were used in the determination of factors in the episodes and non-episodes. High loadings on silicon, aluminum, magnesium, potassium, iron, titanium in various combinations were considered to be representative of road dusts. High loadings on carbon and sodium were considered to be representative of combustion sources or a beehive burner. It was recognized that further resolution of the beehive burner

sample would require more organic carbon analysis as often carbon was found negatively related to the elements representing road dust. In these instances the highest loading present in the factor was considered to be most important and the relationships of the other elements in relation to that element determined the interpretation of the factor.

TABLE 9: PCA Eigenvalues and Primary Factors: Street Sweepings

Factor	1 Quartz	2 K-Feldspar	3 Ca-Feldspar	4 $CaCl_2$
Aluminum	**-0.385746**	**-0.727238**	0.235853	0.273748
Calcium	0.02104	0.216242	**0.434242**	**-0.402602**
Carbon	-0.254511	0.066238	0.013045	-0.172094
Chlorine	-0.0179	0.021926	0.020204	**-0.794484**
Magnesium	-0.169	0.045959	**0.87634**	-0.000642
Potassium	0.178417	**-0.780345**	-0.153556	0.052515
Silicon	**0.925532**	0.095762	-0.155087	0.294976
Sodium	**-0.58962**	**0.42697**	**-0.592113**	-0.000233
Titanium	0.075129	0.319792	0.261967	0.262254
Eigenvalue	2.001901	1.58271	1.381198	1.017577
% Total Variance	22.24	17.59	15.35	11.31
Cumulative %	22.24	39.83	55.18	66.48

Numbers in bold indicate the amount and pattern of elemental loadings. Loadings of more than 0.71 (50% overlapping variance) are excellent, above 0.63 (40% overlapping variance) are very good, above 0.55 (30% overlapping variance) are good, above 0.45 (20% overlapping variance) are fair and above 0.32 (10% overlapping variance) are poor (Comrey & Lee,1992).

TABLE 10 PCA Eigenvalues and Primary Factors: Snow Removal

Factor	1 K-Feldspar	2 Quartz	3 Ca-Feldspar	4 Iron Oxide
Aluminum	**-0.560605**	**0.646837**	0.036581	0.284251
Calcium	-0.041711	-0.017216	**0.539144**	0.023874
Carbon	0.226843	0.192275	**0.584015**	-0.124624
Iron	0.00188	-0.095712	0.250099	**0.645165**
Magnesium	-0.034599	0.031329	**0.822765**	0.179537
Potassium	**-0.879112**	0.025729	-0.092366	-0.14056
Silicon	0.100726	**-0.937193**	-0.310894	-0.06923
Sodium	**0.434801**	**0.673709**	-0.299675	-0.316012
Titanium	0.05285	0.146133	-0.174331	**0.839523**
Eigenvalue	2.035569	1.585771	1.394461	1.120288
% Total Variance	22.62	17.62	15.49	12.45
Cumulative %	22.62	40.24	55.73	68.18

For explanation of numbers in bold please see Table 9

TABLE 11: PCA Eigenvalues and Primary Factors: Unpaved Road Dust

Factor	1 K-Feldspar	2 Quartz	3 Ca-Feldspar	4 K-Feldspar
Aluminum	0.135617	0.000808	-0.221656	**-0.898927**
Calcium	**-0.674218**	0.111947	**-0.452729**	0.037285
Carbon	0.048052	**0.711692**	-0.058023	0.22966
Iron	**-0.811085**	-0.134186	-0.154332	0.064016
Magnesium	-0.019441	0.11226	**-0.893256**	-0.085845
Potassium	**-0.526038**	-0.171125	0.126022	**-0.616231**
Silicon	0.047764	**-0.855528**	0.098539	**0.474723**
Sodium	0.081441	**0.599026**	**0.604642**	0.219517
Titanium	**-0.836736**	0.043886	0.212483	-0.088563
Eigenvalue	2.371355	1.676352	1.6037	1.189796
% Total Variance	26.35	18.63	17.82	13.22
Cumulative %	26.35	44.97	62.79	76.01

For explanation of numbers in bold please see Table 9

TABLE 12: PCA Eigenvalues and Primary Factors: Beehive Burner

Factor	1 Organic	2 Other	3 Other
Aluminum	-0.222555	-0.113832	**-0.822882**
Calcium	0.13134	**-0.823181**	0.264934
Carbon	**0.769954**	0.038805	**0.35759**
Iron	0.054956	0.033764	0.06981
Magnesium	0.014023	**-0.785683**	**-0.381262**
Potassium	0.008147	0.055472	**-0.824935**
Silicon	**-0.94565**	0.232724	0.076628
Sodium	**0.580893**	**0.537579**	0.08566
Titanium	-0.00064	0.008674	0.02259
Eigenvalue	2.31896	1.682383	1.311348
% Total Variance	25.77	18.69	14.57
Cumulative %	25.77	44.46	59.03

For explanation of numbers in bold please see Table 9

Characterization of Episodes and Non-Episodes in the Bowl Area

Episode 1

Amorphous particulates were found to be the dominant shape in this episode, while oval, sphere, smooth-flat, flat, rod, rectangular, and cube shaped particulates were found in much smaller numbers (Tables 13 & 14). The presence of 70% amorphous particulates suggests that road dust may be an important contributor, however many other sources can contribute to amorphous particulates population including uncontrolled combustion sources so this is not diagnostic (Dockery & Pope,1994). Comparison of morphological data between monitoring sites indicate slight differences between them (Table 13). The number of "oval" shaped particulates was slightly smaller at the Lakewood site compared to either Plaza or Van Bien suggesting that combustion sources may have had less of an impact at that site (Table 13). The absence of the "rectangular" particulate at the Plaza also suggests another source contributes to ambient levels at the other sites, however, the identity of the source of the "rectangular" particulates is unknown (Table 13).

The particle size data shows no significant difference between the different monitoring stations. The total mean particle size indicates that anthropogenic combustion sources forming fine particulates were the most important contributing sources to this episode (Table 5 & 15). This is further illustrated by the particle size distribution which indicates that over 73% of the total particulates were fine particulates (Figure 7). The particle size distribution is highly positively skewed which is consistent with other studies (Kim *et al.*,1987). As indicated in the previous discussion combustion sources such as beehive burners tend to contribute to the fine particulate fraction while road dusts can be distinguished by significant contributions to coarse particulates.

Qualitative chemical composition averages show some significant differences between the different locations analyzed, however, this data has to be considered with some caution due to the large standard deviations and confidence intervals involved. The three most important elements present in the episode were carbon, sodium, and silicon (Table 16). This suggests that road dust (silicon) and combustion sources (carbon) may be the largest contributors to the PM_{10} (Chow,1995). The Plaza location has significantly more sulphur, potassium and calcium and significantly less carbon than the Lakewood site suggesting that the Plaza location was impacted by the proximity of industrial sulphur sources (Table 16).

Table 13: Distribution of Various Morphological types in Selected Episodes

Episode	Amorphous %	Oval %	Round %	Sphere %	Flat %
1	70.00	4.89	2.67	5.22	15.11
950121 plaza	70.00	6.00	2.33	5.00	16.33
950121 vanbien	65.67	5.67	1.67	6.33	16.33
950121 lakewood	74.33	3.00	4.00	4.33	12.67
2	79.80	0.00	0.22	0.44	19.56
950328 plaza	79.33	0.00	0.00	0.33	20.33
950328 vanbien	82.00	0.00	0.33	0.00	17.67
950328 lakewood	78.00	0.00	0.33	1.00	20.67
3	81.00	0.11	0.22	0.44	18.00
960227 plaza	77.33	0.33	0.00	0.00	22.00
960227 vanbien	84.33	0.00	0.33	0.33	15.00
960227 lakewood	81.33	0.00	0.33	1.00	17.00

Episode	Smooth Flat %	Cube %	Rectangle %	Rod %
1	0.11	0.11	1.55	0.00
950121 plaza	0.00	0.00	0.00	0.00
950121 vanbien	0.00	0.00	3.33	0.00
950121 lakewood	0.33	0.33	1.33	0.00
2	0.00	0.00	0.00	0.00
950328 plaza	0.00	0.00	0.00	0.00
950328 vanbien	0.00	0.00	0.00	0.00
950328 lakewood	0.00	0.00	0.00	0.00
3	0.00	0.00	0.22	0.00
960227 plaza	0.00	0.00	0.33	0.00
960227 vanbien	0.00	0.00	0.00	0.00
960227 lakewood	0.00	0.00	0.33	0.00

Episodes (n=300); Totals (n=900)

TABLE 14: Comparison of Morphology between Episodes and Non-Episodes

	Episode 1		Episode 2		Episode 3		Total Episode		ANOVA Results
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Amorphous	210[a]	13.00	239.33[b]	6.11	243[b]	10.54	230.78	18.02	F(2,6)=9.28, p=0.014586
Oval	14.67[a]	4.93	0[b]	0.00	0.33[b]	0.58	5.00	7.67	F(2,6)=25.58, p=0.001156
Round	8.0[a]	3.61	0.67[b]	0.58	0.67[b]	0.58	3.11	4.11	F(2,6)=11.81, p=0.00832
Sphere	15.67[a]	3.06	1.33[b]	1.53	1.33[b]	1.53	6.11*	7.41	F(2,6)=44.02, p=0.00026
Flat	45.33	6.35	58.67	4.93	54.00	10.82	52.67	8.93	F(2,6)=2.27, p=0.184694
Smooth Flat	1.33	1.53	0.00	0.00	0.00	0.00	0.44	1.01	F(2,6)=2.29, p=0.182832
Cube	0.33	0.58	0.00	0.00	0.00	0.00	0.11	0.33	F(2,6)=1.0, p=0.421875
Rectangle	4.67	5.03	0.00	0.00	0.33	0.58	1.67	3.39	F(2,6)=2.38, p=0.173714
	Non-Episode 1		**Non-Episode 2**		**Non-Episode 3**		**Total Non-Episode**		**ANOVA Results**
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Amorphous	212.67[a]	3.22	262.67[b]	14.57	262.33[b]	0.58	245.89	26.01	F(2,6)=33.41, p=0.000559
Oval	11[a]	3.46	0.67[b]	0.58	1.0[b]	0.00	4.22	5.38	F(2,6)=25.16, p=0.001209
Round	9.33	5.69	1.67	1.53	2.33	1.53	4.44	4.77	F(2,6)=4.39, p=0.066972
Sphere	12.00	2.00	11.00	8.00	7.67	3.06	10.22*	4.82	F(2,6)=0.60, p=0.579120
Flat	48.67[a]	4.73	24[b]	7.00	25.67[b]	3.06	32.78	12.76	F(2,6)=21.20, p=0.001905
Rectangle	3[a]	2.00	0[b]	0.00	0[b]	0.00	1.00	1.80	F(2,6)=6.75, p=0.029131
Rod	3.33	3.06	0.00	0.00	1.00	0.00	1.44	2.19	F(2,6)=2.55, p=0.158075
E versus NE									
Amorphous									F(1,16)=2.05, p=0.171212
Oval									F(1,16)=0.062, p=0.806402
Round									F(1,16)=0.40, p=0.534195
Sphere									F(1,16)=1.95, p=0.181791
Flat									F(1,16)=14.68, p=0.00147
Smooth Flat									F(1,16)=1.73, p=0.206983
Cube									F(1,16)=1.0, p=0.332195
Rectangle									F(1,16)=0.27, p=0.609669
Rod									F(1,16)=3.93, p=0.064868

Across superscript (abc) indicates significant differences between means within Episodes and Non-Episodes
Column Superscript(* ** ***) indicates significant differences between means of Episodes and Non-Episodes
Total means for above Episodes and Non-episodes (n=300)

TABLE 15:Comparison of Particle Size by Location for Episodes/Non-Episodes

	Plaza		Van Bien		Lakewood		Total		ANOVA Results
	Mean μm	SD	Mean μm	SD	Mean μm	SD	Mean μm	SD	
Episode									
1	2.07	2.40	2.49	2.96	2.24	3.09	2.27[1]	2.83	F(2,896)=1.74, p=0.175770
2	3.98[a]	2.52	3.77[a]	2.61	3.33[b]	3.54	3.69[2]	2.93	F(2,897)=3.82, p=0.022345
3	3.32	2.47	3.27	2.26	3.02	2.88	3.21[3]	2.55	F(2,896)=1.16, p=0.313691
Mean							3.05*	2.84	F(2,2695)=61.43, p=0.00000
Non-Episode									
1	2.69	2.82	2.27	2.43	2.57	3.59	2.51[1]	2.99	F(2,896)=1.55, p=0.213163
2	2.60	2.91	2.99	2.22	2.51	2.42	2.70[1]	2.54	F(2,897)=3.03, p=0.048769
3	2.3	2.68	1.88	2.03	2.26	2.75	2.15[2]	2.51	F(2,897)=2.62, p=0.073575
Mean							2.45**	2.78	F(2,2696)=9.93, p=0.000051
E versus NE									F(1,5395)=63.99, p=0.00000

Superscript across rows and down columns (123/* **) indicate significant differences between means (p<0.05)
Plaza, Van Bien, Lakewood samples (n=299 - 300); Total Sample (n=900)

TABLE 16: Qualitative Chemical Characterization of PM10 Episodes

Episodes	Al		Ba		C		Ca		Cl	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	3.78*	3.87	0.02	0.43	33.41*	18.76	1.27	4.24	nd	nd
950121 plaza	4.34[a]	4.08	0.06	0.74	27.22[a]	17.24	1.64[a]	4.64	nd	nd
950121 vanbien	3.22[b]	4.59	nd	nd	36.45[b]	19.38	1.91[a]	5.33	nd	nd
950121 lakewood	3.79[ab]	2.60	nd	nd	36.58[b]	18.15	0.25[b]	1.58	nd	nd
2	13.29**	7.67	nd	nd	16.06**	12.78	1.05	3.39	0.03	0.29
950328 plaza	14.37[a]	8.23	nd	nd	15.72	12.61	1.22	4.53	0.08[a]	0.50
950328 vanbien	14.39[a]	6.55	nd	nd	14.43	10.03	0.72	1.61	0.01[b]	0.07
950328 lakewood	11.10[b]	7.69	nd	nd	18.03	14.99	1.22	3.36	nd[b]	nd
3	12.44***	7.68	0.01	0.19	14.88**	12.43	1.31	4.34	0.03	0.59
960227 plaza	12.53	7.24	nd	nd	15.57	13.96	2.22[a]	6.56	0.06	0.99
960227 vanbien	12.68	7.08	nd	nd	15.05	11.19	0.98[b]	2.55	0.01	0.15
960227 lakewood	12.10	8.63	0.02	0.34	14.03	11.95	0.74[b]	2.38	0.01	0.15

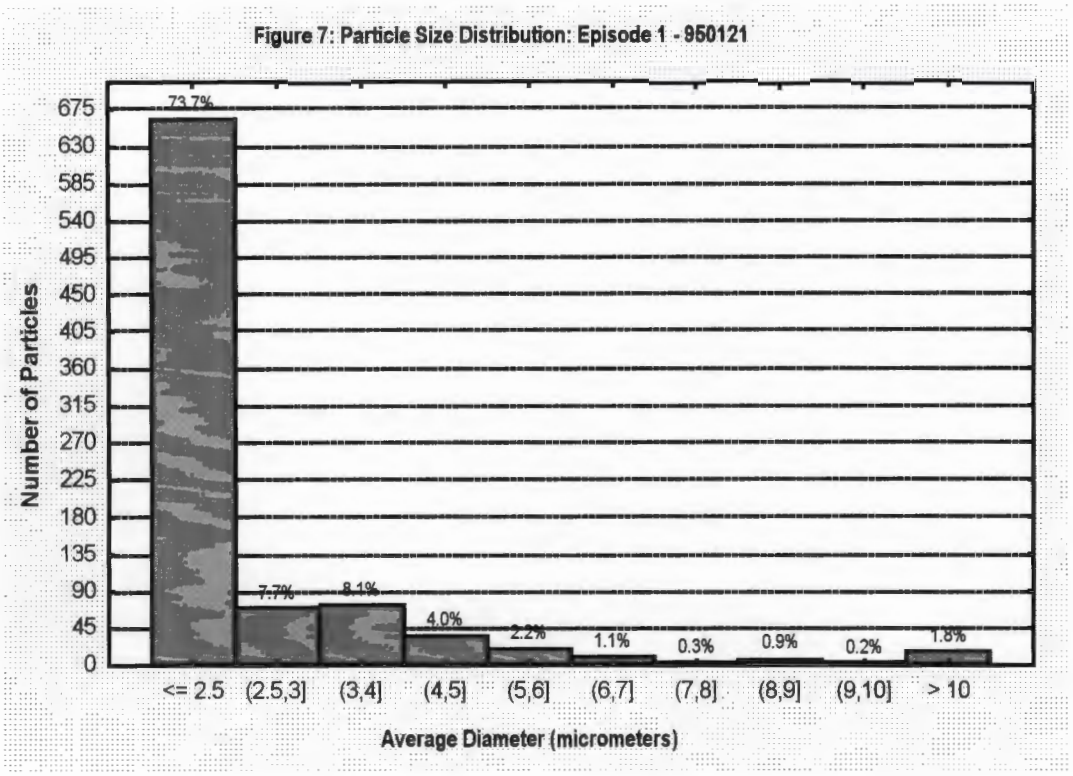
Superscript down columns (abc)/(* ** ***) indicate significant differences between means (p<0.05); Confidence Intervals (±10%); nd = not detected

TABLE 16: Qualitative Chemical Characterization of PM10 Episodes cont.

Episodes	Cu		Fe		K		Mg		Mn	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	0.48	1.44	0.25	2.07	2.24*	2.65	0.11*	0.99	nd*	nd
950121 plaza	nd	nd	0.43	2.76	2.32[a]	2.35	0.18	1.23	nd	nd
950121 vanbien	0.14	2.49	0.22	2.14	2.65[a]	3.33	0.06	0.59	nd	nd
950121 lakewood	nd	nd	0.09	0.80	1.74[b]	2.01	0.10	1.03	nd	nd
2	nd	nd	0.16	1.24	1.42**	1.50	2.99**	4.95	nd*	nd
950328 plaza	nd	nd	0.19[a]	0.98	1.48	1.58	3.10[a]	5.22	nd	nd
950328 vanbien	nd	nd	nd[a]	nd	1.35	1.43	3.56[a]	5.16	nd	nd
950328 lakewood	nd	nd	0.29[ab]	1.90	1.44	1.50	2.31[b]	4.38	nd	nd
3	nd	nd	0.19	1.28	1.41**	1.40	3.53***	6.04	0.01**	0.17
960227 plaza	nd	nd	0.11	0.85	1.42	1.34	3.89	6.52	nd	nd
960227 vanbien	nd	nd	0.17	1.15	1.37	1.30	3.64	5.84	0.01	0.19
960227 lakewood	nd	nd	0.29	1.69	1.45	1.55	3.04	5.71	0.02	0.22

Episodes	Na		P		S		Si		Ti	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	29.56*	8.77	nd	nd	4.64*	10.02	24.64*	12.98	0.05	0.80
950121 plaza	30.53[a]	8.91	nd	nd	6.28[a]	10.12	26.88[a]	13.32	0.14[a]	1.39
950121 vanbien	27.96[b]	8.95	nd	nd	5.44[a]	12.22	21.94[b]	12.83	nd[b]	nd
950121 lakewood	30.17[a]	8.23	nd	nd	2.18[b]	6.41	25.10[a]	12.34	nd[b]	nd
2	21.92**	10.65	0.06	1.40	0.76**	3.75	42.24**	15.36	0.02	0.26
950328 plaza	20.92[a]	10.64	0.19	2.43	0.61[a]	4.02	42.09[a]	14.41	0.03	0.30
950328 vanbien	20.29[a]	9.32	nd	nd	0.38[a]	1.73	44.87[b]	14.25	0.02	0.24
950328 lakewood	24.55[b]	11.41	nd	nd	1.29[b]	4.76	39.75[a]	16.90	0.02	0.25
3	22.94***	11.01	0.04	0.67	0.88**	2.82	42.28**	14.96	0.06	0.72
960227 plaza	22.73	10.92	0.07	1.00	1.31[a]	3.16	40.03[a]	13.52	0.06	0.87
960227 vanbien	23.59	10.28	0.03	0.57	1.00[a]	2.93	41.42[a]	13.42	0.04	0.34
960227 lakewood	22.50	11.80	nd	nd	0.33[b]	2.19	45.40[b]	17.15	0.08	0.83

Superscript down columns (abc)/(* ** ***) indicate significant differences between means ($p<0.05$); Confidence Intervals (±10%); nd = not detected
ANOVA results for Table 16 in Appendix I



The PCA analysis determined four factors (or PM_{10} sources) which accounted for 61.19% of the total variance in the sample (Table 17). The first factor (accounting for 24.57% of the total variance) contained extremely high loadings of calcium, potassium, and sulphur and a corresponding negative correlation to carbon (Table 17). This is clearly an indicator for an industrial factor due to the presence of sulphur and the fact that it is the largest factor is consistent with the much smaller mean particle size results. A study by Chow *et al.*(1992) found that sources of sulphur dioxide were just as important to ambient PM_{10} as sources of primary materials such as dusts. The three Pulp mills and Husky oil refinery produce 94% of the sulphur dioxide emissions in the Prince George Airshed (PGATMC,1996). These sources most probably account for this factor. The second factor (17.47%) contains high loadings of silicon, aluminum, and sodium and a corresponding negative correlation to carbon (Table 17). This is a road dust factor probably indicating "Na-Feldspars". The third (10.01%) and fourth (9.14%) factors also represented "Iron

and Magnesium oxides" in road dust (Table 17). A PCA was performed on each location and the results were similar to those found above (Appendix G). The only difference of interest was that the Lakewood site was impacted more by road dust than by the industrial source.

TABLE 17: PCA Eigenvalues and Primary Factors: Episode 1- 950121

Factor	1 Industrial Sulphur Source	2 Road Dust Na-Feldspars	3 Road Dust Iron Oxide	4 Road Dust Mg Oxide
Aluminum	0.195519	**0.670223**	**0.332950**	0.067686
Barium	-0.036382	0.009692	0.114253	-0.052970
Calcium	**-0.870979**	-0.192732	0.133028	-0.020303
Carbon	**0.511455**	**-0.835988**	-0.086391	-0.071784
Copper	0.170480	-0.008943	-0.137072	**0.717078**
Iron	0.065998	0.026635	**0.612403**	-0.011859
Magnesium	-0.036698	0.022679	0.074969	**0.753564**
Potassium	**-0.845694**	0.025150	-0.112908	-0.028499
Silicon	0.226530	**0.823898**	-0.006699	-0.097429
Sodium	0.210878	**0.604545**	-0.275128	0.014745
Sulphur	**-0.928687**	-0.219404	0.076706	0.057721
Titanium	-0.020109	-0.033728	**0.749117**	0.096757
Eigenvalue	2.948397	2.096229	1.201292	1.096906
% Total Variance	24.57	17.47	10.01	9.14
Cumulative %	24.57	42.04	52.05	61.19

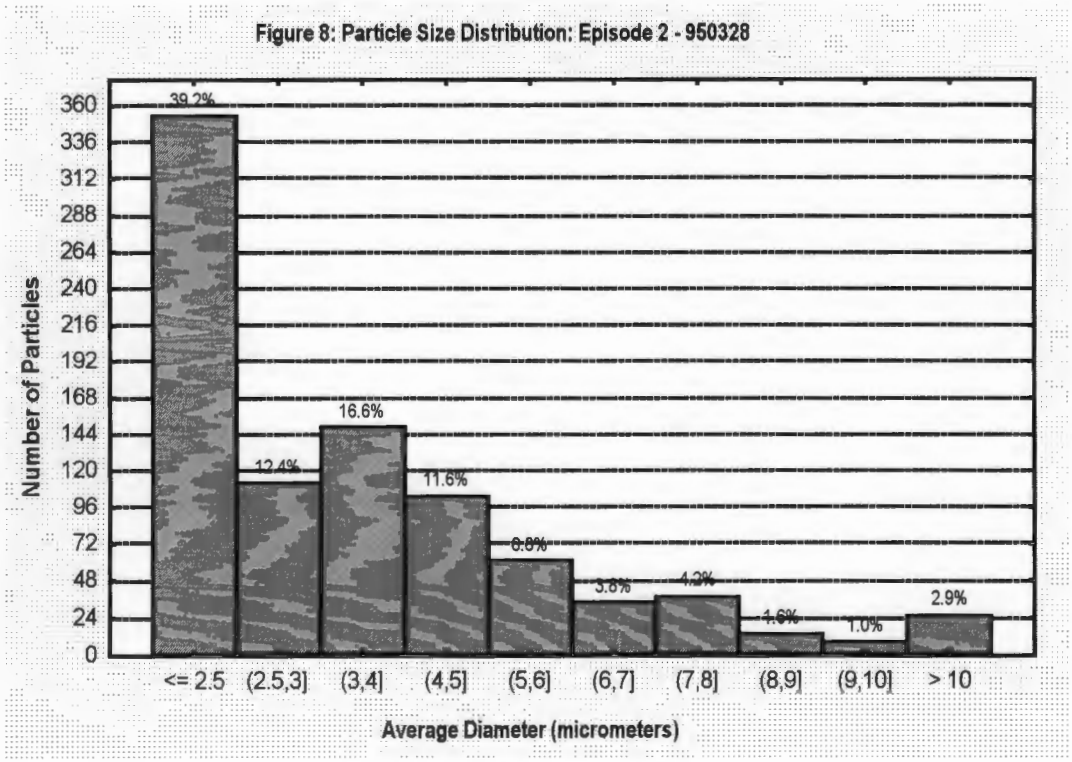
For explanation of numbers in bold please see Table 9

Episode 2

Amorphous particulates were found to be the dominant shape in this episode, while sphere, flat, and round shaped particulates were found in much smaller numbers (Table 13 & 14). The presence of amorphous and flat particulates suggest that road dust may be an important contributor to the episode. The morphological data showed little difference between the monitoring sites suggesting that each site was equally affected by the main sources (Table 13). The particle size data shows a significant difference between the locations. The Lakewood location had a significantly smaller mean particle size compared to the Plaza and Van Bien sites (Table 15). This suggests that sources contributing larger particle sizes (likely road dust) are more important at the Plaza and Van Bien locations. This also corresponds to the amount of PM_{10}

being sampled as the Van Bien location had twice the amount of PM_{10} of the Lakewood location. The particle size distribution illustrates a noticeable peak at the 3-4 μm range which suggests that the source contributing quite substantially to this episode is road dust (Figure 8). This positively skewed / bimodal distribution is consistent with other studies and is seen in most of episodes examined in this study (Kim *et al.*,1987).

The qualitative chemical composition averages indicate some significant differences between the locations. The four most significant elements present in this episode were aluminum, carbon, sodium, and silicon (Table 16). This suggests that road dust (silicon, aluminum) and combustion sources (carbon) may be the largest contributors to the PM_{10} (Chow,1995). The Lakewood location had significantly less silicon, aluminum, and magnesium and significantly more sulphur and sodium than either Plaza or Van Bien locations (Table 16). This suggests that



industrial sources were impacting this location and the road dust source (characterized often by silicon, aluminum, and magnesium) was not as important.

The PCA determined five factors which accounted for 62.87% of the total variance (Table 18). The first factor (17.91%) contained high loadings on aluminum and potassium and corresponding negative loadings on carbon and represents the road dust source "K-Feldspar" (Table 18). The second factor (14.85%) which has high loadings on calcium and sulphur and a low loading on phosphorus represents an industrial source which has been discussed previously (Table 18). Factor three (11.95%) had extremely high loadings on silicon and smaller negative loadings on carbon, chlorine, and sodium represents road dust "Quartz" (Table 18). The fourth factor (9.58%) with loadings on magnesium and sodium also represents road dust "Magnesium Oxide" (Table 18). It is unclear what the fifth factor represents in this case. A PCA was performed on each location and the results were similar to those found above (Appendix G). The only difference of interest was that the first factor at Lakewood site was industrial opposed to road dust at the other sites

TABLE 18: PCA Eigenvalues and Primary Factors: Episode 2- 950328

Factor	1 Road Dust K-Feldspar	2 Industrial Sulphur Source	3 Road Dust Quartz	4 Road Dust Mg Oxide	5 Other
Aluminum	**-0.823241**	0.080392	-0.031509	0.313102	0.007178
Calcium	0.041241	**-0.914956**	0.007017	0.042907	-0.177648
Carbon	**0.546088**	0.112625	**0.644555**	0.152618	-0.033988
Chlorine	0.022124	0.018748	**0.3398**	-0.060019	0.031853
Iron	0.040154	0.148446	0.074004	0.291549	**-0.444053**
Magnesium	-0.219916	0.008475	0.103446	**0.762741**	0.020051
Phosphorus	0.080184	**-0.3407**	-0.063028	0.048348	**-0.669094**
Potassium	**-0.736094**	0.028645	-0.015791	-0.005744	-0.00213
Silicon	0.072865	0.23911	**-0.940982**	-0.087712	0.072411
Sodium	-0.003123	0.075792	**0.521777**	**-0.686618**	0.042447
Sulphur	0.028815	**-0.851322**	0.076107	-0.028283	0.173114
Titanium	0.113245	-0.137628	0.024038	**0.326628**	**0.576403**
Eigenvalue	2.149674	1.781623	1.43425	1.149502	1.029822
% Total Variance	17.91	14.85	11.95	9.58	8.58
Cumulative %	17.91	32.76	44.71	54.29	62.87

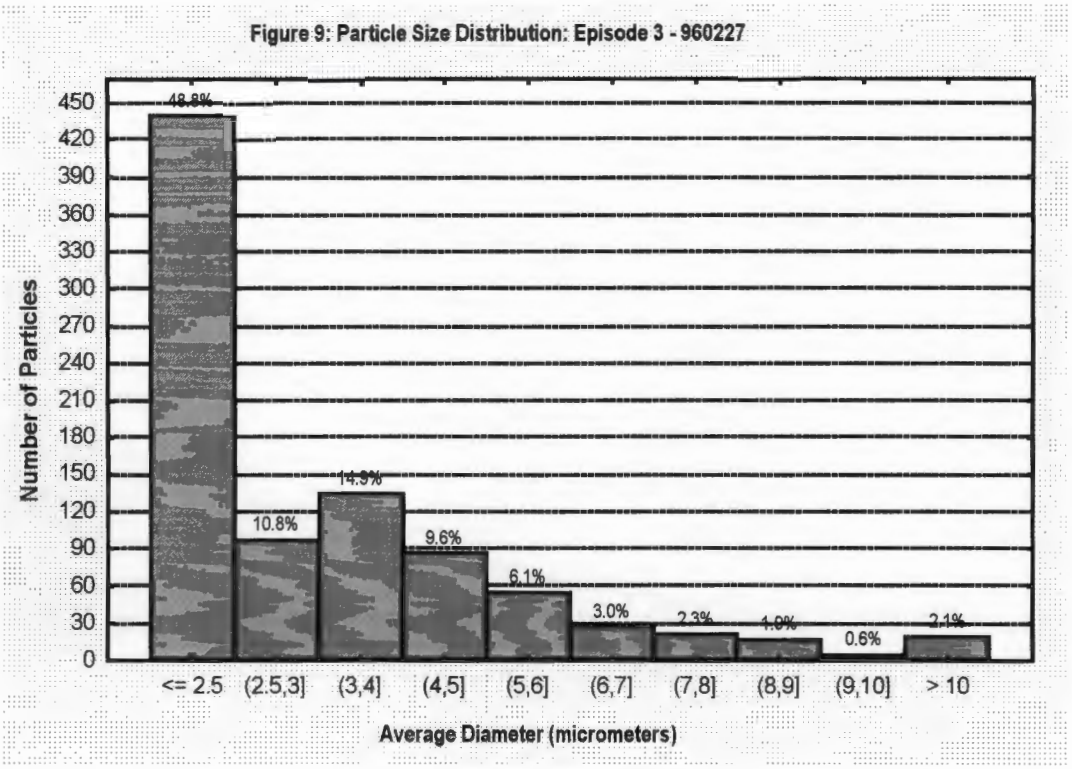
For explanation of numbers in bold please see Table 9

suggesting that this location was affected differently during this episodes, which is consistent with the lower levels of PM_{10} present at this site compared to the other sites.

Episode 3

Amorphous particulates were found to be the dominant shape in this episode, while oval, sphere, flat, round, rectangular shaped particulates were found in much smaller numbers (Tables 13 & 14). The presence of amorphous and flat particulates suggest that road dust may be an important contributor to the episode. The morphological data between monitoring sites showed little difference (Table 14). The particle size data shows no significant difference between the locations (Table 15). The Lakewood location in this case is not exceeding the ambient objective A of $50\mu g/m^3$ in this episode suggesting that sources affecting the other two locations enough to cause an episode do not influence this site as severely. The particle size distributions show a distinct peak at the 3-4μm range which is indicative of road dust being an important source for this episode (Figure 9).

The qualitative chemical composition averages indicate two significant differences between the locations. The four most significant elements present in this episode were aluminum, carbon, sodium, and silicon (Table 16). This suggests that road dust (silicon, aluminum) and combustion sources (carbon) may be the largest contributors to the PM_{10} (Chow,1995).The EDAX chemical composition averages indicate that the Lakewood location contained significantly more silicon and significantly less sulphur than the other sites suggesting that this site was influenced more by road dust than industrial sources (Table 16).



The PCA determined six important factors which accounted for 58.24% of the total variance (Table 19). The first factor (15.09%) has high loadings on sodium and chlorine and a negative loading on magnesium and represents Salt (Table 19). The source of salt could be either industrial or from winter salting activities. The second (10.98%) and third (8.66%) factors are the road dust factors representing "Quartz and K-Feldspar" seen before (Table 19). The fourth factor (8.43%) has high loadings on sulphur and calcium, which as discussed previously probably represents an industrial source (Table 19). It is unclear what the last two factors represent. A PCA was performed on each location and some differences were found at the Plaza location (Appendix G). The Plaza location had a significant combustion factor which wasn't found at either of the other sites.

TABLE 19: PCA Eigenvalues and Primary Factors: Episode 3 - 960227

Factor	1 Salt NaCl	2 Road Dust Quartz	3 Road Dust K-Feldspar	4 Industrial Sulphur Source	5 Other	6 Other
Aluminum	0.217995	0.129919	**-0.785749**	-0.139364	-0.047751	-0.134528
Barium	-0.044995	0.146662	0.084694	**0.63205**	0.118454	0.052751
Calcium	0.30532	-0.120629	0.068794	**0.511571**	**-0.364646**	0.005616
Carbon	0.032191	**-0.794867**	**0.373464**	-0.105339	0.077232	0.096476
Chlorine	**-0.585407**	0.108511	-0.065534	0.043865	-0.299382	**-0.362146**
Iron	-0.058613	0.020914	0.04094	0.013198	-0.003864	**-0.454904**
Magnesium	**0.522589**	-0.088305	-0.190018	0.093802	-0.182595	**-0.485628**
Manganese	0.05065	-0.085596	0.044893	-0.05836	0.184535	**-0.601021**
Phosphorus	0.040753	-0.16102	0.001169	-0.088146	**-0.597112**	0.249276
Potassium	-0.047558	0.016404	**-0.781684**	0.033652	0.139413	0.226054
Silicon	0.185196	**0.902381**	0.126647	-0.196475	0.118116	0.185649
Sodium	**-0.790422**	-0.285655	0.135523	0.023005	0.088916	0.050268
Sulphur	-0.048946	-0.178194	-0.047045	**0.762513**	0.049253	-0.052999
Titanium	-0.029005	0.093974	0.056353	-0.01692	**-0.643683**	-0.052381
Eigenvalue	2.112819	1.537874	1.212316	1.180689	1.058253	1.052121
% Total Variance	15.09	10.98	8.66	8.43	7.56	7.52
Cumulative %	15.09	26.08	34.74	43.17	50.73	58.24

For explanation of numbers in bold please see Table 9

Comparison of Episodes

The three episodes show considerable differences in chemical composition, morphology, and particle size. Episode 1 contained significantly less amorphous particulates and significantly more oval, round, and spherical particulates (Table 14). Episode 1 had a much larger industrial/combustion component as represented by the more "rounded"-featured morphologies. Mean particle size and particle size distributions illustrated that road dust strongly influenced Episode 2 and to a lesser extent Episode 3 (Table 15;Figures 7-9) .There is a recognizable peak at the 3-4μm range indicating the influence of road dust on the ambient air (Figures 7&8). The significantly smaller mean particle size and large percentage of fine particulates in Episode 1 are consistent with the influence of the industrial / combustion component (Table 15). The difference between the episodes is well illustrated by comparing the fine particulate fraction in Episode 1 (74%) compared to Episode 2 (39%) and Episode 3 (49%). The presence of a large proportion of

fine particles has important health considerations because they are more likely to be deposited deeply in the lungs and are believed to remain in the lungs for long periods of time (Dockery & Pope,1994; Vedal,1996). Episodes 2 and 3 contained significantly larger mean particle sizes which is consistent with the impact of road dust (confirmed by the particle size distributions and PCA) (Table 15).

The qualitative chemical composition also indicates significant differences between the episodes which are consistent with the observation that Episode 1 was impacted by industrial / combustion sources while episodes 2 and 3 were impacted more by road dust. Episode 1 had significantly less aluminum, magnesium, silicon (large components in road dusts) and significantly more carbon, potassium, sodium, and sulphur (large components in combustion/industrial sources) (Table 16).

The PCA performed on the three episodes also confirm the differences in source contribution to the three episodes.

Non-Episode 1

Amorphous particulates were found to be the dominant shape in this Non-Episode, while oval, round, sphere, flat, rod, and rectangular shaped particulates were found in much smaller numbers (Table 14 & 20). The presence of 70% amorphous particulates suggests that road dust may be an important contributor, however many other sources can contribute amorphous particulates including uncontrolled combustion sources so this is not diagnostic (Dockery & Pope,1994). The morphological data between locations show a few differences. The Plaza station had less "round" , more "flat", and no "rod" shaped particulates (Table 14). It could be an indication of more clay (road dust) particulates at the Plaza location. The Lakewood station had

fewer "oval" particulates suggesting that combustion sources may not be as important at this site (Table 14).

TABLE 20: Distribution of Various Morphological types in Selected Non-Episodes

Non-Episode	Amorphous %	Oval %	Round %	Sphere %	Flat %
1	70.92	3.66	3.11	3.99	16.21
960122 plaza	71.67	4.33	1.00	4.00	18.00
960122 vanbien	71.33	4.33	3.67	3.33	15.00
960122 lakewood	69.77	2.33	4.65	4.65	15.62
2	87.56	0.22	0.56	3.67	8.00
960304 plaza	82.00	0.00	1.00	6.33	10.67
960304 vanbien	91.00	0.33	0.67	1.00	7.00
960304 lakewood	89.67	0.33	0.00	3.67	6.33
3	87.44	0.33	0.78	2.56	8.56
960509 plaza	87.67	0.33	1.33	1.67	8.33
960509 vanbien	87.33	0.33	0.33	2.33	9.67
960509 lakewood	87.33	0.33	0.67	3.67	7.67

Non-Episode	Smooth Flat %	Cube %	Rectangle %	Rod %
1	0.00	0.00	1.00	1.11
960122 plaza	0.00	0.00	1.00	0.00
960122 vanbien	0.00	0.00	0.33	2.00
960122 lakewood	0.00	0.00	1.66	1.33
2	0.00	0.00	0.00	0.00
960304 plaza	0.00	0.00	0.00	0.00
960304 vanbien	0.00	0.00	0.00	0.00
960304 lakewood	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.33
960509 plaza	0.00	0.00	0.00	0.67
960509 vanbien	0.00	0.00	0.00	0.00
960509 lakewood	0.00	0.00	0.00	0.33

Non-Episode (n=300), Totals (n=900)

The particle size data shows no significant differences between the locations (Table 15). The particle size distribution shows a substantial amount (70%) of the total particulate in the fine fraction suggesting that anthropogenic sources such as combustion are important contributors (Figure 10).

The qualitative chemical composition averages indicate some significant differences between the locations. The four most significant elements present in this Non-Episode were carbon, sodium, sulphur and silicon (Table 21). This suggests that both road dust (silicon) and combustion/industrial sources (carbon, sulphur) were significant contributors to the PM_{10} (Chow,1995). The Van Bien location had significantly less calcium and sulphur than the other sites suggesting that perhaps the industrial source is not as important at this site (Table 21).

The PCA determined five important factors which accounted for 71.48% of the total variance (Table 22). The first factor (21.72%) represents an industrial source (seen previously) (Table 22). The second factor (16.82%) is considered a road dust "Mica or Feldspar" source despite the very low loading on sulphur which was not considered important (Table 22). The third factor (11.81%) has high loadings on carbon and negative loadings on sodium and represents an

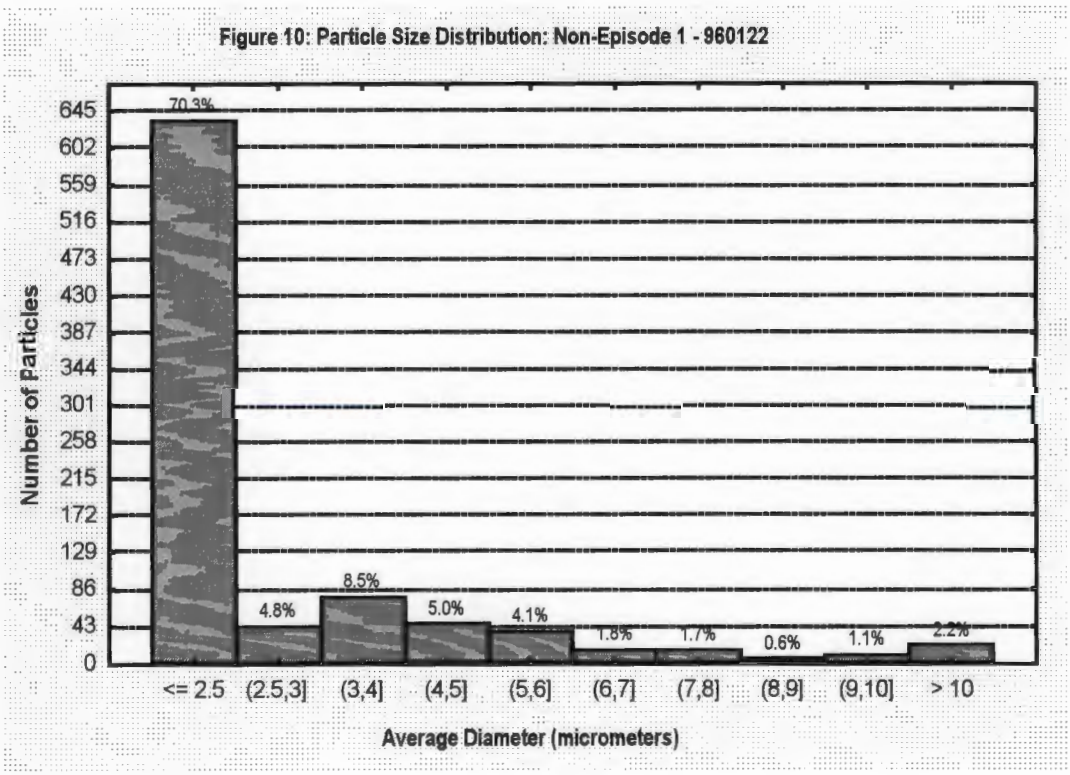


TABLE 21: Qualitative Chemical Characterization of PM10 Non-Episodes

Non-Episodes	Al		Ba		C		Ca	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	4.37*	5.65	nd	nd	26.86*	17.15	1.49*	3.47
960122 plaza	5.08	8.12	nd	nd	27.55	17.02	1.80[a]	4.01
960122 vanbien	4.11	4.06	nd	nd	26.92	18.09	0.92[b]	2.67
960122 lakewood	3.92	3.61	nd	nd	26.11	16.32	1.74[a]	3.55
2	10.37**	7.92	0.01	0.26	13.11**	12.16	0.86**	3.15
960304 plaza	8.08[a]	5.33	nd	nd	14.02	13.49	1.30[a]	4.40
960304 vanbien	12.39[b]	8.86	0.03	0.45	12.38	11.39	1.02[a]	3.01
960304 lakewood	10.64[c]	8.49	nd	nd	12.92	11.46	0.25[b]	0.88
3	8.94***	7.08	nd	nd	14.66***	13.45	1.11**	5.16
960509 plaza	8.91	7.29	nd	nd	16.28[a]	15.50	1.56	6.27
960509 vanbien	8.74	7.03	nd	nd	14.35[ab]	11.78	0.76	3.20
960509 lakewood	9.17	6.92	nd	nd	13.35[a]	12.67	1.02	5.51

Non-Episodes	Cl		Cr		Cu		Fe	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	nd*	nd	nd	nd	nd	nd	0.10	1.24
960122 plaza	nd	nd	nd	nd	nd	nd	0.03[a]	0.58
960122 vanbien	nd	nd	nd	nd	nd	nd	0.02[a]	0.28
960122 lakewood	nd	nd	nd	nd	nd	nd	0.24[b]	2.05
2	0.11**	0.83	0.01	0.33	0.04	1.16	0.17	1.48
960304 plaza	0.14[ab]	1.12	nd	nd	nd	nd	0.09	0.62
960304 vanbien	0.02[a]	0.27	nd	nd	nd	nd	0.25	2.26
960304 lakewood	0.17[b]	0.84	0.03	0.58	0.12	2.01	0.15	1.03
3	nd*	nd	nd	nd	nd	nd	0.17	2.03
960509 plaza	nd	nd	nd	nd	nd	nd	0.27	3.13
960509 vanbien	nd	nd	nd	nd	nd	nd	0.15	1.30
960509 lakewood	nd	nd	nd	nd	nd	nd	0.11	0.93

Superscript down columns (abc)/(* ** ***) indicate significant differences between means ($p<0.05$); Confidence Intervals (±10%); nd = not detected; ANOVA results for Table 21 in Appendix I

TABLE 21: Qualitative Chemical Characterization of PM10 Non-Episodes cont.

Non-Episodes	K		Mg		Mn		Na	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	1.74*	1.66	0.65*	3.22	0.001	0.03	31.19	11.51
960122 plaza	1.54[a]	1.52	0.60	2.21	nd	nd	29.77	10.73
960122 vanbien	1.77[ab]	1.73	0.67	3.82	0.003	0.05	32.66	12.56
960122 lakewood	1.90[b]	1.72	0.70	3.42	nd	nd	31.16	11.00
2	1.55**	1.73	2.91**	6.48	nd	nd	29.01	14.03
960304 plaza	1.76[a]	1.85	1.99[a]	4.36	nd	nd	33.91[a]	11.47
960304 vanbien	1.57[ab]	1.72	3.71[b]	7.75	nd	nd	25.64[b]	14.41
960304 lakewood	1.32[b]	1.59	3.04[b]	6.76	nd	nd	27.48[b]	14.66
3	1.76*	1.46	1.53***	4.55	nd	nd	29.85	11.73
960509 plaza	1.81	1.46	1.79	4.84	nd	nd	28.96	12.62
960509 vanbien	1.70	1.48	1.26	4.16	nd	nd	30.18	11.66
960509 lakewood	1.76	1.45	1.56	4.61	nd	nd	30.41	10.81

Non-Episodes	P		S		Si		Ti	
	Mean %	SD	Mean %	SD	Mean %	SD	Mean %	SD
1	nd	nd	6.37*	11.09	27.00*	13.19	0.003	0.08
960122 plaza	nd	nd	6.69[a]	11.56	26.94	12.82	nd	nd
960122 vanbien	nd	nd	4.25[b]	9.64	28.35	13.53	nd	nd
960122 lakewood	nd	nd	8.18[a]	11.63	25.71	13.13	0.01	0.14
2	nd	nd	0.83**	2.77	41.00**	16.02	0.02	0.30
960304 plaza	nd	nd	1.82[a]	3.84	36.86[a]	12.88	0.03	0.40
960304 vanbien	nd	nd	0.43[b]	2.12	42.54[b]	17.11	0.02	0.25
960304 lakewood	nd	nd	0.25[b]	1.53	43.61[b]	16.94	0.02	0.21
3	0.02	0.44	1.27**	4.34	40.51**	12.53	0.04	0.59
960509 plaza	nd	nd	1.75[a]	4.46	38.34[a]	13.80	0.05	0.87
960509 vanbien	nd	nd	1.52[a]	5.35	41.30[b]	11.97	0.05	0.48
960509 lakewood	0.04	0.76	0.54[b]	2.68	41.89[b]	11.44	0.02	0.24

Superscript down columns (abc)/(* ** ***) indicate significant differences between means ($p<0.05$); Confidence Intervals (±10%); nd = not detected; ANOVA Results for Table 21 in Appendix I

organic/combustion source (Table 22). It is unclear what the fourth factor represents; however, the fifth factor (9.74%) represents road dust "Iron oxide" (Table 22). A PCA was performed on each location and these results were similar to those above (Appendix G).

TABLE 22: PCA Eigenvalues and Primary Factors: Non-Episode 1 - 960122

Factor	1 Industrial Sulphur Source	2 Road Dust Mica or Feldspar	3 Combustion	4 Other	5 Road Dust Iron oxide
Aluminum	-0.082603	**-0.731939**	0.185347	-0.112057	-0.192337
Calcium	**0.823817**	0.239079	0.068284	-0.00024	-0.061116
Carbon	**-0.511879**	**0.535083**	**0.613017**	0.182375	0.074749
Iron	-0.030758	0.029482	-0.04035	-0.01939	**-0.831406**
Magnesium	0.105447	0.047085	0.07135	**-0.824367**	-0.003701
Manganese	-0.071328	-0.037361	-0.02355	**-0.698072**	0.071341
Potassium	**0.732949**	-0.279021	0.081481	0.165646	0.09405
Silicon	-0.128613	**-0.866575**	-0.122703	0.132209	0.148229
Sodium	-0.201671	0.113541	**-0.945421**	0.093395	0.025557
Sulphur	**0.806972**	**0.399058**	0.006405	-0.256343	-0.114334
Titanium	0.052121	-0.042583	0.033356	0.067261	**-0.5478**
Eigenvalue	2.389593	1.850272	1.298811	1.251996	1.071776
% Total Variance	21.72	16.82	11.81	11.38	9.74
Cumulative %	21.72	38.54	50.35	61.73	71.48

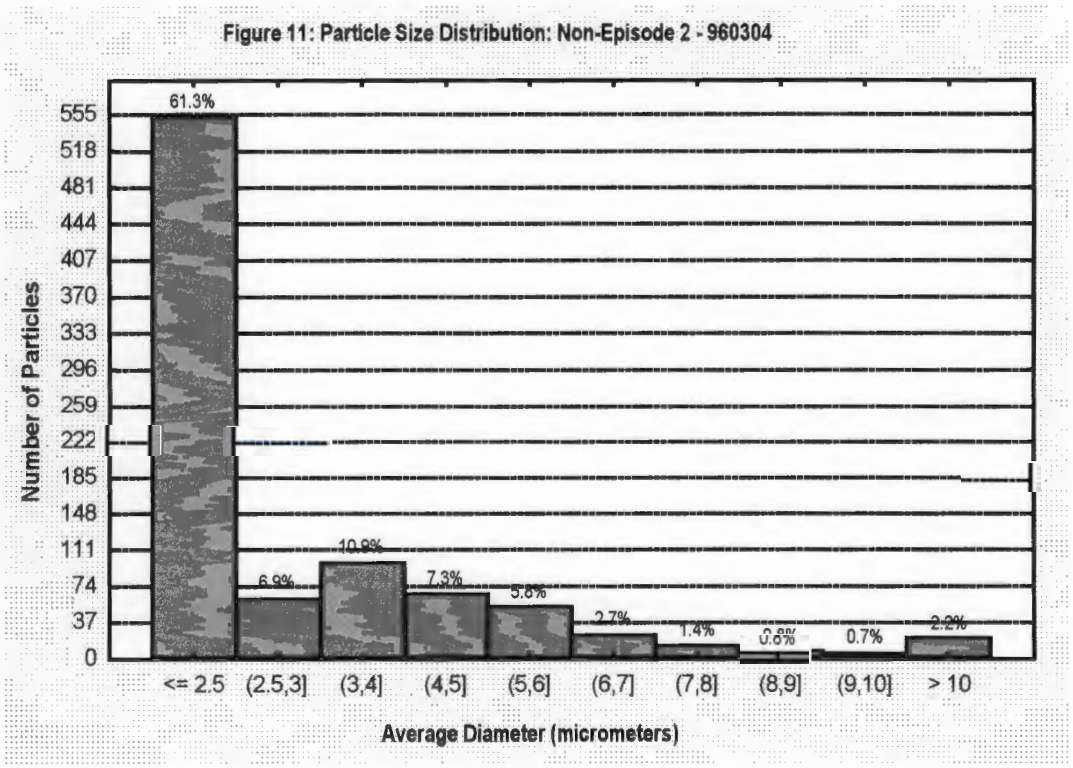
For explanation of numbers in bold please see Table 9

Non-Episode 2

Amorphous particulates were found to be the dominant shape in this episode, while oval, round, sphere, and flat shaped particulates were found in much smaller numbers (Table 14 & 20). The presence of 87% amorphous particulates suggests that road dust may be an important contributor, however many other sources can contribute amorphous particulates including uncontrolled combustion sources so this is not diagnostic of a particular source (Dockery & Pope,1994). The morphological data between the locations indicated some differences between location. The Van Bien location had fewer "sphere" shaped particulates suggesting combustion may have been less important at this site while the Plaza location contained more flat particulates suggesting that road dust may have had a greater influence on this site (Table 14).

The mean particle size shows no significant difference between the locations (Table 15). The particle size distribution illustrates a small peak at the 3-4μm range which is indicative of road dust, however, dominance of fine particulates (<2.5μm) accounting for 61% of the total particulates indicates that other anthropogenic sources are more important (Figure 11).

The qualitative chemical composition showed that the four most abundant elements were aluminum, carbon, sodium, and silicon (Table 21). This suggests that road dust (silicon, aluminum) and combustion sources (carbon) may be the largest contributors to the PM_{10} (Chow,1995). The Plaza site had significantly more sodium and sulphur and significantly less aluminum, magnesium, and silicon suggesting it was more highly influenced by industrial sources rather than by road dust (Table 21).



The PCA determined six important factors which accounted for 60.53% of the total variance (Table 23). The first factor (15.75%) was a combustion source indicative of the large

carbon loading and negative silicon and aluminum loadings (Table 23). Factors 2 "Feldspar"(11.16%), 4 "Iron oxide"(8.23%), and 6 "Ca-Feldspar"(7.54%) represented road dust (Table 23). Factor 3 (10.17%) represents an industrial source and factor 5 (7.67%) was salt (Table 23). A PCA was performed at each location which indicated some differences in the importance of sources (Appendix G). As expected the Van Bien location was influenced greater by road dust source (which was consistent with the mean particulate size) and contained no combustion factor (Appendix G). The Lakewood location was influenced by a salt factor and road dust source far more than either combustion and industrial sources (Appendix G).

TABLE 23: PCA Eigenvalues and Primary Factors: Non-Episode 2 - 960304

Factor	1 Combustion	2 Road Dust Feldspar	3 Industrial Sulphur Source	4 Road Dust Iron oxide	5 Salt NaCl	6 Road Dust Ca-Feldspar
Aluminum	**-0.339675**	**-0.655003**	0.183092	0.016479	-0.251503	0.036213
Barium	0.017783	0.114206	0.067545	**-0.769963**	0.019492	0.048118
Calcium	0.179929	-0.045304	0.100452	0.102127	0.046704	**-0.725378**
Carbon	**0.836986**	0.151004	-0.313336	0.057033	-0.223798	0.036552
Chromium	0.156996	**-0.645835**	0.019088	-0.063849	0.089968	0.25451
Chlorine	-0.059182	-0.066785	-0.078649	0.082704	**0.81367**	-0.087542
Copper	0.038461	0.02561	-0.088047	0.029826	-0.014465	-0.009782
Iron	0.007863	-0.181695	0.06226	**-0.682213**	-0.050109	-0.112962
Magnesium	0.006194	**-0.627457**	-0.107274	-0.047001	0.028114	**-0.503023**
Potassium	-0.070466	-0.048594	**0.811913**	0.103153	-0.234671	0.047254
Silicon	**-0.816336**	0.153844	-0.206241	0.10411	**-0.34481**	0.109922
Sodium	0.318645	**0.37007**	0.209965	-0.117216	**0.655536**	0.276704
Sulphur	0.217014	0.152032	**0.697756**	0.044586	0.18395	-0.220325
Titanium	-0.098619	0.138095	-0.00871	-0.141978	-0.037479	-0.5049
Eigenvalue	2.205583	1.562109	1.424358	1.152662	1.073641	1.055448
% Total Variance	15.75	11.16	10.17	8.23	7.67	7.54
Cumulative %	15.75	26.91	37.09	45.32	52.99	60.53

For explanation of numbers in bold please see Table 9

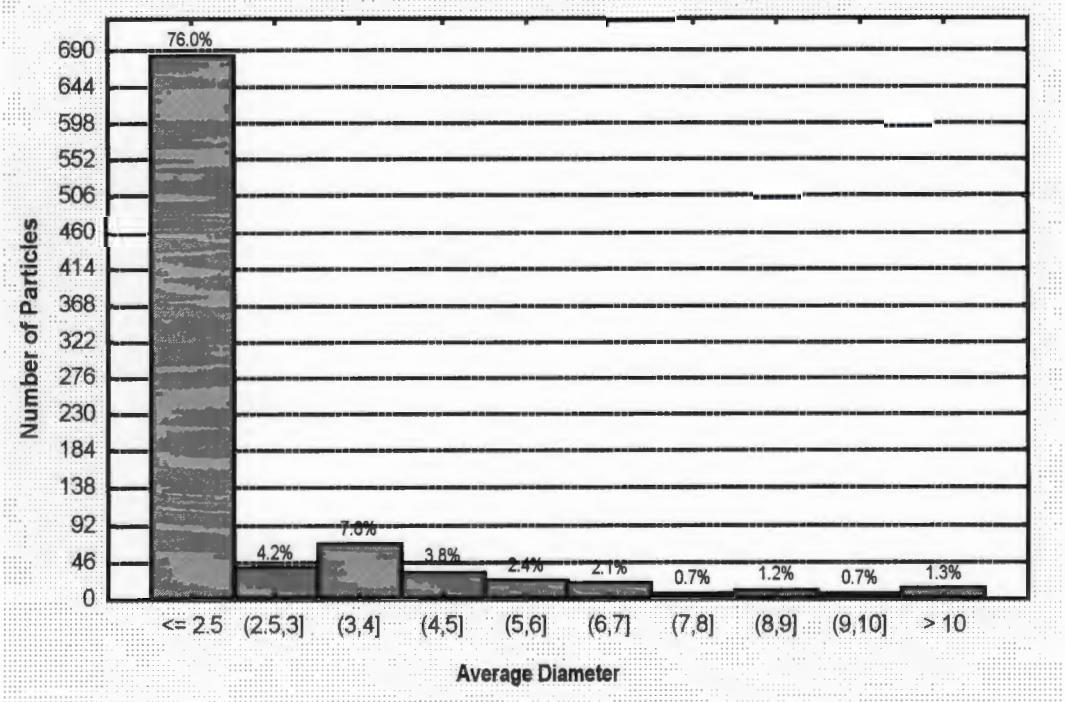
Non-Episode 3

Amorphous particulates were found to be the dominant shape in this Episode, while oval, round, sphere, flat shaped particulates were found in much smaller quantities (Table 14 & 20). The presence of 87% amorphous particulates suggests that road dust may be an important

contributor, however many other sources can contribute amorphous particulates including uncontrolled combustion sources so this is not diagnostic of a particular source (Dockery & Pope,1994). The morphological data indicates little difference between the three locations analyzed. The mean particle size indicates no significant difference between locations (Table 15). The particle size distribution illustrates that the fine particulate is dominant (76%) even in the cleanest of air, which is represented by this Non-Episode (Figure 12).

The qualitative chemical composition indicates that the four most abundant elements were aluminum, carbon, sodium, and silicon (Table 21). This suggests that road dust (silicon, aluminum) and combustion sources (carbon) may be the largest contributors to the PM_{10} (Chow,1995). There is significantly less silicon at the Plaza location and significantly less sulphur at the Lakewood location (Table 21). This is consistent with the vicinity of industrial sources to these locations.

Figure 12: Particle Size Distribution: Non-Episode 3 - 960509



The PCA determined four important factors which accounted for 57.28% of the total variance (Table 24). The first factor (18.28%) was a combustion source, while the second factor "Mica or Feldspar" (16.67%) and the fourth factor "Iron oxide" (9.89%) were road dust sources (Table 24). The third factor (12.44%) was an industrial source (Table 24). A PCA was performed at each location which indicated that the combustion source was more influential at the Plaza location than the other sites (Appendix G).

TABLE 24: PCA Eigenvalues and Primary Factors: Non-Episode 3 - 960509

Factor	1 Combustion	2 Road Dust Mica or Feldspar	3 Industrial Sulphur Source	4 Road Dust Iron oxide
Aluminum	-0.312653	**0.710797**	-0.215107	-0.035597
Calcium	0.112692	0.25147	**0.695974**	0.049704
Carbon	**0.865114**	-0.030629	0.112018	0.079386
Iron	0.067092	0.00625	-0.018065	**-0.756789**
Magnesium	0.08778	**0.722679**	0.162375	-0.039793
Phosphorus	0.033281	0.073158	0.107738	0.089235
Potassium	**-0.65575**	-0.047459	0.193647	0.116731
Silicon	**-0.629076**	0.093326	**-0.579232**	0.055646
Sodium	-0.063879	**-0.818941**	-0.079645	0.035406
Sulphur	-0.257774	-0.19155	**0.784045**	-0.053435
Titanium	0.008844	0.102006	0.002656	**-0.719186**
Eigenvalue	2.011002	1.833428	1.368153	1.087702
% Total Variance	18.28	16.67	12.44	9.89
Cumulative %	18.28	34.95	47.39	57.28

For explanation of numbers in bold please see Table 9

Comparison of Non-Episodes

The three Non-Episodes show some differences in morphology, particle size, and chemical composition. The morphological information suggests that combustion sources (such as beehive burners) may have been more influential in Non-Episode 1 compared to Non-Episodes 2 and 3 because of the larger numbers of oval and flat shaped particulates (Tables 4 & 14).

The mean particle size data indicates statistically significant differences between the three non-episodes. The third Non-Episode had a significantly smaller mean particle size than the other

two Non-Episodes (Table 15). Non-Episode 2 had a large peak at the 3-4μm range indicating that road dust was dominant on this date (Figures 10-12). As the ambient PM_{10} decreases, the proportion of fine particulates (<2.5μm) increases suggesting that the ambient air normally contains a much larger proportion of fine particulates (Figures 7-12). This has implications for health effects because even at low ambient PM_{10} levels, there are potentially detrimental effects on health, perhaps due to the large number of fine particulates present (Kao & Friedlander,1995).

The qualitative chemical composition averages did differentiate between the three Non-Episodes. Non-Episode 1 had significantly more carbon, calcium, and sulphur and significantly less aluminum, magnesium, and silicon compared to Non-Episodes 2 and 3 which was consistent with the large industrial factor present (Table 21).

Examination of the PCA also indicates the importance of the Industrial source in the first Non-Episode (Tables 22 - 24). The three Non-Episodes were highly influenced by the same three sources (combustion / industrial / road dust) which appear to have the most influence on the ambient PM_{10} in Prince George. This finding is consistent with the MELP estimates that road dust, beehive burners, and pulp mills are the three largest sources of PM_{10} in Prince George (MELP,1996).

Comparison of Episodes and Non-Episodes

There are significant differences between the Episodes and Non-Episodes with respect to morphology, particle size, and chemical composition. The morphological data indicates the only significant difference between episodes and non-episodes is in the amount of spherical shaped particulates which are indicative of beehive burner/combustion sources (Table 4 & 14). There are significantly more spherical shaped particulates in the Non-Episodes which suggests that beehive burners / combustion sources are more influential in Non-Episode conditions (Table 14). The

particle size data indicates that Episodes have a significantly larger mean particle size than Non-Episodes (Table 15). The influence of road dust to the PM_{10} is responsible for this increase in the mean particle size. Comparison of the particle size distributions illustrates this road dust influence as a decrease in fine particulates and an increase in the peak found between 3-4μm (Figures 13 & 14). The mean particle size is important due to the belief that fine particulates have a larger impact on health because they are able to penetrate deep into the lungs and remain there for long periods of time.

Comparison of the qualitative chemical composition averages indicate some significant differences between Episodes and Non-Episodes (Table 25). The Episodes have significantly more aluminum, carbon, and magnesium. The aluminum and magnesium are indicators of road dust while the carbon is an indicator of combustion sources (Chow,1995). The Non-Episodes have significantly more sulphur and sodium suggesting that normally the industrial particulates are a more important contributor to PM_{10} (Table 25).

All the significant correlation between elements and particle diameters are summarized in Table 26. These values are extremely small and only indicate very weak correlation. The PM_{10} sampled in this study is reasonably uniform in elemental composition across the particle sizes which is unexpected. Other studies have found crustal related elements (aluminum, silicon) and metallic elements (cadmium, copper, lead, manganese, and iron) have bimodal distribution patterns (Kao & Friedlander,1995; Infante & Acosta,1991). Some studies have found substantial co-variation between $PM_{2.5}$ and sulphate, which was also not seen in this data (Ostro *et al.*,1991). The assumption that elemental composition is dependent on particle size was not illustrated in this data perhaps due to the large degree of uncertainty inherent in qualitative analysis.

Figure 13: Particle Size Distribution: Episodes

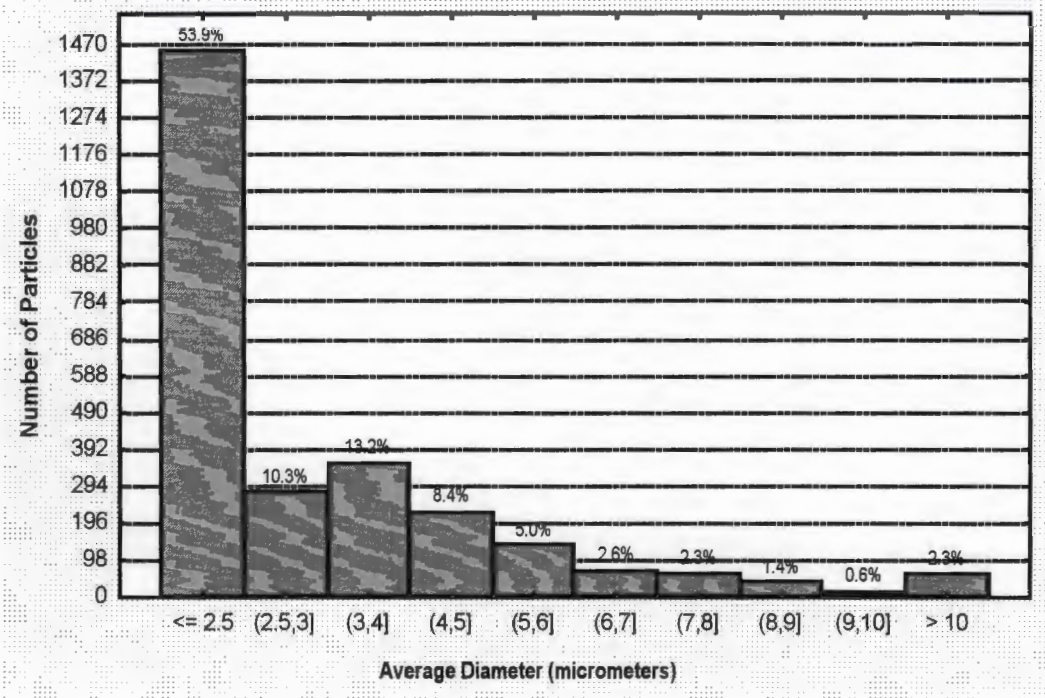
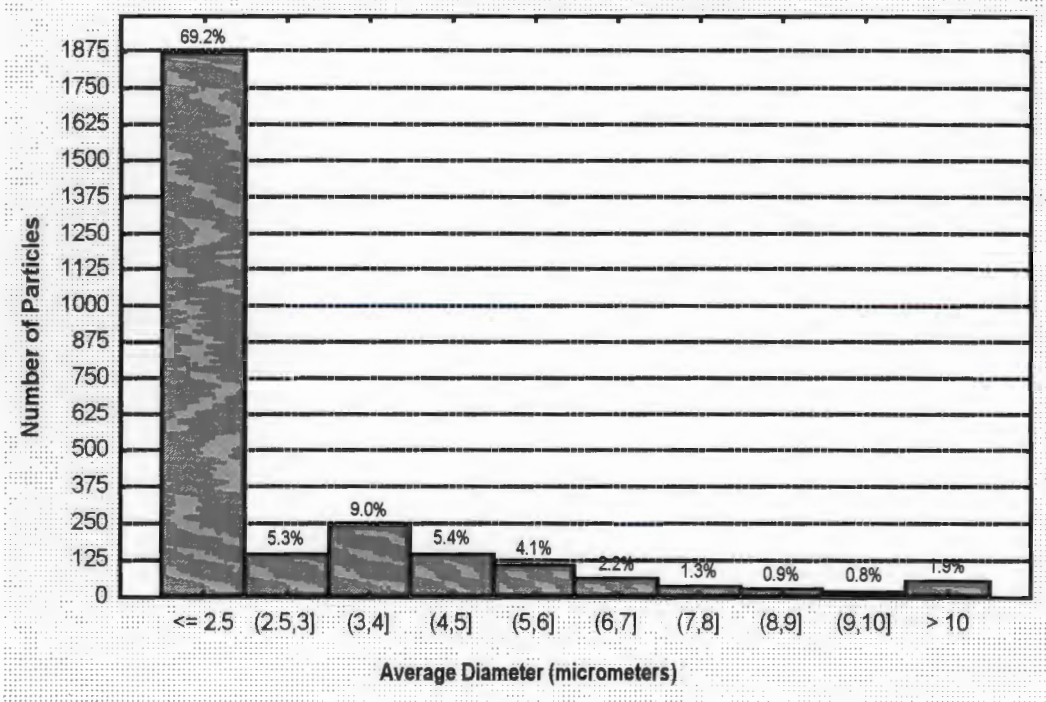


Figure 14: Particle Size Distribution: Non-Episodes



Other studies used bulk analysis of different portions of the PM_{10} to distinguish these patterns (Kao & Friedlander,1995; Infante & Acosta,1991). Another possibility is that the road dust (dominant source) in the Prince George area may contain a uniform chemical composition.

TABLE 25 : Comparison of Qualitative Chemical Characterization in Episodes / Non-Episodes

	Episode		Non-Episode		
Element	**Mean %**	**SD**	**Mean %**	**SD**	**ANOVA Results**
Aluminum	9.84^a	7.92	7.9^b	7.4	H(1,n=5397)=103.71, p=0.0000
Barium	0.0009	0.27	0.003	0.15	H(1,n=5397)=1.047611, p=0.3061
Calcium	1.21	4.01	1.15	4.04	H(1,n=5397)=2.80, p=0.0941
Carbon	21.45^a	17.17	18.21^b	15.66	H(1,n=5397)=59.76, p=0.0000
Chlorine	0.019	0.38	0.037	0.18	H(1,n=5397)=3.02, p=0.0821
Chromium	nd	nd	0.004	0.19	H(1,n=5397)=1.15, p=0.2830
Copper	0.016	0.83	0.097	2.42	H(1,n=5397)=2.72, p=0.0988
Iron	0.198	1.58	0.145	1.62	H(1,n=5397)=4.14, p=0.0419
Magnesium	2.21^a	4.78	1.7^b	5.02	H(1,n=5397)=94.44, p=0.0000
Potassium	1.69	1.97	1.68	1.62	H(1,n=5397)=12.59, p=0.0004
Silicon	36.39	16.68	36.18	15.41	H(1,n=5397)=0.43, p=0.5132
Sodium	24.8^a	10.73	30.03^b	12.49	H(1,n=5397)=271.17, p=0.0000
Sulphur	2.09^a	6.63	2.83^b	7.08	H(1,n=5397)=12.11, p=0.0005

Superscript across rows indicate significant differences between means ($p<0.05$);
Confidence Intervals (±10%); nd = not detected

The qualitative composition of different morphological shapes was compared to further define the sources of ambient PM_{10}. Only those elements showing significant differences between morphological shapes were reported (Tables 27 & 28). Amorphous particulates dominated the ambient samples and were contributed by many sources including road dust (accounting for the aluminum, calcium, magnesium, and silicon) and combustion (carbon) (Chow,1995) (Tables 27 & 28). The oval and spherical shaped particulates, which are diagnostic of combustion sources, contained significantly more carbon and significantly less aluminum, magnesium, and silicon compared to the amorphous particulates (Table 27). The flat particulates in the Episodes contained significantly more aluminum, calcium, magnesium, and silicon and significantly less sodium and carbon than the combustion morphological shapes and indicates that these are clay

particles (Chow,1995). The rectangular shapes contained very high levels of sulphur and calcium indicative of an industrial source. All the morphological shapes identified except (smooth-flat) contained some level of sulphur suggesting that there is an interaction occurring between sulphur (SO_2) and the fine particulates in the ambient air (Table 27 & 28). The sulphur may be coating the surface of the particulates (Keyser *et al.*,1978). The distinctions between morphological shapes in the Non- Episodes are not as evident most probably due to the contributions of many different sources instead of just a few sources seen in the Episodes.

The PCA performed on the Episodes and Non-Episodes illustrate that importance of source differs between locations and dates (Tables 17-19;22-24). In Episode 1, there was an industrial source providing the most significant PM_{10} contribution while Episodes 2 and 3 were influenced more by road dust. The Non-Episodes were all influenced by combustion, industrial, and road dust sources. Overall, the main sources seem to remain quite consistent between all dates sampled except the combustion factor was more evident in the Non-Episodes.

TABLE 26 : Comparison of Significant Correlation between Elemental Composition and Particulate Diameter

	Episodes		Non-Episodes	
Element	**Correlation**	**Correlation equation**	**Correlation**	**Correlation equation**
Aluminum	0.19	Al = 8.2199 + 0.52916*Diameter	0.21	Al = 6.4791 + 0.57803*Diameter
Carbon			0.17	C = 15.746 + 1.0067*Diameter
Calcium	0.08	Ca = 0.86700 + 0.11216*Diameter	0.13	Ca = 0.67335 + 0.19566*Diameter
Magnesium	0.15	Mg = 1.4366 + 0.25283*Diameter	0.22	Mg = 0.70873 + 0.40482*Diameter
Manganese	0.06	Mn = -0.0027 + 0.00193*Diameter	0.1	Mn = -0.0012 + 0.00064*Diameter
Potassium	0.04	K = 1.5983 + 0.03030*Diameter	-0.07	K = 1.7886 - 0.0431*Diameter
Silicon			-0.17	Si = 38.581 - 0.9780*Diameter
Sodium	-0.31	Na = 28.397 - 1.176*Diameter	-0.33	Na = 33.835 - 1.552*Diameter
Sulphur	0.09	S = 1.4447 + 0.21142*Diameter	0.14	S = 1.8990 + 0.37813*Diameter

TABLE 27: Comparison of Qualitative Chemical Composition and Morphology in Episodes

		Aluminum		Calcium		Carbon		Copper	
	Particulates	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Amorphous	2075	9.99^{a}	7.44	1.11^{a}	3.65	20.68^{a}	16.34	0.00^{a}	0.00
Oval	45	3.56^{b}	2.09	0.00^{a}	0.00	35.70^{b}	17.42	0.96^{b}	6.42
Round	28	5.46^{b}	5.30	1.30^{ab}	6.15	26.09^{ac}	15.11	0.00^{a}	0.00
Sphere	55	5.18^{b}	5.71	0.30^{a}	1.83	33.64^{bc}	19.14	0.00^{a}	0.00
Flat	474	10.83^{c}	9.88	1.57^{b}	4.98	22.07^{ad}	19.36	0.00^{a}	0.00
Smooth Flat	4	5.56^{abc}	1.19	1.89^{ab}	3.78	18.00^{acd}	8.76	0.00^{a}	0.00
Cube	1	0.00^{abc}	0.00	0.00^{ab}	0.00	2.45^{abc}	0.00	0.00^{a}	0.00
Rectangle	16	3.62^{b}	6.79	10.16^{c}	9.08	15.44^{ad}	16.54	0.00^{a}	0.00
		Magnesium		**Silicon**		**Sodium**		**Sulphur**	
	Particulates	**Mean (%)**	**SD**	**Mean (%)**	**SD**	**Mean (%)**	**SD**	**Mean (%)**	**SD**
Amorphous	2075	2.21^{a}	4.55	37.37^{a}	16.40	24.99^{a}	10.61	1.75^{a}	5.60
Oval	45	0.07^{b}	0.44	26.92^{b}	10.68	29.97^{b}	6.97	1.33^{ab}	3.30
Round	28	0.00^{b}	0.00	29.58^{bc}	12.01	31.28^{b}	11.36	4.25^{b}	10.93
Sphere	55	0.46^{b}	1.99	27.55^{b}	11.18	28.86^{b}	8.40	1.66^{ab}	5.40
Flat	474	2.75^{c}	5.98	35.05^{c}	18.04	22.68^{c}	10.92	2.86^{b}	8.42
Smooth Flat	4	0.00^{abc}	0.00	33.89^{abc}	3.96	38.31^{bd}	4.30	0.00^{ab}	0.00
Cube	1	14.39^{d}	0.00	0.00^{b}	0.00	58.53^{d}	0.00	23.28^{c}	0.00
Rectangle	16	1.89^{abc}	7.56	20.98^{b}	18.99	18.61^{c}	15.45	22.52^{c}	21.61
Rod	0	na	na	na	na	na	na	na	na

ANOVA Results summarized in Appendix H

TABLE 28: Comparison of Qualitative Chemical Composition and Morphology in Non-Episodes

		Aluminum		Calcium		Carbon	
	Particulates	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Amorphous	2212	8.23[a]	7.46	1.12[a]	4.02	17.66[a]	15.08
Oval	38	5.01[b]	1.63	0.55[a]	1.29	22.08[ab]	13.00
Round	40	5.16[b]	2.51	0.97[a]	2.62	20.08[ab]	13.60
Sphere	92	6.82[ab]	4.88	1.60[a]	6.71	16.93[a]	15.02
Flat	295	6.75[b]	8.32	1.24[a]	3.31	21.68[b]	19.71
Rectangle	9	4.38[ab]	2.45	5.40[b]	5.67	16.21[ab]	7.23
Rod	13	4.66[ab]	2.97	0.66[a]	1.76	27.48[b]	19.23
		Magnesium		**Silicon**		**Sulphur**	
	Particulates	**Mean (%)**	**SD**	**Mean (%)**	**SD**	**Mean (%)**	**SD**
Amorphous	2212	1.81[a]	5.10	36.62[ac]	15.34	2.54[a]	7.10
Oval	38	0.06[b]	0.36	35.39[ab]	10.48	2.26[ab]	5.16
Round	40	0.28[ab]	1.36	34.72[ab]	14.61	4.04[ab]	8.72
Sphere	92	1.13[ab]	3.54	39.08[a]	16.89	2.56[a]	7.11
Flat	295	1.61[ab]	5.50	32.76[ab]	15.63	4.59[b]	9.43
Rectangle	9	0.00[ab]	0	30.14[ab]	14.93	12.23[c]	14.99
Rod	13	0.56[ab]	1.41	29.76[cb]	15.22	5.55[ab]	10.71

ANOVA results summarized in Appendix H

Comparison of Episodes and Non-Episodes in the BCR site

BCR Episodes

Amorphous particulates were found to be the dominant shape in these Episodes, while round, sphere, smooth-flat, flat, and rectangular shaped particulates were found in much smaller numbers (Table 29). The presence of 86% amorphous particulates suggests that road dust may be an important contributor, however many other sources can contribute amorphous particulates including uncontrolled combustion sources so this is not diagnostic of any particular source (Dockery & Pope,1994). Comparison of the morphology data between episodes indicates few differences (Table 29). In two episodes 950831 and 960813 there seems to be a larger proportion of "flat" particulates which may be a result of increased unpaved road dust levels (Table 4 & 29). Analysis of the mean particle size data indicates no significant differences between the episodes (Table 30). The average particle size is quite large (4.1-4.6μm) which is illustrated in the particle size distributions which show a very large peak between the 3-4μm range (Table 30; Figure 15). This suggests that road dust was an important source.

The qualitative chemical composition indicated that the most abundant elements were aluminum, carbon, magnesium, sodium, and silicon (Table 31). This suggests that road dust (silicon, aluminum, magnesium) and combustion sources (carbon) were likely the largest contributors to the PM_{10} (Chow,1995). The qualitative chemical composition averages indicate some significant differences between the various episodes. In most cases this difference should be considered cautiously due to the uncertainty involved in the qualitative analysis. The episodes occurring on 940923 and 950831 had significantly more carbon suggesting a combustion/industrial source is a larger contributor to these episodes (Table 31).

TABLE 29: Comparison of Morphology Types: BCR site

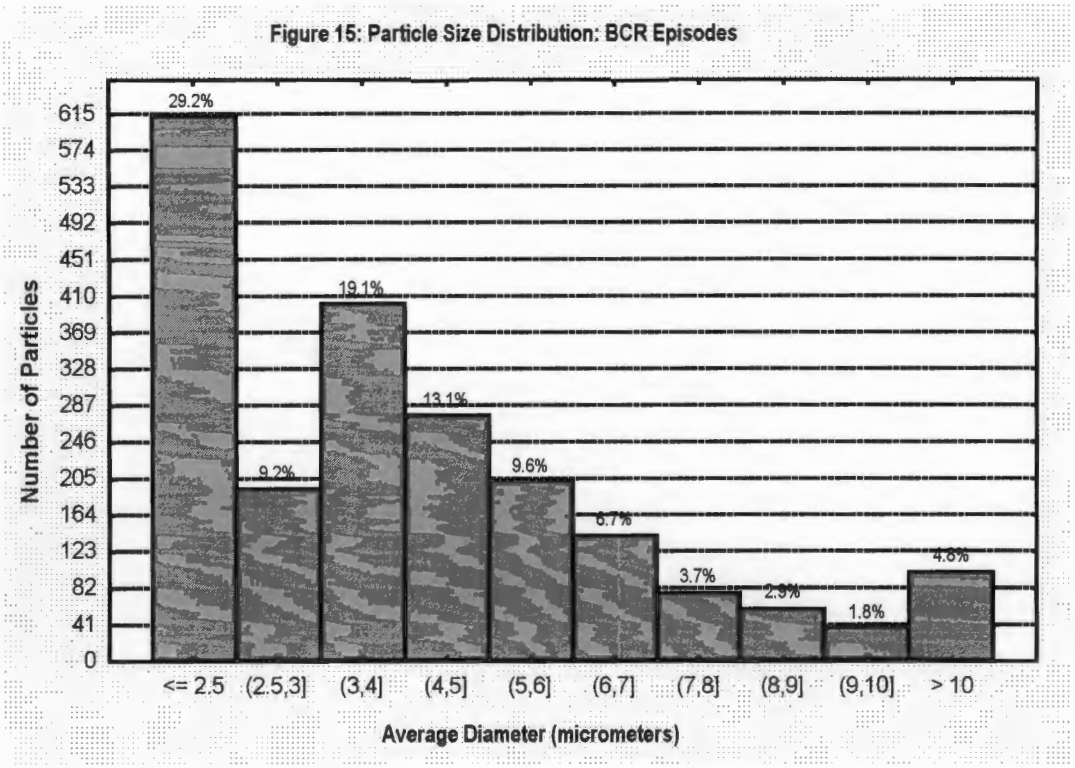
	Amorphous %	Oval %	Round %	Sphere %	Flat %	Smooth %	Rectangle %
Episode	86.91	0.00	0.24	0.19	12.62	0.05	0.00
940408	89.67	0.00	0.00	0.00	10.33	0.00	0.00
940923	88.67	0.00	0.33	0.33	10.33	0.33	0.00
950316	87.33	0.00	0.00	0.33	12.33	0.00	0.00
950328	88.00	0.00	0.00	0.00	12.00	0.00	0.00
950831	83.67	0.00	1.33	0.33	14.67	0.00	0.00
960304	88.67	0.00	0.00	0.33	11.00	0.00	0.00
960813	82.33	0.00	0.00	0.00	17.67	0.00	0.00
Non-Episode	79.98	1.84	0.00	4.34	13.69	0.00	0.17
960122	72.33	3.00	0.00	7.67	16.67	0.00	0.33
930509	87.63	0.67	0.00	1.00	10.71	0.00	0.00

Episode / Non-Episode (n=300); Total Episode (n=2100); Total Non-Episode (n=599)

TABLE 30: Comparison of Particle Size for Episodes/Non-Episodes in the BCR site

Episode								**ANOVA Results**
940408		**940923**		**950316**		**950328**		
Mean (μm)	**SD**	**Mean (μm)**	**SD**	**Mean (μm)**	**SD**	**Mean (μm)**	**SD**	
4.10	2.78	4.60	3.38	4.29	2.77	4.18	3.01	
950831		**960304**		**960813**		**Total**		
Mean (μm)	**SD**	**Mean (μm)**	**SD**	**Mean (μm)**	**SD**	**Mean (μm)**	**SD**	
4.36	3.00	4.30	4.62	4.57	3.93	4.34*	3.41	F(6,2092)=0.895, p=0.497252
Non-Episode								
960122		**960509**		**Total**				
Mean (μm)	**SD**	**Mean (μm)**	**SD**	**Mean (μm)**	**SD**			
2.91	3.17	3.32	3.08	3.12**	3.13			F(1,597)=2.604, p=0.107100
E versus NE								H(1,n=2698)=171.48, p=0.000

Columns with different superscripts (* ** ***) indicate significant differences between means (p<0.05)
BCR samples (n=300); BCR Episode Total (N=2100); BCR Non-Episode Total (N=599)



The PCA indicated seven important factors (sources) accounting for 63.68% of the total variance. Factors 1 "K-Feldspar" (12.96%), 3 "Iron oxide" (9.18%), 4 "Quartz" (8.7%), and 5 "Sodium" (7.82%) all represent types of road dusts (Table 32). Factor 2 (11.21%) was an industrial source. The last two factors were not interpreted because those combinations of elements were not seen previously (Table 32). A PCA was performed on each episode and the results were in most cases consistent with those above (Appendix G). In most cases road dust was the most important contributor to the ambient PM_{10} while an industrial factor was also evident (Appendix G). Contrary to the qualitative chemical averages, the PCA performed on Episode 950831 contained four factors all of which represented road dust and no factors representing combustion, however, it is unclear what the source of carbon is. The PCA performed on Episode 960304 indicated that industrial and combustion sources were more important contributors to this episode (Appendix G). The above episode did not exceed the $50\mu g/m^3$ objective to the extent of

the other BCR episodes analyzed suggesting that the very high levels of ambient PM_{10} in the BCR site have a high road dust component while lower levels of PM_{10} are more influenced by the industrial and combustion sources in the area to a greater extent.

TABLE 31: Qualitative Chemical Characterization of PM_{10} Episodes and Non-Episodes in the BCR site

Episodes	Al Mean	(%) SD	Ba Mean	(%) SD	C Mean	(%) SD	Ca Mean	(%) SD
Average	15.04*	7.91	0.01	0.50	13.89*	12.02	1.34	3.68
940408	15.93^{a}	8.58	0.08	1.43	12.18^{a}	8.60	1.74^{a}	4.35
940923	14.85^{abc}	7.52	nd	nd	17.57^{b}	14.25	1.87^{a}	5.39
950316	15.46^{ab}	7.55	nd	nd	13.35^{a}	9.06	0.86^{b}	2.36
950328	14.33^{bc}	7.20	nd	nd	12.69^{a}	7.67	0.99^{b}	1.97
950831	14.70^{abc}	7.57	nd	nd	18.25^{b}	17.52	0.99^{b}	3.04
960304	15.56^{ab}	8.76	nd	nd	9.85^{a}	11.94	1.65^{a}	4.07
960813	14.02^{c}	8.29	nd	nd	13.82^{c}	12.47	1.73^{a}	4.32
Non-Episodes								
Average	8.45**	8.97	nd	nd	19.56**	15.62	1.59	5.07
960122	3.38^{a}	5.13	nd	nd	26.84^{a}	16.86	1.70	3.91
960509	13.53^{b}	9.12	nd	nd	12.27^{b}	9.90	1.47	6.02

Episodes	Cl Mean	(%) SD	Cr Mean	(%) SD	Cu Mean	(%) SD	Fe Mean	(%) SD
Average	0.01	0.16	0.01	0.23	nd	nd	0.05	0.60
940408	0.20^{ab}	0.26	nd	nd	nd	nd	0.49	0.53
940923	nd^{a}	nd	nd	nd	nd	nd	0.16	1.21
950316	0.01^{ab}	0.20	nd	nd	nd	nd	0.02	0.25
950328	nd^{a}	nd	nd	nd	nd	nd	0.19	0.32
950831	nd^{a}	nd	nd	nd	nd	nd	0.01	0.18
960304	0.03^{b}	0.25	nd	nd	nd	nd	0.07	0.58
960813	nd^{a}	nd	0.04	0.66	nd	nd	0.08	0.71
Non-Episodes								
Average	0.01	0.21	nd	nd	0.07	1.79	0.13	1.58
960122	0.02	0.29	nd	nd	0.15	2.53	0.19	2.09
960509	nd	nd	nd	nd	nd	nd	0.06	0.80

Superscript down columns (abc / * ** ***) indicate significant differences between means ($p<0.05$)
Confidence Intervals: (±10%); (nd=not detected)
ANOVA results summarized in Appendix H

TABLE 31: Qualitative Chemical Characterization of PM_{10} Episodes and Non-Episodes in the BCR site (cont.)

Episodes	K Mean	(%) SD	Mg Mean	(%) SD	Mn Mean	(%) SD	Na Mean	(%) SD
Average	1.52	1.80	4.02*	6.46	0.002	0.08	17.89*	11.25
940408	1.46[a]	1.59	4.67[a]	6.79	nd	nd	18.05[a]	10.99
940923	1.90[b]	2.00	4.19[a]	6.67	nd	nd	14.45[b]	10.19
950316	1.55[a]	1.82	4.00[ab]	5.88	nd	nd	18.01[a]	11.59
950328	1.17[c]	1.25	3.13[b]	4.70	0.13	0.23	21.83[c]	9.98
950831	1.46[a]	1.62	4.05[ab]	7.38	nd	nd	15.23[b]	10.74
960304	1.46[a]	1.77	3.95[ab]	5.70	nd	nd	19.46[a]	12.16
960813	1.62[a]	2.30	4.21[a]	8.04	nd	nd	18.12[a]	11.07
Non-Episodes								
Average	1.62	1.99	2.08**	5.04	nd	nd	28.20**	14.74
960122	1.68	2.31	0.69[a]	2.94	nd	nd	34.94[a]	13.59
960509	1.56	1.60	3.47[b]	6.20	nd	nd	21.46[b]	12.63

Episodes	P Mean	(%) SD	S Mean	(%) SD	Si Mean	(%) SD	Ti Mean	(%) SD
Average	0.07	1.23	0.33*	2.38	45.74*	15.28	0.08	1.35
940408	0.50	0.79	0.63[acd]	2.54	45.15	14.65	0.01	0.21
940923	nd	nd	0.20[bc]	1.86	44.54	16.28	0.28	2.71
950316	0.13	1.40	0.07[b]	0.84	46.49	14.24	0.04	0.45
950328	0.09	1.53	0.39[abc]	1.92	45.33	13.28	0.18	0.22
950831	nd	nd	nd[b]	nd	45.13	14.99	0.19	2.48
960304	nd	nd	0.49[cd]	3.36	47.44	17.01	0.05	0.58
960813	0.18	2.27	0.79[d]	4.29	45.36	17.08	0.03	0.58
Non-Episodes								
Average	0.08	2.01	3.62**	9.40	34.60**	17.30	0.004	0.09
960122	nd	nd	6.39[a]	11.84	24.04[a]	12.85	nd	nd
960509	0.16	2.85	0.86[b]	4.62	45.15[b]	14.52	0.01	0.13

Superscript down columns (abc/* ** ***) indicate significant differences between means ($p<0.05$)
Confidence Intervals (±10%); (nd=not detected)
ANOVA results Summarized in Appendix H

TABLE 32: PCA Eigenvalues and Primary Factors: BCR Episodes

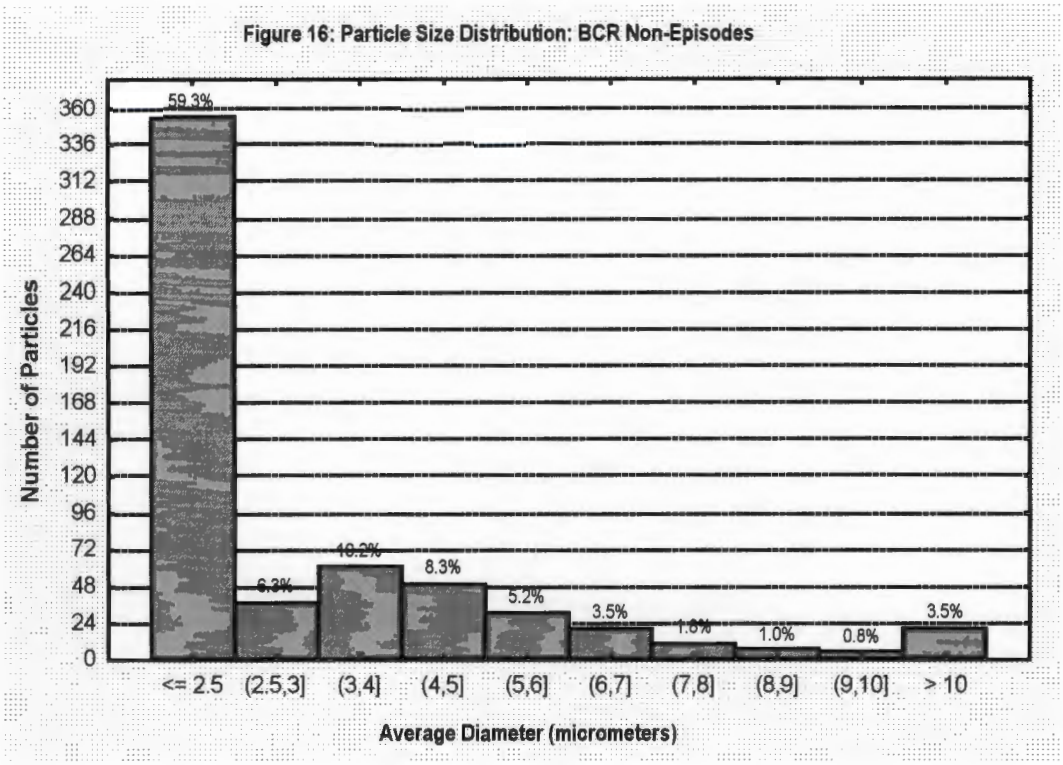
Factor	1 Road Dust K-Feldspar	2 Industrial Sulphur Source	3 Road Dust Iron oxides	4 Road Dust Quartz	5 Road Dust Sodium	6 Other	7 Other
Aluminum	**-0.819599**	0.059259	0.043077	-0.042135	0.232219	0.07551	0.152748
Barium	0.035679	**-0.728365**	0.008507	-0.004364	0.064975	0.215118	-0.040719
Calcium	0.008074	-0.285618	-0.016052	0.06019	0.077653	**-0.782876**	0.099806
Carbon	**0.377601**	0.065034	-0.008856	**0.76413**	0.059728	0.102159	-0.230579
Chlorine	0.075098	0.113333	0.12202	0.026219	0.063272	**-0.377037**	**0.471438**
Chromium	0.02935	-0.027001	-0.158985	-0.018856	0.004977	0.165122	**0.730371**
Iron	-0.05534	0.00186	**-0.802375**	0.019424	0.063433	0.042819	0.195862
Magnesium	-0.086237	0.001739	0.020287	0.239025	**0.760782**	-0.088843	0.224641
Manganese	-0.201013	0.033335	-0.032592	0.054746	-0.139784	-0.047825	-0.137743
Phosphorus	-0.002234	0.151284	-0.043304	0.002182	0.016561	**-0.622552**	-0.169032
Potassium	**-0.759766**	-0.013333	-0.045034	-0.05863	0.017741	0.012221	-0.137262
Silicon	0.189123	0.115002	0.016434	**-0.935349**	0.097581	0.161228	-0.144189
Sodium	0.078292	0.002973	0.103828	**0.323518**	**-0.816587**	0.053263	0.192849
Sulphur	0.025094	**-0.768555**	0.004513	0.056314	-0.067491	-0.296266	0.016225
Titanium	0.015304	0.010624	**-0.817711**	-0.004257	-0.014316	-0.068193	-0.100612
Eigenvalue	1.944412	1.681125	1.377258	1.304731	1.173345	1.060679	1.010437
% Total Variance	12.96	11.21	9.18	8.7	7.82	7.07	6.74
Cumulative %	12.96	24.17	33.35	42.05	49.87	56.94	63.68

For explanation of numbers in bold please see Table 9

BCR Non-Episodes

The two Non-Episodes were extremely different from each other with regards to morphology, particle size and chemical composition. Amorphous particulates were found to be the dominant shape, while oval, sphere, flat, and rectangular shaped particulates were found in much smaller quantities (Table 29). The presence of 80% amorphous particulates suggests that road dust may be an important contributor, however many other sources can contribute amorphous particulates including uncontrolled combustion sources so again this is not diagnostic of any source (Dockery & Pope,1994). Comparison of morphological data indicates that the Non-Episode 960122 was influenced more by combustion sources due to the larger percentages of "oval" and "spherical" shaped particulates (Table 29). Episode 960122 also contained more "flat" particulates which with the "round" shaped particulates can be indicative of combustion sources such as beehive burners (Table 4). The mean particle size shows no significant differences between the two Non-Episodes (Table 30). The particle size distribution indicates a large proportion of fine particulates (59%) in the Non-Episodes (Figure 16).

The qualitative chemical composition indicates that the most abundant elements were aluminum, carbon, sodium, sulphur and silicon (Table 31). This suggests that road dust (silicon, aluminum) and combustion / industrial sources (carbon, sulphur) may be the largest contributors to the PM_{10} (Chow,1995). The qualitative chemical composition averages show significant differences between the two Non-Episodes analyzed (Table 31). Episode 960122 contained significantly more carbon, sodium and sulphur and significantly less aluminum, magnesium, and silicon which is also consistent with the morphological and particulate size results (Table 31). Episode 960122 appears to have been highly influenced by a combustion / industrial source.



The PCA determined five important factors accounting for 59.07% of the total variance (Table 33). Factors 1 "Mica" (19.71%) and 5 "Iron oxides"(7.81%) represent road dust while factors 3 (9.57%) and 4 (8.63%) represented industrial and combustion sources (Table 33). It is unclear what source factor 2 represented as the combination of calcium and phosphorus was not diagnostic of a particular source. A PCA was performed on each of the Non-Episodes which confirmed that they were different. In Non-Episode 960122 the first factor was a industrial source (21.12%) and the third factor was combustion source (12.63%) which is consistent with the other analysis completed (Appendix G). The results of Non-Episode 960509 was similar to the PCA completed above (Table 33).

TABLE 33: PCA Eigenvalues and Primary Factors: BCR Non-Episodes

Factor	1 Road Dust Mica	2 Other	3 Industrial Sulphur Source	4 Combustion	5 Road Dust Iron oxide
Aluminum	**0.721978**	0.103842	-0.233608	**0.338654**	-0.113542
Calcium	0.078747	**-0.731369**	**0.422669**	0.015412	0.018609
Carbon	-0.295134	0.029186	-0.09765	**-0.791347**	0.127121
Chlorine	0.174885	0.057501	-0.002937	**-0.567659**	-0.202524
Copper	-0.010038	-0.014302	-0.016663	-0.004108	0.084723
Iron	0.035955	0.080938	0.041863	0.131461	**0.891598**
Magnesium	**0.75958**	0.06799	0.156017	-0.08279	0.101109
Phosphorus	-0.006269	**-0.804326**	-0.102539	0.018474	0.019515
Potassium	0.079389	0.218498	**0.548521**	**0.326517**	**-0.342648**
Silicon	**0.358154**	0.090119	**-0.587593**	**0.54718**	-0.175183
Sodium	**-0.815283**	0.186859	0.110425	-0.038407	0.052866
Sulphur	-0.05094	-0.133232	**0.885211**	-0.002018	-0.01941
Titanium	-0.132927	-0.135055	-0.098389	0.102079	-0.173419
Eigenvalue	2.562497	1.735712	1.244378	1.122053	1.014908
% Total Variance	19.71	13.35	9.57	8.63	7.81
Cumulative %	19.71	33.06	42.64	51.27	59.07

For explanation of numbers in bold please see Table 9

BCR Episodes versus Non-Episodes

There are significant differences between the BCR Episodes and Non-Episodes which are a result of the influence of the main PM_{10} sources present at the BCR location.

Comparison of elemental analysis (ICP) indicated few significant differences between the concentrations of the elements tested (Table 34). The average concentrations of most elements are smaller in the non-episodes however the differences were not statistically significant (Table 34). This may be a function of the variation seen in the filter blank (Appendix F).

Comparison of morphology between Episodes and Non-Episodes indicates that in Non-Episodes there are significantly more oval and spherical shaped particulates (Table 35). The influence of combustion sources is greater in Non-Episodes than Episodes which seems to be overwhelmed by road dust. The mean particle size data indicates that Episodes have a significantly larger particle size than Non-Episodes supporting the conclusion that road dust plays an important role in Episodes of the BCR site (Table 30). The particle size distributions illustrate this point

TABLE 34: Comparison of Quantitative Elemental Analysis in the BCR site

Element	Episode Mean %	SD	Non-Episode Mean %	SD	ANOVA Results
Aluminum	13.214	8.279	3.957	5.595	H(1,n=9)=3.09, p=0.0790
Barium	3.373	3.887	nd	nd	H(1,n=9)=2.34, p=0.1263
Calcium	15.324	8.551	9.635	13.625	H(1,n=9)=0.34, p=0.5582
Chromium	0.006	0.004	nd	nd	H(1,n=9)=3.19, p=0.0740
Copper	0.003	0.007	0.009	0.012	H(1,n=9)=0.10, p=0.7484
Iron	2.458	0.961	0.924	0.344	H(1,n=9)=2.14, p=0.1432
Lithium	0.006	0.004	0.007	0.010	H(1,n=9)=0.09, p=0.7697
Magnesium	3.385	1.813	1.637	2.374	H(1,n=9)=0.77, p=0.3798
Manganese	0.063	0.030	0.007	0.009	H(1,n=9)=2.62, p=0.1059
Nickel	0.0083[a]	0.003	0.0022[b]	0.003	H(1,n=9)=4.2, p=0.0404
Phosphorus	0.107	0.044	0.075	0.051	H(1,n=9)=0.34, p=0.5582
Potassium	3.176	2.193	nd	nd	H(1,n=9)=3.19, p=0.0740
Sodium	11.580	5.230	14.850	4.320	H(1,n=9)=1.37, p=0.2416
Strontium	0.091	0.169	nd	nd	H(1,n=9)=2.16, p=0.1416
Tin	0.005	0.009	nd	nd	H(1,n=9)=1.09, p=0.2967
Titanium	0.468	0.149	0.320	0.350	H(1,n=9)=0.34, p=0.5582
Vanadium	0.0075[a]	0.003	nd[b]	nd	H(1,n=9)=4.24, p=0.0396
Zinc	2.180	1.755	1.413	1.998	H(1,n=9)=0.54, p=0.4623

Superscripts across rows indicate significant differences in means ($p<0.05$)
BCR Episodes (n=7); BCR Non-Episodes (n=2)

TABLE 35: Comparison of Morphology between BCR Episodes and Non-Episodes

	Episode Mean	SD	Non-Episode Mean	SD	ANOVA Results
Amorphous	260.71	8.36	239.50	31.82	H(1,n=9)=1.77, p=0.1840
Oval	0[a]	0.00	5.50[b]	4.95	H(1,n=9)=7.88, p=0.005
Round	0.71	1.50	0.00	0.00	H(1,n=9)=0.64, p=0.4227
Sphere	0.57[a]	0.54	13.00[b]	14.14	H(1,n=9)=4.75, p=0.0292
Flat	37.86	8.05	41.00	12.73	H(1,n=9)=0.086, p=0.7688
Smooth	0.14	0.38	0.00	0.00	H(1,n=9)=0.29, p=0.593
Rectangle	0.00	0.00	0.50	0.71	H(1,n=9)=3.5, p=0.0614

Superscript across rows indicates significant differences between means ($p<0.05$)
Episode (n=2100); Non-Episode (n=599)
Means are based on Total Particulate number above

through the difference in the composition of fine particulates, 29% versus 59% (Figures 15 & 16).

The qualitative chemical composition averages show significant differences between Episodes and Non-Episodes (Table 31). Episodes contain significantly more aluminum, magnesium, and silicon (road dust indicators), while the Non-Episodes contain significantly more

carbon, sodium, and sulphur (industrial/combustion indicators) especially the Non-Episode 960122 (Table 31).

The correlation between elemental composition and particulate diameter were analyzed to determine the significant correlation found in Table 36. The weak correlation identified between elemental composition and diameter indicated that in Episodes and Non-Episodes aluminum and magnesium were found in larger concentrations in larger particulates and sodium is found in larger concentrations in smaller particulates (Table 36). In the Episodes phosphorus was found in larger concentrations in larger particulates while in Non-Episodes carbon and chlorine were found in larger concentrations in larger particulates (Table 36). There were expectations of larger correlation which would indicate that elements are concentrated on certain size fractions however, this was not the case in this data set.

The qualitative composition of different morphological shapes was compared to further define the sources of ambient PM_{10}. Only those elements showing significant differences between morphological shapes were reported (Table 37). Amorphous particulates dominated the ambient samples and were contributed by many sources (Table 37). It is interesting that there is less carbon and sodium in the amorphous particulates in the Episodes compared to the Non-Episodes which suggests that the source of amorphous particulates in the Episodes is road dust while in the Non-Episodes it is road dust and combustion. The oval and spherical shaped particulates which represent combustion sources contained significantly more carbon compared to the amorphous particulates (Table 37). The flat particulates in the Episodes contained less carbon which suggests that they may be clay particles (Chow,1995).

The PCA performed illustrate the dominance of road dust in Episodes in the BCR site (Table 32 & 33). The industrial/combustion source still influences the ambient PM_{10} in the BCR site, but not to the extent seen in the Non-Episodes.

TABLE 36: Comparison of Significant Correlation between Elemental Composition and Particulate Diameter in the BCR site

	Episodes		Non-Episodes	
Element	**Correlation**	**Correlation equation**	**Correlation**	**Correlation equation**
Aluminum	0.18	Al = 13.170 + 0.41619*Diameter	0.24	Al = 6.2709 + 0.69960*Diameter
Carbon			0.09	C = 18.165 + 0.45308*Diameter
Chlorine			0.31	Cl = -0.0553 + 0.02045*Diameter
Magnesium	0.1	Mg = 3.2359 + 0.18227*Diameter	0.15	Mg = 1.3124 + 0.24693*Diameter
Phosphorus	0.09	P = -0.0667 + 0.03027*Diameter		
Sodium	-0.24	Na = 21.321 - 0.7930*Diameter	-0.31	Na = 32.669 - 1.438*Diameter

TABLE 37: Comparison of Qualitative Chemical Composition and Morphology in BCR Episodes & Non-Episodes

		Calcium		Carbon		Sodium	
Episodes	**Particulates**	**Mean (%)**	**SD**	**Mean (%)**	**SD**	**Mean (%)**	**SD**
Amorphous	1824	1.43^{a}	3.82	13.55^{a}	10.71	18.39^{ab}	11.08
Round	5	0.00^{a}	0.00	52.53^{b}	36.65	10.63^{bc}	10.61
Sphere	4	0.00^{a}	0.00	24.61^{ac}	19.42	28.00^{a}	19.88
Flat	265	1.21^{a}	3.91	15.94^{c}	19.14	14.37^{c}	11.27
Smooth Flat	1	9.53^{b}	0.00	6.37^{ac}	0.00	6.73^{abc}	0.00
Non-Episodes							
Amorphous	479	nd	nd	19.09	15.49	27.84	14.65
Oval	11	nd	nd	24.01	12.29	32.85	5.90
Sphere	26	nd	nd	24.43	11.55	33.03	7.34
Flat	82	nd	nd	20.45	17.65	27.79	17.42
Rectangle	1	nd	nd	7.59	0.00	48.82	0.00

ANOVA results summarized in Appendix I

Calcium results in Non-Episodes showed no significant differences and were not included, nd = no difference

Comparison of Bowl and BCR areas: Episodes and Non-Episodes

Comparison of morphology between the bowl and BCR locations indicates that during Episodes there are more amorphous and less oval, round, sphere, flat, smooth-flat, and rectangular shaped particulates at the BCR site compared to the bowl area (Tables 14 & 29). This is consistent with the conclusion that road dust is the main source contributing to the BCR site. The morphological composition of Non-Episodes is consistent between the two areas suggesting that in normal ambient air, similar sources influence each location equally (Tables 14 & 29).

The mean particle size measurements show a similar trend between Episodes and Non-Episodes in both the bowl and BCR locations. The episodes in both locals have significantly larger particle sizes than the Non-Episodes (Tables 15 & 30). The BCR location had larger particle sizes for both Episodes and Non-Episodes than the Bowl area which is consistent with the conclusion that road dust (which contributes to coarse particulates) is a more important contributor at the BCR site than at the Bowl Location (Table 15 & 30). This trend is illustrated in the particle size distributions (Figures 11-14). Comparison of the Episodes indicates that there is a much larger proportion of coarse particulates at the BCR site (Figures 11 & 13). The Non-Episodes show a similar trend except the Bowl Location had 10% more fine particulates than the BCR location (Figures 12 & 14).

The qualitative chemical analyses indicate that during episodes, the BCR location contained more aluminum, magnesium, and silicon and less carbon, sodium, and sulphur than the bowl area which suggests that road dust has a greater influence in the BCR site (Tables 16 & 31). During Non-Episodes there were few differences between the two locations which is consistent with the morphological and particle size information. The PCA performed on the Episodes and Non-Episodes indicate the same general trends at both locations. During Episodes road dust and

industrial factors are dominant while during Non-Episodes road dust, industrial, and combustion factors are all significant (Tables 17-19,22-24,32-33).

Examination of differences in Particle Size and Filter Location

To determine the importance of filter location on randomization of results, the mean particle size was analyzed across locations on the filter of the Bowl area results. The filter was sampled in three locations (Figure 2). In the Non-Episode filters, there was a significant difference between the outside edge location (A) and the inner locations (B & C) (Table 38). The outside edge of the filter was receiving smaller particle sizes which may have been either a function of the small amounts of particulates being sampled. Overall results from the bowl area again indicate there is a significant difference between the different locations on the filter (Table 38). The difference is quite small (0.24 - 0.34μm) and should not have too much impact on the overall results. Therefore, in future studies, location of sample for SEM EDAX analysis can be taken at any location on the filter.

TABLE 38: Comparison of Particle Size Distribution on Different Filter Locations

Episode	Mean (μm)	SD	ANOVA Results
A	3.02	2.97	
B	3.07	2.68	
C	3.09	2.85	F(2,2697)= 2.63, p=0.072318
Non-Episode			
A	2.11^{a}	2.66	
B	2.73^{b}	2.86	
C	2.52^{b}	2.52	F(2,2698)= 43.92, p=0.000000
Total			
A	2.56^{a}	2.86	
B	2.90^{b}	2.78	
C	2.80^{b}	2.70	F(2,5398)= 33.99, p=0.00000

Episodes / Non-Episodes: A, B, C (n=900); Total (n=1800) Superscript indicates significant differences between means ($p<0.05$)

Comparison of Particle Diameter and Mass

As illustrated in Figures 17 & 18 the average particle size distribution is not similar to the average particle mass distribution. The mass of each particle was determined by calculating the volume of the particle ($4/3\pi r^3$) and multiplying by the average particle density found in soils ($2.65 g/m^3$). These figures indicate that particle mass has a similar distribution as size except for a small portion of larger particles which contribute significantly to the total mass. This suggests that contrary to the particle size where fine particulates dominate the distribution, they do not dominate the amount of mass present in the ambient air. These results should however be considered cautiously due to the assumptions required to determine the mass. As illustrated in this study, most of the particulates are not spherical in shape and mass is a function of elemental composition which varies significantly between particles (Linton *et al.*,1980).

Figure 17: Average Particle Size Distribution: Episodes and Non-Episodes

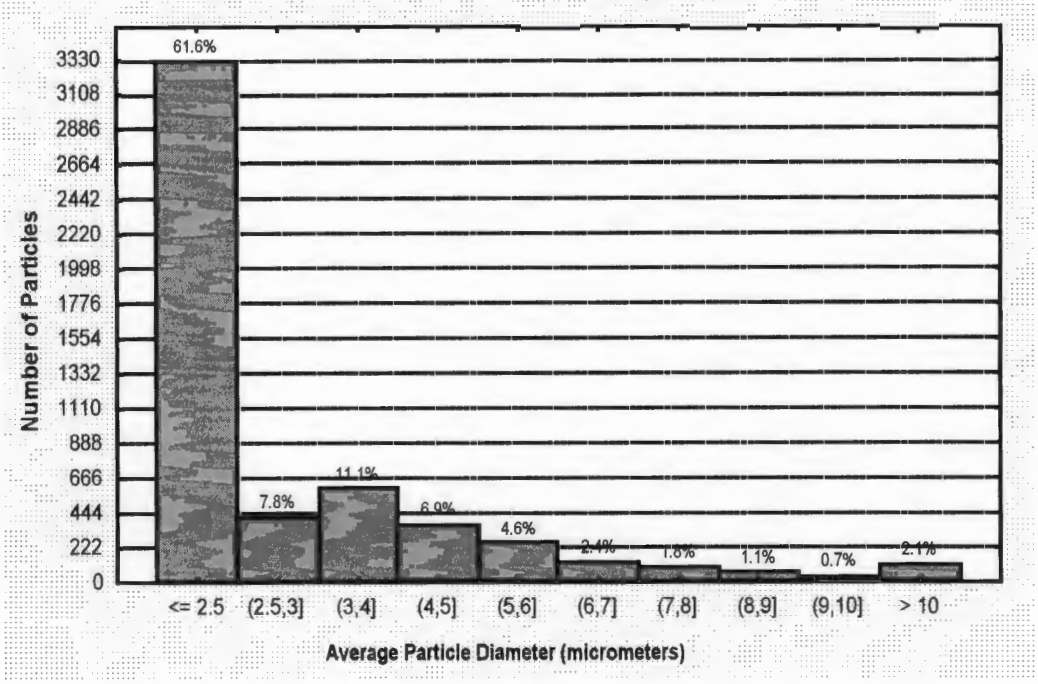
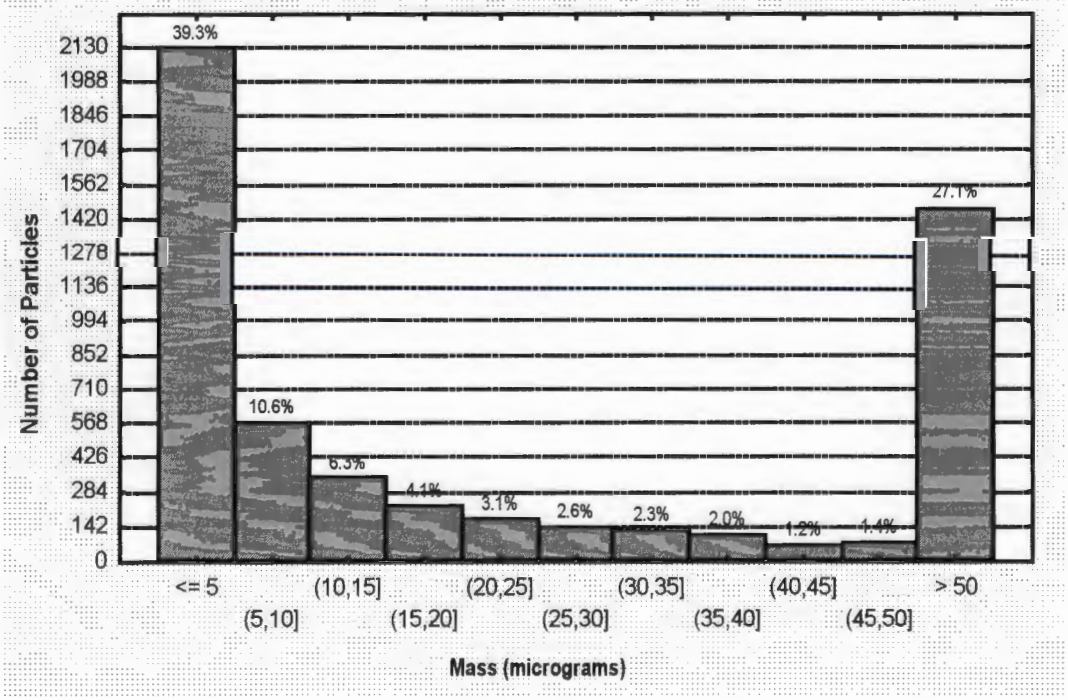


Figure 18: Average Particle Mass Distribution: Episodes and Non-Episodes



CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

Source Characterization

Morphological and chemical examinations of the major PM_{10} sources in the Prince George Airshed indicated the presence of some distinguishing features between the various sources present. Anthropogenic combustion sources such as beehive burners form more spherical and oval shaped particulates which is related to the high temperatures involved in their formation. In general, the majority of particulates examined had an amorphous shape which is not diagnostic for any individual source. Flat morphology was also detected in all sources and suggesting road dust or perhaps anthropogenic (incomplete combustion) origins.

The particle size distribution was the most informative and reliable data acquired in this study. The four sources of PM_{10} examined indicated different particle size distribution patterns. The beehive burner sample was dominated by fine particulates (<2.5μm) which was consistent with data published for combustion sources. The road dust samples contained significantly more particulates in the coarse fraction (>2.5μm), and is consistent with the behavior of the mechanical breakup of soil particulates. The presence of clay particulates account for the smaller size fraction found in the road dust samples (especially in the unpaved road dust).

The average road dust and beehive burner qualitative chemical composition from SEM-EDAX analysis were useful in recognizing differences between sources. These measurements were qualitative in nature with high standard deviations due to the methodology, and the large variation in chemical compositions within the particle samples. Despite the qualitative nature of the data, there were recognizable differences between the mean concentrations of many elements. In general, the beehive burner sample had more carbon while the road dust samples had more

aluminum, magnesium, and silicon which is consistent with the literature. These differences were used to identify the relative contribution of sources in the ambient samples.

The ICP bulk quantitative analysis was not considered informative due to the problems encountered with extraction. The teflon coated glass fiber filters contributed extensive contaminants during the extraction procedure which masked much of the information for the PM_{10}. Filters with significant PM_{10} samples produced more interpretable results because the blank did not significantly mask the sample. The ICP results indicated some differences between the sources, especially the pulp mill PM_{10} suggesting different elemental composition with respect to chromium, magnesium, nickel, and phosphorus. The results from the BCR site showed few significant differences between elemental composition which also may have been attributable to interference from the filter. The quantitative analysis of sources and ambient PM_{10} is important for discerning differences and possible tracer elements, however this analysis must be replicated using a different filter media for satisfactory results.

Episodic and Non-Episodic events

Morphological and chemical examination of the ambient PM_{10} in the Prince George Airshed illustrated the contribution from major PM_{10} sources. The Episodes tend to be dominated by amorphous shaped particulates, while Non-Episodes show a large variety of particulate shapes such as spherical and oval. The other particulate types (rectangular, round, rod, and cube) were rarely seen and it was unclear as to their origins. Overall, due to the predominance of amorphous particulates, the use of morphological features to characterize the ambient PM_{10} in Prince George was not as useful as other techniques.

The mean particle size and particle size distributions illustrated a definite trend between most Episodes and Non-Episodes. Most of the Episodes examined contained a bimodal

distribution with a large concentration of particulates in the fine fraction (<2.5μm) and a second smaller peak at the 3-4μm range. The fine particulates generally represent anthropogenic sources such as combustion while the coarse size fractions represent crustal materials such as road dust. Although, road dust source contributes some fine fraction of PM_{10} to the ambient air, its major contribution to the coarse size fractions is diagnostic for its presence in ambient PM_{10}. All but one of the Episodes examined contained this second peak indicating that road dust was an important factor in Episodes. The first Episode (950121) for the bowl area was dominated by anthropogenic sources as indicated by the distinctive small mean particulate size. The Non-Episodes examined were highly positively skewed and contained a large peak in the fine fraction of PM_{10} and a much smaller generally indiscernible peak at the 3-4μm diameter range. In Non-Episodes, anthropogenic sources influenced the ambient PM_{10} as indicated by the mean particle size and particle size distribution. The fine fraction which is believed to cause considerably more health problems, dominates most of the Episodes/Non-Episodes examined. There is evidence that PM_{10} ambient levels less than $20\mu g/m^3$ may have health impacts and the dominance of $PM_{2.5}$ in instances of lower ambient PM_{10} levels may be one explanation for this. The Episodes also illustrated that road dust and industrial sources influence the PM_{10} levels differently at various locations and during Episodic/Non-Episodic events.

The mean qualitative chemical composition was useful in recognizing the importance of different sources in Episodes and Non-Episodes. The influence of the road dust source was associated with a dominance of silicon, aluminum and magnesium while predominance of carbon indicated the contribution from combustion sources. The presence of sulphur in the particulates was expected considering the industrial sources present in Prince George, however, the amount of sulphur in the Non-Episodes was slightly higher than in the Episodes suggesting that sulphur

particulates are constantly present in the ambient air. The presence of sulphur in the fine fraction (which dominate non-episodes) may have health implications. It is unclear whether the particulates themselves originate from a specific source or the PM_{10} is interacting with sulphur aerosols to form sulphur coated PM_{10}.

The correlation of mean particle diameter and chemical composition revealed very weak relationship suggesting that the Prince George PM_{10} is reasonable uniform chemically in all size ranges. The qualitative nature of the chemical composition may have affected the relationships.

The comparison of morphology and chemical composition revealed some relationships between morphological shapes seen in the ambient PM_{10} and chemical composition. The episodes examined indicated that percentages of silicon, aluminum, and magnesium in amorphous particles were larger in those Episodes dominated by road dust. The rectangular shapes contained very high levels of sulphur and calcium indicative of an industrial source. All the morphological shapes identified except (smooth-flat) contained sulphur suggesting that there is an interaction occurring between sulphur dioxide (SO_2) which is coating the fine particulates in the ambient air. If sulphur is being transported with the fine particulates it may be causing health impacts additional to those caused by PM_{10}.

The above trends with respect to morphology, particle size, particle size distribution, and chemical composition were also present in the BCR site. The dominance of the road dust source was especially evident in the BCR episodes.

Contribution from Various Sources to Ambient PM_{10} Composition

The final objective of this study was to determine the contribution of various sources during Episodic/Non-Episodic events. Principal Component Analyses (PCA) show four discernable sources contributing to the ambient PM_{10}: Road Dust, Industrial, Combustion, and

Salt. These sources were not identical in elemental loadings throughout the various PCA due to variability in source composition and meteorological conditions. The particulate emitted from a source often undergoes changes due to temperature, relative humidity, and the presence of aerosols which may react with it. The four main sources (factors) were identified by interpreting the pattern and extent of loadings of particular elements and the correlation between loadings (positive/negative). Most of the Episodes analyzed were dominated by various types of road dusts. The BCR site Episodes were characterized by high levels of road dust. Episode 1 (950122) for the bowl area and the Non-Episodes, contained more particles of anthropogenic origin (industrial/combustion). Generally, Non-Episodes have more distinct sources of PM_{10} compared to the Episodes because road dust is less dominant. The salt factor could be a result of several different sources. The salt could be a result of either industrial sources or winter salting applications. The combustion source has to be considered a combination of all possible combustion sources (beehive burner, vehicles, fireplace burning, etc...). Study of organic particulates would be required to distinguish between these sources.

The combined results of the various analyses indicate it is possible to determine source apportionment using the microscopic techniques described in this study. The combined use of morphological, particulate diameter, and particulate elemental composition can be used to distinguish between road dust and industrial/combustion sources present in the PM_{10} in the Prince George Airshed.

RECOMMENDATIONS FOR FUTURE STUDY

1. In order to expand the knowledge about the sources and the ambient PM_{10} further studies are required. Any analysis using ICP would be much more successful if a different filter type was used during the collection. The glass fiber filter normally used by the Ministry of the Environment contributes too much contamination for quantitative analysis. A cellulose or pure teflon filter should be used for future analysis (Chow,1995). In order to examine the different size fractions quantitatively, a cascading or dichotomous collector could be incorporated into sampling procedure.
2. Future definition of the organic portion (examination for tracer compounds unique to specific sources) of ambient PM_{10} would help to characterize combustion sources and their contributions to total PM_{10}. This analysis would be most successful if glass fiber filters and foam (PUF) were used to trap the volatile and solid organic PM_{10}.
3. For a complete study of PM_{10} in the Prince George airshed, concurrent sampling using Teflon filters (Microscopic), Glass fiber filters (Organic), and Cellulose filters (Elemental - ICP) would produce a complete characterization of the ambient PM_{10} for specific periods of time.
4. Further analysis of the PM_{10} incorporating organic composition in the BCR site should be considered due to the high levels of PM_{10} in the area. Further definition of source apportionment in this area would provide useful information that could be applied to reduction strategies. There are a considerable number of people working in that area being exposed to these PM_{10} levels that are considered detrimental to health. Serious consideration should be given to decreasing the PM_{10} levels by paving roads.
5. Improved source profiles of the major PM10 contributors using organic and elemental analyses would be useful in future source apportionment.

6. A health study examining the effects of PM_{10} on health in the Prince George area would be useful. This study could be incorporated into the complete study of PM_{10} (Recommendation #3) which would allow researchers to compare levels of PM_{10} over a long period of time with health indicators.

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Appendix A

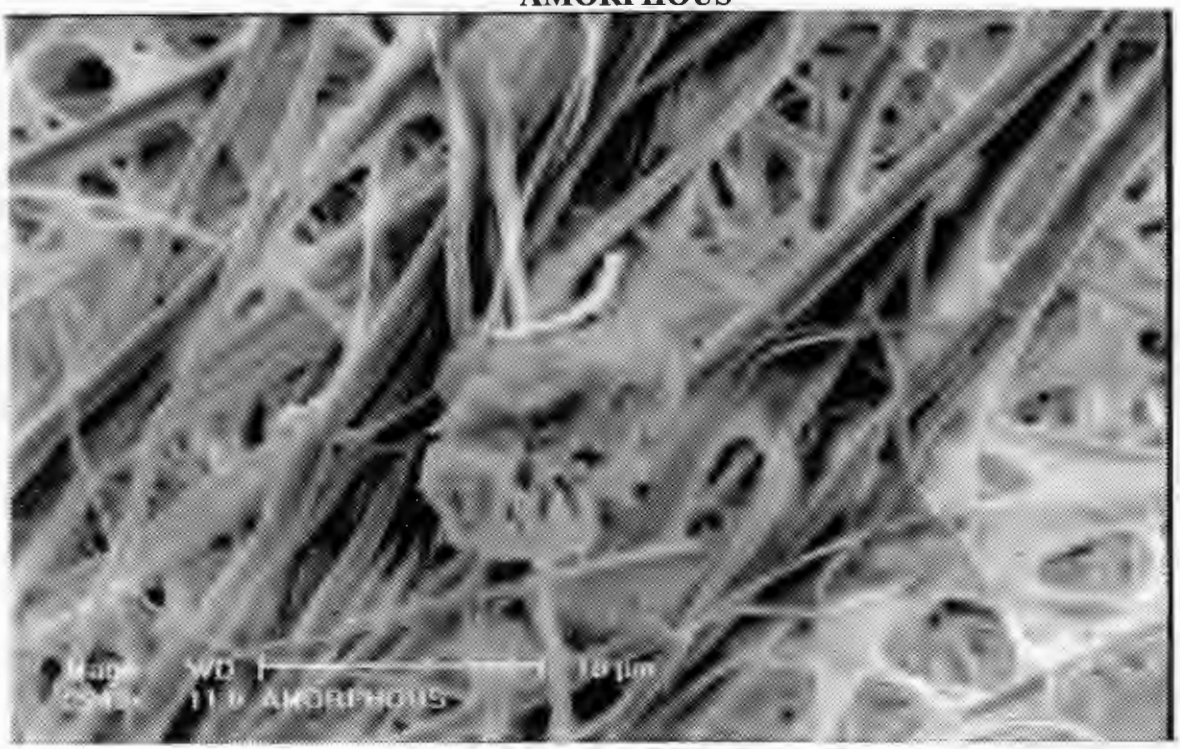
TABLE 1: Meteorological Conditions on Study Dates

Dates	Episode / Non-Episode BCR / Bowl	Temperature °C	Wind Speed (m/s)	Wind Direction	Interpretation
April 8, 1994	BCR Episode	-2 to 13	0-5.5	North	Wind speeds high, no evidence of inversion
September 23,1994	BCR Episode	12 to 20	0-3	South	Night-time cooling may have caused inversion, strong wind speeds during day
January 21,1995	Bowl Episode 1	-10 to -7	0-1	N/A	Conditions probably promoted stable boundary layer - causing inversion
March 16, 1995	BCR Episode	-2 to 12	0-3	South-West	Night-time cooling and calm winds may have caused inversion, dissipating by 7AM
March 28, 1995	Bowl Episode 2 / BCR Episode	-1 to 14	0-3	North	Night-time cooling may have caused inversion, dissipating by 9AM
August 31, 1995	BCR Episode	5 to 21	1.0-4	South	No indication of inversion
January 22,1996	BCR / Bowl Non-Episode 1	-34.5 to -19	0.1-1.7	North	No indication of inversion
February 27, 1996	Bowl Episode 3	-18.1 to -0.5	0-5.7	North	Night-time cooling may have caused an inversion, dissipating by 10AM
March 4, 1996	Bowl Non-Episode 3 / BCR Episode	-14 to -4	1-6.2	North	Very good air circulation
May 9, 1996	BCR / Bowl Non-Episode 3	-1.7 to 6.9	0.3-5.7	North	Excellent air circulation, precipitation
August 13, 1996	BCR Episode	8 to 22	0.3-3.7	South	No indication of inversion

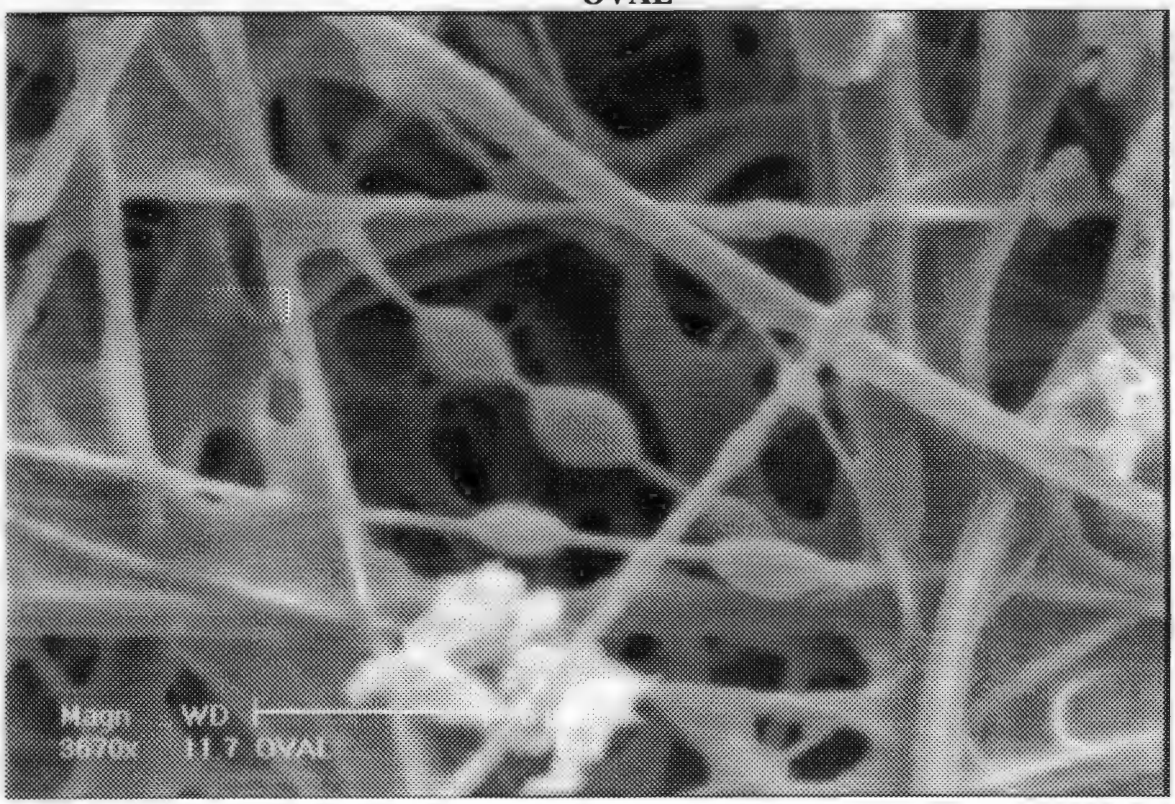
(B.C. Environment,1998; Environment Canada 1994-1996)

Appendix B: Morphological Characterization

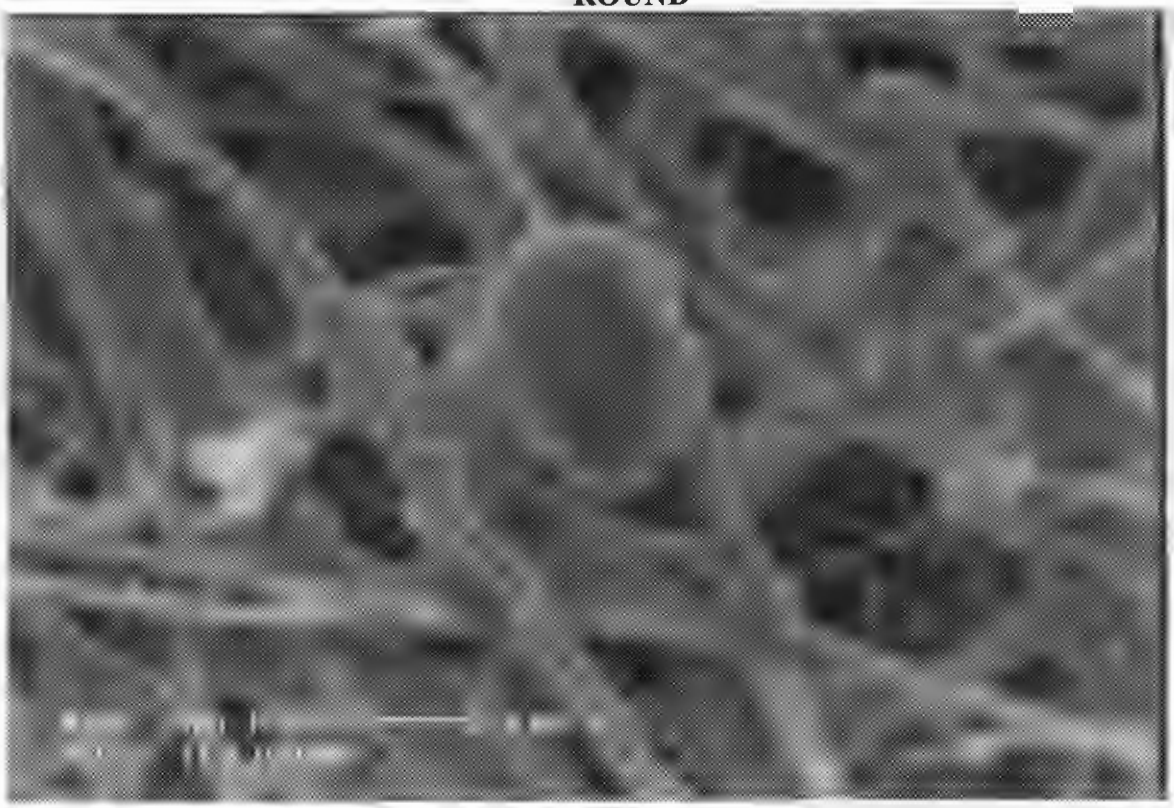
AMORPHOUS



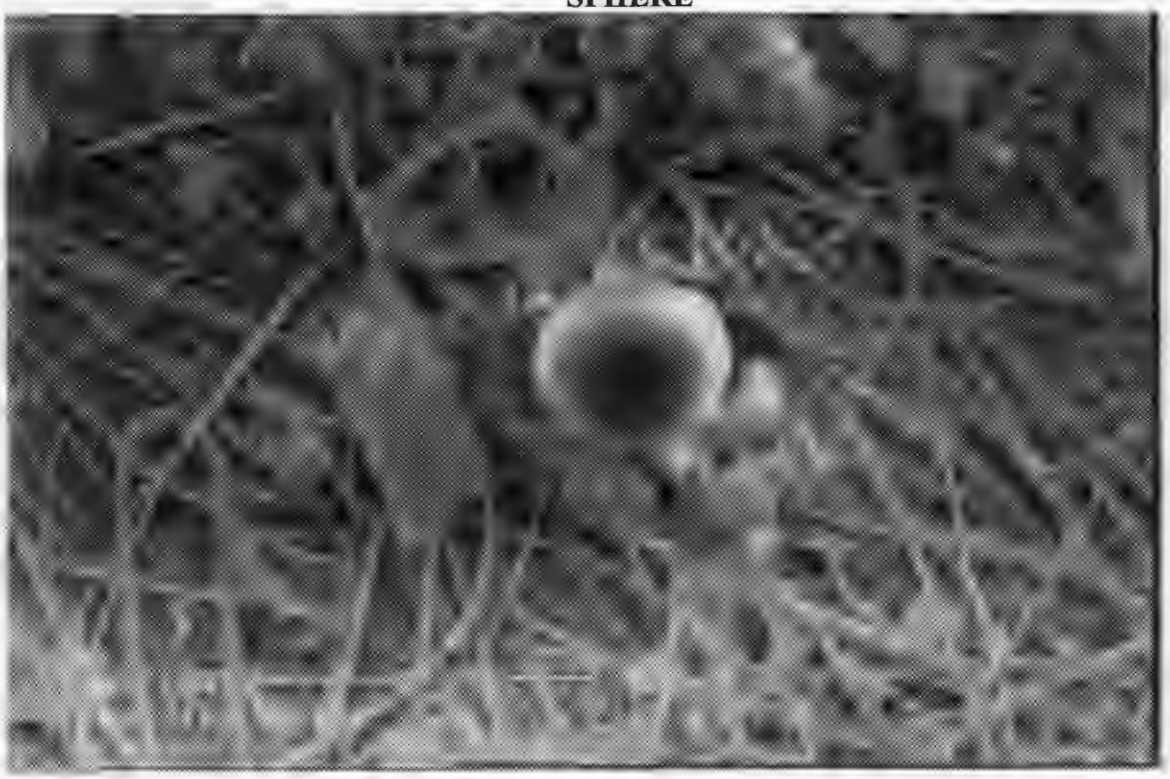
OVAL



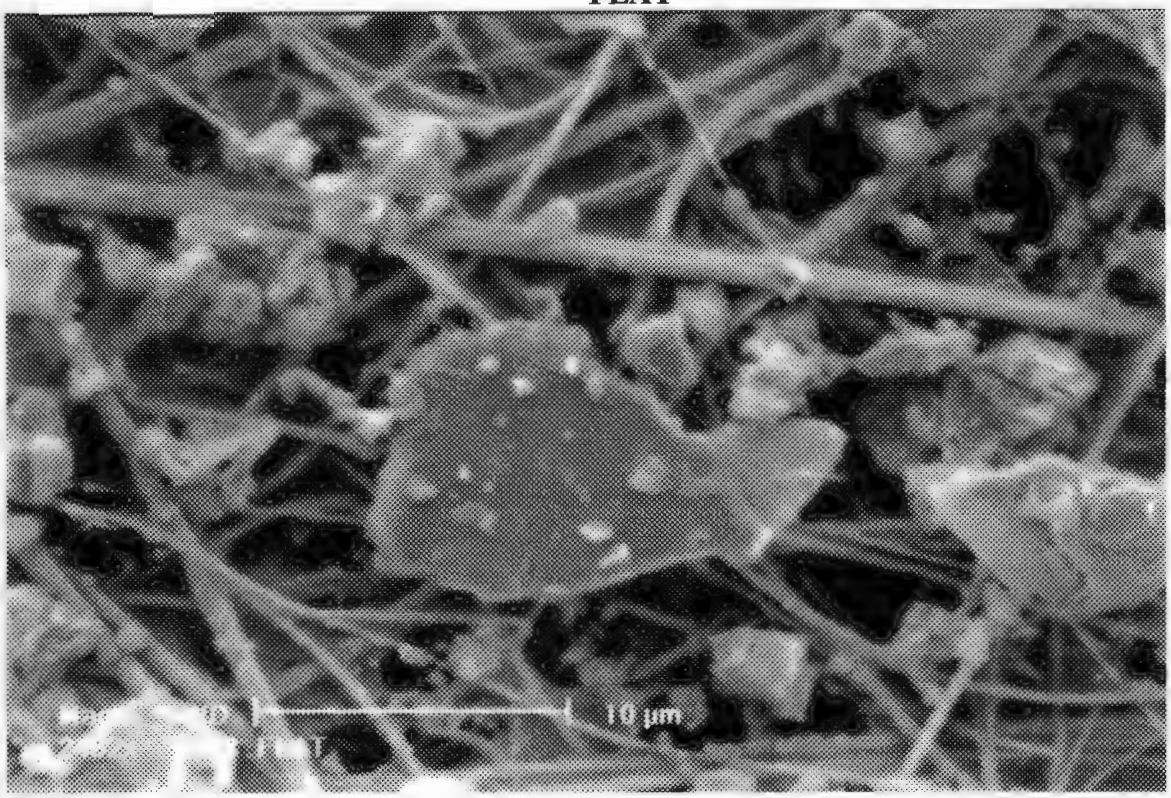
ROUND



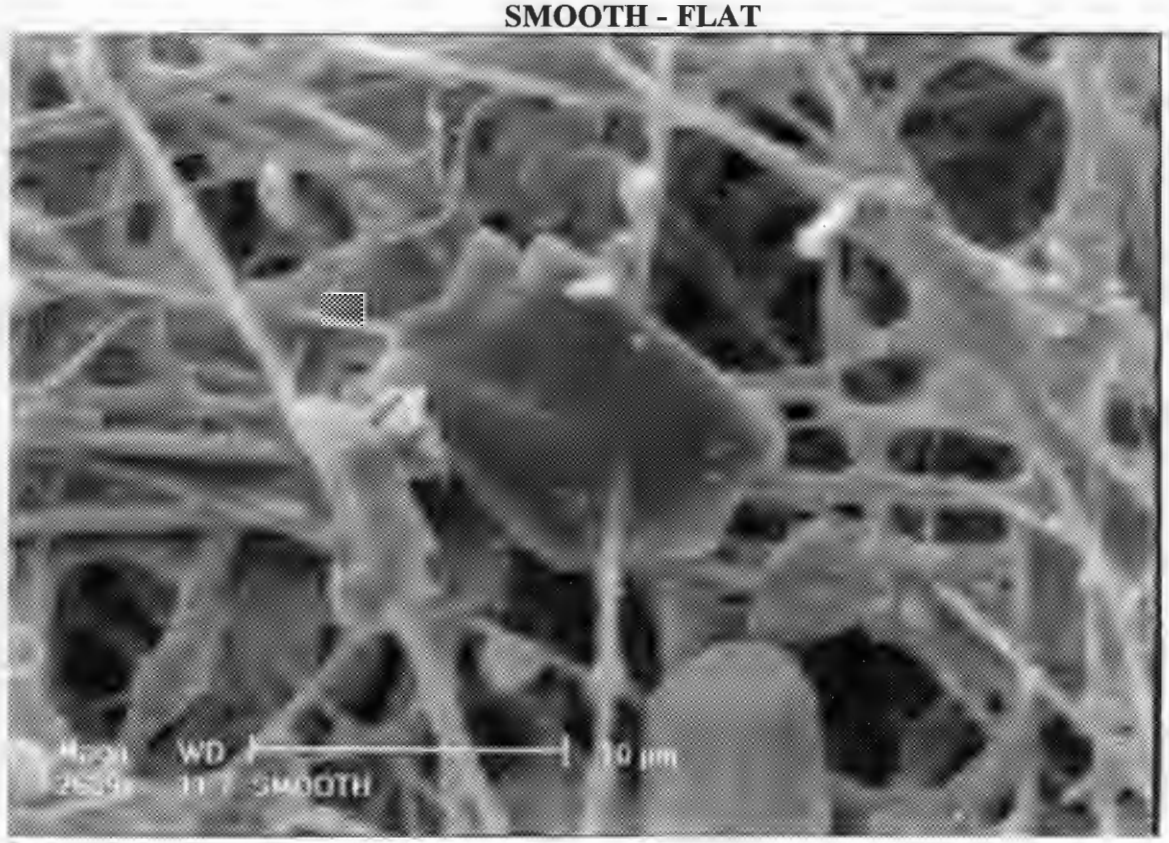
SPHERE



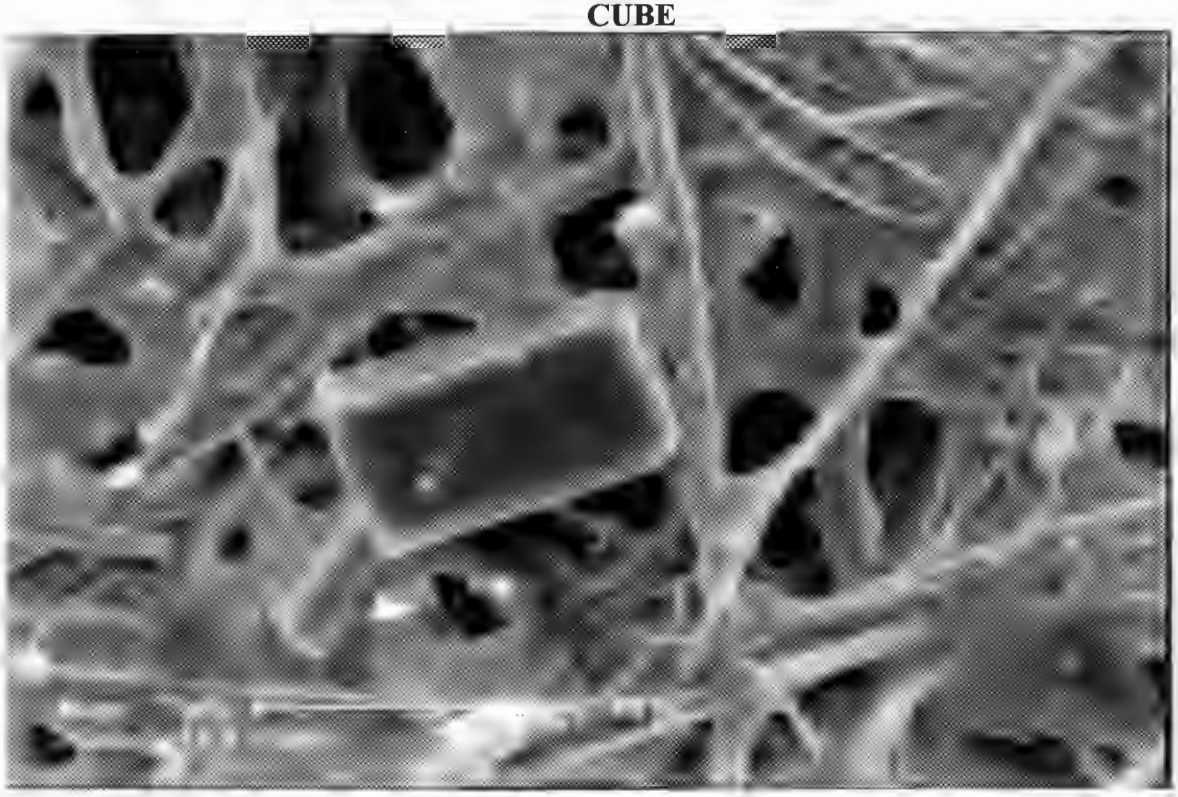
FLAT



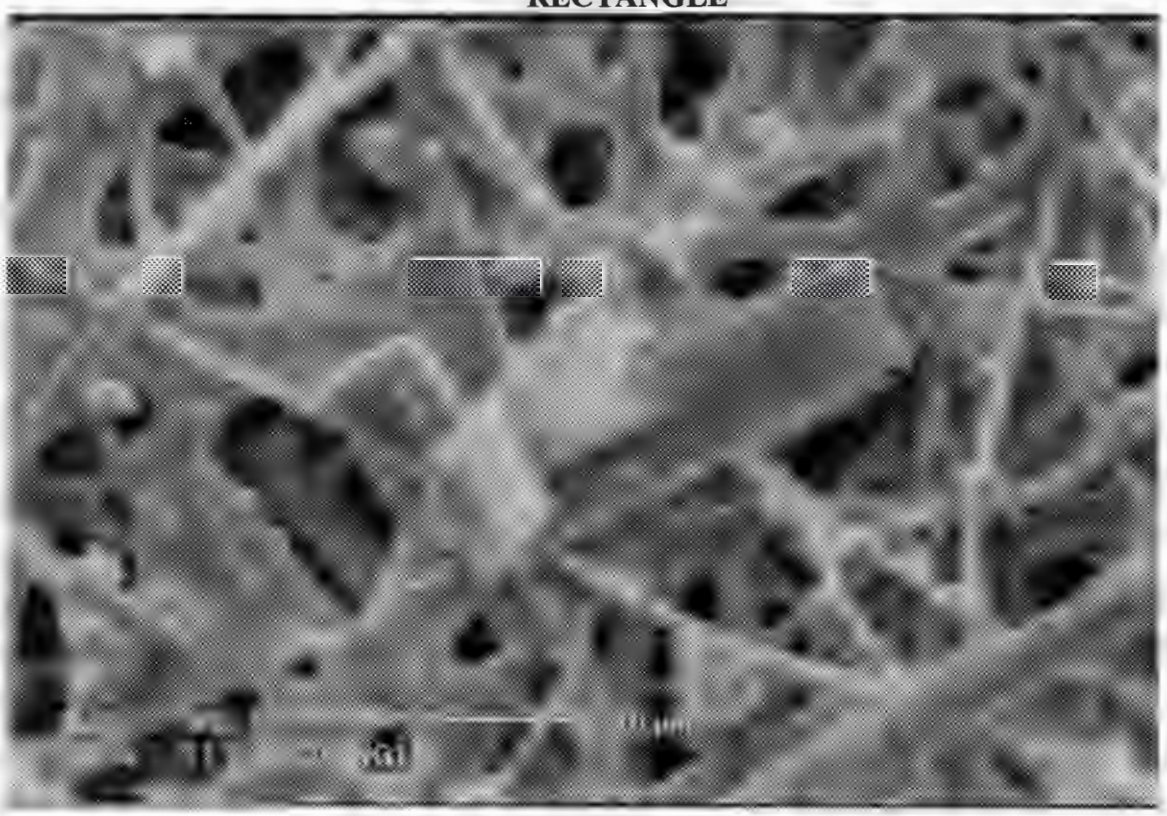
SMOOTH - FLAT



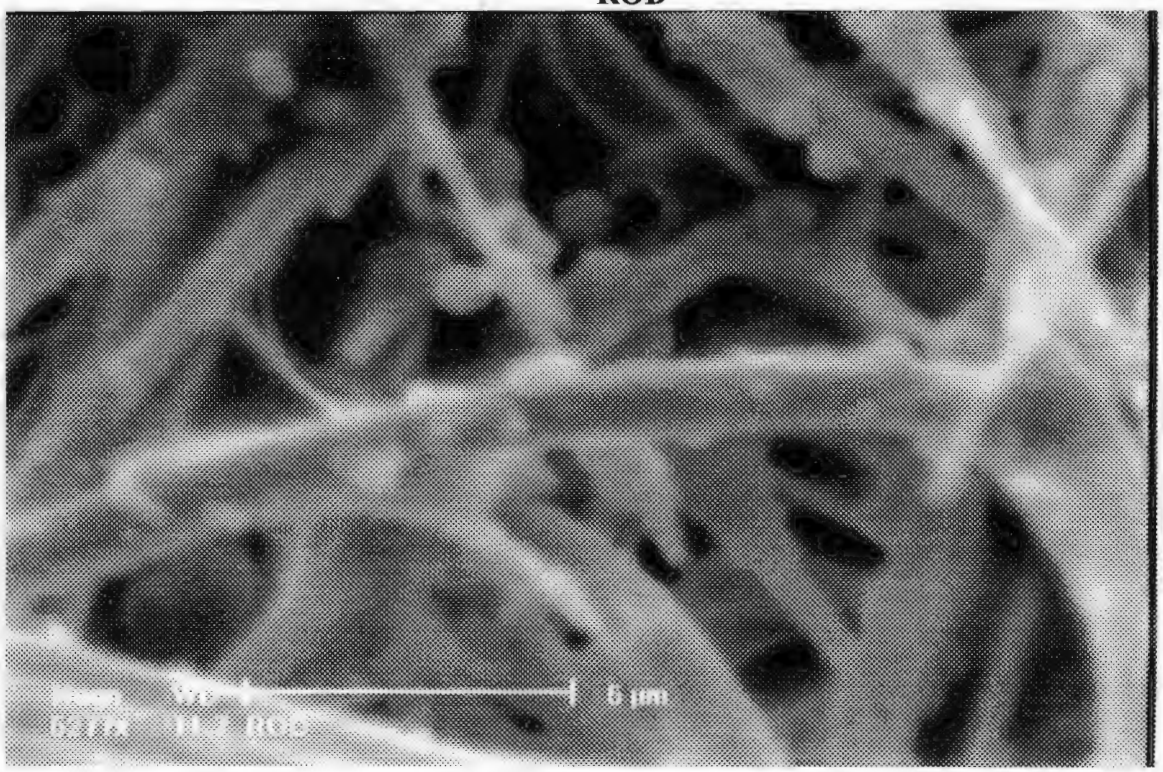
CUBE



RECTANGLE



ROD



APPENDIX C: Data from Carbon Coated Sample (950121 Van Bien)

Particulate	Sodium	Magnesium	Aluminum	Silicon	Sulphur	Potassium	Calcium	Titanium	Iron
2d1	63.14	0.00	0.00	15.51	12.84	8.51	0.00	0.00	0.00
2d2	52.30	0.00	8.75	38.95	0.00	0.00	0.00	0.00	0.00
2d3	38.54	0.00	5.50	27.49	5.68	2.44	0.00	20.35	0.00
2d4	66.99	0.00	0.00	13.76	13.98	5.28	0.00	0.00	0.00
2d5	44.33	0.00	9.64	46.04	0.00	0.00	0.00	0.00	0.00
2d6	70.26	0.00	0.00	0.00	21.16	8.58	0.00	0.00	0.00
2d7	0.00	54.59	0.00	45.41	0.00	0.00	0.00	0.00	0.00
2d8	25.94	3.90	26.44	41.84	1.89	0.00	0.00	0.00	0.00
2d9	16.19	0.00	0.00	10.21	23.93	0.00	49.67	0.00	0.00
2d10	37.23	0.00	7.58	50.96	2.13	2.10	0.00	0.00	0.00
2d11	62.41	0.00	0.00	37.59	0.00	0.00	0.00	0.00	0.00
2d12	63.31	0.00	0.00	14.52	14.32	7.85	0.00	0.00	0.00
2d13	40.76	0.00	11.66	41.60	5.97	0.00	0.00	0.00	0.00
2d14	43.31	0.00	5.20	33.81	12.14	5.55	0.00	0.00	0.00
2d15	38.17	0.00	8.46	51.58	0.00	1.80	0.00	0.00	0.00
2d16	12.89	0.00	5.28	79.18	2.64	0.00	0.00	0.00	0.00
2d17	55.05	0.00	5.05	28.98	6.14	4.78	0.00	0.00	0.00
2d18	57.30	0.00	0.00	21.35	13.77	7.58	0.00	0.00	0.00
2d19	78.17	0.00	0.00	9.65	12.18	0.00	0.00	0.00	0.00
2d20	39.71	0.00	8.25	46.71	3.17	2.15	0.00	0.00	0.00
2d21	64.94	0.00	0.00	17.09	12.29	5.68	0.00	0.00	0.00
2d22	43.83	0.00	7.15	45.03	2.43	1.57	0.00	0.00	0.00
2d23	36.89	0.00	0.00	11.43	29.91	14.53	7.25	0.00	0.00
2d24	47.58	0.00	5.21	34.31	8.84	4.06	0.00	0.00	0.00
2d25	32.20	0.00	8.69	52.67	3.72	2.72	0.00	0.00	0.00
2d26	49.50	0.00	5.87	31.36	8.18	5.10	0.00	0.00	0.00
2d27	54.12	0.00	0.00	32.22	13.66	0.00	0.00	0.00	0.00
2d28	40.38	0.00	4.78	26.35	18.45	1.98	8.06	0.00	0.00
2d29	53.38	0.00	0.00	35.89	10.73	0.00	0.00	0.00	0.00
2d30	15.36	0.00	0.00	3.80	44.32	13.61	22.91	0.00	0.00
2d31	40.79	0.00	7.31	44.29	4.39	3.21	0.00	0.00	0.00
2d32	47.93	0.00	5.95	32.81	9.57	3.74	0.00	0.00	0.00
2d33	45.02	0.00	8.95	44.70	0.00	1.33	0.00	0.00	0.00
2d34	46.49	0.00	8.37	45.14	0.00	0.00	0.00	0.00	0.00
2d35	45.43	0.00	7.68	42.21	2.55	2.13	0.00	0.00	0.00
2d36	56.28	0.00	8.23	35.49	0.00	0.00	0.00	0.00	0.00
2d37	27.60	0.00	3.05	20.34	27.04	11.79	10.19	0.00	0.00
2d38	53.48	0.00	0.00	1.34	45.17	0.00	0.00	0.00	0.00
2d39	56.29	0.00	0.00	21.45	16.06	6.20	0.00	0.00	0.00
2d40	29.34	0.00	7.93	54.50	4.51	3.72	0.00	0.00	0.00
2d41	61.90	0.00	3.58	20.04	9.17	5.32	0.00	0.00	0.00
2d42	51.32	0.00	6.09	34.13	5.99	2.46	0.00	0.00	0.00
2d43	52.68	0.00	5.67	33.23	5.50	2.92	0.00	0.00	0.00
2d44	38.59	0.00	7.22	49.37	1.79	3.02	0.00	0.00	0.00
2d45	44.07	0.00	7.46	46.90	0.00	1.57	0.00	0.00	0.00
2d46	58.86	0.00	0.00	26.71	10.94	3.50	0.00	0.00	0.00
2d47	43.58	0.00	6.18	30.56	13.83	5.85	0.00	0.00	0.00
2d48	37.13	0.00	6.96	44.22	8.36	3.34	0.00	0.00	0.00
2d49	51.69	4.92	5.71	31.23	4.99	1.46	0.00	0.00	0.00

2d50	49.03	0.00	6.41	36.63	4.28	3.65	0.00	0.00	0.00
2d51	25.25	33.73	16.79	15.21	4.46	1.29	0.00	0.00	3.26
2d52	67.84	0.00	0.00	13.68	12.23	6.24	0.00	0.00	0.00
2d53	62.23	0.00	0.00	0.00	37.77	0.00	0.00	0.00	0.00
2d54	35.43	0.00	5.12	48.11	8.34	3.00	0.00	0.00	0.00
2d55	43.38	0.00	7.76	48.87	0.00	0.00	0.00	0.00	0.00
2d56	46.64	0.00	6.97	41.11	3.19	2.09	0.00	0.00	0.00
2d57	45.94	0.00	7.29	43.42	1.77	1.58	0.00	0.00	0.00
2d58	44.04	0.00	7.67	44.16	2.66	1.47	0.00	0.00	0.00
2d59	31.91	0.00	7.25	33.00	20.98	6.85	0.00	0.00	0.00
2d60	32.83	0.00	0.00	2.98	35.09	1.76	27.34	0.00	0.00
2d61	29.14	0.00	0.00	7.24	41.85	0.00	21.77	0.00	0.00
2d62	71.65	0.00	0.00	6.54	13.84	7.96	0.00	0.00	0.00
2d63	35.36	0.00	7.64	51.50	3.17	2.33	0.00	0.00	0.00
2d64	48.44	0.00	6.73	37.29	5.38	2.16	0.00	0.00	0.00
2d65	29.96	0.00	2.14	15.07	32.04	12.43	8.36	0.00	0.00
2d66	37.88	0.00	6.92	41.34	10.04	3.82	0.00	0.00	0.00
2d67	50.24	0.00	8.42	40.06	0.00	1.28	0.00	0.00	0.00
2d68	15.70	0.00	0.00	6.15	42.40	14.33	21.43	0.00	0.00
2d69	49.52	0.00	6.11	38.33	6.04	0.00	0.00	0.00	0.00
2d70	28.69	0.00	0.00	6.08	35.72	18.47	11.04	0.00	0.00
2d71	26.70	0.00	2.80	16.37	32.14	12.24	9.76	0.00	0.00
2d72	22.60	0.00	0.00	4.72	39.73	21.50	11.46	0.00	0.00
2d73	19.82	0.00	0.00	0.00	46.19	16.81	17.18	0.00	0.00
2d74	8.87	35.61	25.87	25.49	2.05	0.52	0.00	0.00	1.60
2d75	36.24	0.00	7.90	47.31	5.74	2.80	0.00	0.00	0.00
2d76	18.33	0.00	1.95	11.21	36.66	9.87	21.97	0.00	0.00
2d77	13.26	0.00	0.00	9.71	42.57	16.00	18.46	0.00	0.00
2d78	16.78	0.00	7.59	62.84	4.21	5.92	2.66	0.00	0.00
2d79	20.59	0.00	0.00	7.91	37.49	17.36	16.65	0.00	0.00
2d80	16.53	0.00	8.28	65.87	3.40	4.18	1.75	0.00	0.00
2d81	29.91	0.00	8.25	50.08	7.92	3.84	0.00	0.00	0.00
2d82	51.25	0.00	0.00	48.75	0.00	0.00	0.00	0.00	0.00
2d83	65.58	0.00	0.00	21.54	7.64	5.23	0.00	0.00	0.00
2d84	57.55	0.00	0.00	29.45	9.56	3.44	0.00	0.00	0.00
2d85	61.84	0.00	0.00	26.50	11.67	0.00	0.00	0.00	0.00
2d86	46.05	0.00	7.47	42.55	2.29	1.65	0.00	0.00	0.00
2d87	45.78	0.00	0.00	0.00	33.67	20.55	0.00	0.00	0.00
2d88	57.08	0.00	0.00	37.80	5.11	0.00	0.00	0.00	0.00
2d89	32.39	0.00	4.46	25.46	18.00	9.43	10.26	0.00	0.00
2d90	47.93	0.00	0.00	35.47	16.60	0.00	0.00	0.00	0.00
2d91	58.69	0.00	0.00	11.48	21.51	8.32	0.00	0.00	0.00
2d92	17.25	0.00	0.00	8.33	40.33	12.58	21.51	0.00	0.00
2d93	54.33	0.00	0.00	15.34	30.32	0.00	0.00	0.00	0.00
2d94	26.04	0.00	3.68	66.52	3.76	0.00	0.00	0.00	0.00
2d95	63.75	0.00	0.00	27.45	8.80	0.00	0.00	0.00	0.00
2d96	33.30	0.00	0.00	8.26	34.47	12.24	11.73	0.00	0.00
2d97	28.29	0.00	2.94	20.78	23.56	14.02	10.41	0.00	0.00
2d98	61.72	0.00	0.00	38.28	0.00	0.00	0.00	0.00	0.00
2d99	67.30	0.00	0.00	11.51	15.87	5.32	0.00	0.00	0.00
2d100	66.65	0.00	0.00	18.53	9.92	4.90	0.00	0.00	0.00

APPENDIX D: Blank Teflon Filter

Particulate #	Carbon	Oxygen	Fluorine	Sodium	Aluminum	Silicon	Potassium
TB1	3.60	27.45	50.57	8.65	1.20	8.53	0.00
TB2	3.28	27.48	50.06	9.04	1.31	8.59	0.24
TB3	2.75	33.32	45.00	9.84	1.66	7.18	0.25
TB4	3.46	26.37	52.10	8.56	1.22	8.02	0.26
TB5	2.95	29.36	46.33	8.80	1.48	10.66	0.42
TB6	5.00	19.83	60.89	5.99	0.93	7.10	0.26
TB7	2.94	27.28	49.20	8.60	1.61	9.96	0.41
TB8	4.44	21.33	60.73	6.44	0.92	6.14	0.00
TB9	5.37	16.72	69.64	3.74	0.43	4.10	0.00
TB10	2.63	30.08	49.24	8.75	1.23	7.82	0.25
TB11	3.35	26.92	54.17	8.32	1.26	5.77	0.22
TB12	2.49	35.14	42.38	9.69	1.42	8.61	0.27
TB13	1.92	29.78	53.18	8.26	1.06	5.67	0.15
TB14	4.40	19.32	66.18	4.27	0.64	5.07	0.14
TB15	0.20	65.67	10.15	7.23	2.19	14.38	0.17
TB16	1.03	40.18	34.71	11.34	1.82	10.56	0.36
TB17	2.74	28.46	50.65	7.96	1.29	8.59	0.31
TB18	2.70	29.85	48.08	8.30	1.40	9.32	0.36
TB19	1.90	32.39	42.41	9.97	1.74	11.16	0.43
TB20	3.34	24.89	53.72	7.90	1.26	8.58	0.31
TB21	1.38	38.97	32.88	10.16	2.01	13.91	0.70
TB22	1.04	46.61	30.64	9.31	1.54	10.61	0.25
TB23	0.51	48.04	16.70	10.72	3.16	20.15	0.71
TB24	2.47	32.45	43.33	10.74	1.62	9.11	0.28
TB25	1.64	48.99	23.04	11.85	1.86	12.13	0.49
TB26	1.85	31.63	44.45	10.09	1.74	9.90	0.35
TB27	1.78	39.50	35.05	11.72	1.63	9.96	0.35
TB28	1.21	46.64	27.66	12.55	1.87	9.79	0.28
TB29	1.45	37.04	36.87	10.73	1.85	11.66	0.40
TB30	2.00	32.34	42.60	9.76	1.81	11.05	0.45
TB31	3.19	27.74	47.21	7.30	1.69	12.15	0.72
TB32	2.64	31.26	48.29	9.26	1.11	7.21	0.23
TB33	1.46	43.51	33.26	10.41	1.59	9.48	0.30
TB34	1.57	37.90	34.58	10.89	2.11	12.46	0.50
TB35	1.01	48.78	24.82	12.25	1.74	10.99	0.40
TB36	2.33	33.45	41.54	10.78	1.75	9.79	0.37
TB37	3.19	25.26	53.09	7.22	1.29	9.56	0.40
TB38	1.28	36.14	38.65	10.02	1.73	11.71	0.47
TB39	3.19	25.41	51.43	7.33	1.43	10.71	0.48
TB40	0.64	53.05	18.92	10.82	2.12	13.95	0.50
TB41	2.46	27.01	46.51	8.64	2.01	12.84	0.54
TB42	6.19	16.14	66.82	4.03	0.72	5.95	0.15
TB43	0.50	52.85	19.19	9.16	2.56	15.46	0.29
TB44	2.29	36.38	42.86	9.15	1.04	8.06	0.23
TB45	4.70	18.78	64.24	6.43	0.80	4.89	0.16
TB46	2.58	32.37	45.39	8.39	1.13	9.85	0.30
TB47	1.62	40.03	33.61	7.24	2.27	14.96	0.28
TB48	1.04	38.56	34.99	8.68	2.15	14.26	0.33
TB49	4.99	18.08	64.61	5.36	0.75	6.03	0.19
TB50	3.98	23.53	55.57	7.31	1.07	8.25	0.28
TB51	3.73	23.96	56.14	8.02	1.01	6.96	0.18
TB52	0.77	60.17	13.39	8.05	2.20	15.07	0.34

TB53	3.85	24.83	52.87	7.34	1.54	9.30	0.28
TB54	4.45	22.83	58.20	6.82	0.84	6.64	0.23
TB55	1.06	26.83	44.42	7.36	2.26	17.14	0.94
TB56	1.88	28.00	44.51	8.82	1.78	14.31	0.70
TB57	1.76	39.66	34.03	10.99	1.62	11.52	0.42
TB58	2.08	31.34	41.16	9.63	2.06	13.21	0.53
TB59	0.89	32.34	31.10	8.17	3.05	23.11	1.35
TB60	3.02	29.18	46.72	9.92	1.45	9.39	0.32
TB61	4.01	23.92	56.24	8.20	1.05	6.36	0.23
TB62	3.51	24.24	57.29	8.08	0.93	5.77	0.18
TB63	2.24	35.84	41.14	9.91	1.66	8.94	0.26
TB64	5.14	16.95	64.98	5.95	0.89	5.92	0.17
TB65	1.59	42.86	30.78	11.19	1.63	11.55	0.40
TB66	3.05	25.83	50.11	8.12	1.47	10.86	0.57
TB67	3.00	26.54	51.64	8.83	1.44	8.30	0.25
TB68	1.65	38.83	34.89	10.46	1.79	11.94	0.45
TB69	3.56	25.23	54.19	8.27	1.23	7.28	0.24
TB70	0.92	29.39	39.07	10.79	2.73	16.34	0.77
TB71	0.97	35.57	34.67	11.61	2.32	14.27	0.59
TB72	3.83	19.58	63.26	7.04	0.97	5.13	0.20
TB73	2.03	30.68	46.31	10.07	1.61	8.99	0.30
TB74	1.48	41.17	31.93	11.92	1.86	11.26	0.38
TB75	2.00	30.40	36.14	10.09	2.69	17.94	0.74
TB76	6.83	9.15	78.19	2.67	0.38	2.77	0.00
TB77	1.40	25.68	49.34	8.45	1.95	12.58	0.60
TB78	1.33	47.21	26.04	11.92	1.70	11.37	0.44
TB79	4.60	23.31	56.12	8.01	1.15	6.56	0.25
TB80	0.78	45.82	22.76	11.54	2.49	15.94	0.67
TB81	4.06	24.39	55.98	8.26	1.14	5.98	0.19
TB82	1.14	34.11	40.14	11.48	1.95	10.94	0.22
TB83	1.00	39.41	32.17	12.28	1.94	12.66	0.53
TB84	1.87	37.08	37.93	10.09	1.67	10.91	0.45
TB85	1.06	43.56	27.01	10.69	2.17	14.73	0.79
TB86	1.93	33.60	43.99	10.20	1.34	8.66	0.28
TB87	1.27	48.05	26.14	13.09	1.52	9.78	0.15
TB88	1.77	30.33	42.50	9.43	1.71	13.56	0.70
TB89	0.81	52.33	18.54	14.26	2.10	11.57	0.39
TB90	2.11	28.14	45.96	10.14	1.81	11.41	0.43
TB91	3.97	20.46	61.99	6.99	0.92	5.43	0.24
TB92	1.81	34.95	39.69	11.40	1.67	10.13	0.35
TB93	1.70	34.07	35.79	9.72	2.40	15.77	0.56
TB94	3.95	20.43	61.03	7.84	1.17	5.47	0.13
TB95	1.32	45.02	26.09	12.65	2.05	12.41	0.47
TB96	1.65	32.51	39.46	8.96	2.07	14.56	0.78
TB97	0.78	38.01	30.48	9.46	2.74	17.74	0.79
TB98	0.73	54.66	13.69	13.46	2.30	14.66	0.50
TB99	1.04	45.42	24.58	12.45	2.19	13.86	0.46
TB100	2.62	28.49	50.39	8.34	1.36	8.51	0.28
Mean	**2.41**	**33.03**	**42.89**	**9.19**	**1.62**	**10.48**	**0.38**
SD	**1.37**	**10.35**	**13.79**	**2.12**	**0.55**	**3.69**	**0.22**

Appendix E: Standard Recoveries for Elemental Analysis (ICP)

TABLE 2: Comparison of Average Sample Standards in Quantitative Analysis

Filter	Sample (g)	Al(%)	Ca%	Cr%	Cu%	Fe%	K%	Mg%	Mn%
RS SO2 1	0.271	7.234	1.546	0.001	0.003	5.343	0.022	0.005	0.064
Recovery (%)		90.000	79.000	76.200	450.000	96.000	90.500	88.300	89.400
RS SO3 1	0.263	2.694	13.817	0.003	0.003	1.421	0.011	0.048	0.046
Recovery (%)		88.000	N/A	116.000	200.000	94.000	95.000	N/A	88.000
RS SO4 1	0.266	4.745	0.780	0.006	0.003	2.191	0.015	0.005	0.052
Recovery (%)		87.000	70.000	101.900	153.000	92.000	87.000	89.000	87.000
WQB-1 1	0.252	7.581	0.750	0.010	0.009	4.780	0.236	0.232	0.385
Recovery (%)		103.700	N/A	N/A	119.000	99.600	N/A	N/A	175.000
Filter	Sample (g)	Na%	Ni%	P%	Si%	Sr%	Ti%	V%	Zn%
RS SO2 1	0.271	0.013	0.002	0.003	0.128	0.013	0.008	0.006	0.001
Recovery (%)		N/A	N/A	N/A	51.300	39.000	89.000	99.800	9.900
RS SO3 1	0.263	0.002	0.003	0.001	0.076	0.005	0.002	0.005	0.000
Recovery (%)		30.900	178.000	N/A	47.900	24.800	N/A	N/A	N/A
RS SO4 1	0.266	0.004	0.004	0.001	0.140	0.003	0.003	0.009	0.000
Recovery (%)		N/A	138.000	102.000	N/A	20.500	90.000	96.000	N/A
WQB-1 1	0.252	0.001	0.351	0.256	0.089	0.051	0.228	0.013	0.013
Recovery (%)		N/A	N/A	N/A	N/A	N/A	N/A	105.000	42.900

Appendix F: Teflon Blank for Quantitative Elemental Analysis (ICP)

TABLE 3: Average Means/Standard Deviation for Blank Filter

Al		Ba		Ca		Cd	
ppm	SD	ppm	SD	ppm	SD	ppm	SD
161.132	74.005	87.464	37.915	202.595	89.721	-0.003	0.001
Cr		**Cu**		**Fe**		**K**	
ppm	SD	ppm	SD	ppm	SD	ppm	SD
0.152	0.053	0.195	0.038	4.486	2.230	52.948	20.983
Li		**Mg**		**Mn**		**Na**	
ppm	SD	ppm	SD	ppm	SD	ppm	SD
0.174	0.066	39.720	18.913	-0.115	0.048	142.830	60.983
Ni		**P**		**Si**		**Sn**	
ppm	SD	ppm	SD	ppm	SD	ppm	SD
0.064	0.026	1.657	0.529	383.066	159.768	0.389	0.389
Sr		**Ti**		**V**		**Zn**	
ppm	SD	ppm	SD	ppm	SD	ppm	SD
3.542	3.542	5.411	5.411	0.192	0.192	78.325	78.325
Zr							
ppm	SD						
0.725	0.725						

Appendix G: PCA TABLES by Location

TABLE 4: PCA Eigenvalues and Primary Factors: Episode 1- 950121 Plaza

Factor	1 Industrial Sulphur Source	2 Road Dust Mica	3 Road Dust Iron oxides	4 Barium	5 Road Dust Magnesium oxides
Aluminum	-0.291415	**0.704569**	**-0.341755**	0.126817	0.179826
Barium	0.033444	0.066444	0.072874	**0.916084**	-0.086137
Calcium	**0.816396**	-0.157126	-0.174712	0.045186	0.104452
Carbon	**-0.499798**	**-0.818742**	0.065066	0.114193	0.150504
Iron	-0.060664	0.033827	**-0.751883**	-0.024507	-0.189504
Magnesium	0.023942	0.051904	0.053575	-0.110194	**0.869051**
Potassium	**0.675509**	0.137959	0.289539	0.020078	-0.029671
Silicon	-0.27196	**0.826889**	0.132592	0.16291	-0.041536
Sodium	-0.137363	0.0304195	0.286462	**-0.427855**	**-0.493042**
Sulphur	**0.915337**	-0.231559	-0.102658	0.03847	0.045182
Titanium	0.091795	0.037967	**-0.661648**	-0.007045	0.189835
Eigenvalue	2.610731	1.892325	1.46728	1.050734	1.004492
% Total Variance	23.73	17.2	13.34	9.55	8.13
Cumulative %	23.73	40.94	54.58	63.83	72.96

For explanation see Table 9

TABLE 5: PCA Eigenvalues and Primary Factors: Episode 1- 950121 Van Bien

Factor	1 Industrial Sulphur Source	2 Road Dust Na-Feldspar	3 Road Dust Magnesium oxide	4 Iron
Aluminum	0.136162	**-0.675716**	-0.127691	0.265586
Calcium	**-0.927375**	0.197159	0.010431	0.060004
Carbon	**0.602207**	**0.759376**	0.070113	0.192738
Copper	0.005733	0.042788	**-0.795669**	-0.117756
Iron	0.021705	0.055355	-0.029029	**-0.901726**
Magnesium	0.015225	-0.106091	**-0.797655**	0.112806
Potassium	**-0.899888**	0.018277	0.020786	-0.001237
Silicon	0.269251	**-0.825731**	0.022596	-0.00513
Sodium	**0.422204**	**-0.556101**	0.111025	**-0.377627**
Sulphur	**-0.95416**	0.219181	0.026998	0.027521
Eigenvalue	3.148544	1.957879	1.296073	1.068036
% Total Variance	34.19	19.58	12.96	10.68
Cumulative %	34.19	53.76	66.73	77.41

For explanation see Table 9

TABLE 6:PCA Eigenvalues and Primary Factors: Episode 1- 950121 Lakewood

Factor	1 Road Dust Na-Feldspar	2 Industrial Sulphur Source	3 Road Dust Na-Feldspar
Aluminum	**0.849428**	0.169039	-0.093375
Calcium	-0.090432	**-0.898782**	-0.165572
Carbon	**-0.9151**	**0.32444**	-0.189169
Iron	0.093848	0.046767	0.051733
Magnesium	-0.007997	-0.05007	**0.891158**
Potassium	0.051225	**-0.921371**	0.013595
Silicon	**0.856076**	0.200556	-0.241376
Sodium	**0.632275**	-0.001532	**0.480198**
Sulphur	-0.223275	**-0.857012**	0.307036
Eigenvalue	2.933013	2.482965	1.167142
% Total Variance	32.59	27.59	12.97
Cumulative %	32.59	60.18	73.15

For explanation see Table 9

TABLE 7: PCA Eigenvalues and Primary Factors: Episode 2- 950328 Plaza

Factor	1 Road Dust Quartz	2 Industrial Sulphur Source	3 Road Dust Iron oxide	4 Road Dust K-Feldspar	5 Other
Aluminum	-0.055483	0.050021	0.298079	**-0.802033**	0.025486
Calcium	0.00518	**-0.781587**	0.038137	0.07648	**-0.492373**
Carbon	**0.483786**	0.243803	0.112771	**0.624336**	-0.034904
Chlorine	**0.573602**	-0.066409	-0.063677	0.036857	0.135412
Iron	0.057672	0.23109	**0.40554**	-0.15419	-0.258451
Magnesium	0.090861	-0.020866	**0.760068**	-0.190722	0.015474
Phosphorus	-0.074779	-0.138629	0.029465	0.130923	**-0.850776**
Potassium	-0.021863	0.109966	0.044362	**-0.724651**	0.035086
Silicon	**-0.87879**	0.142878	-0.205632	-0.075846	0.222394
Sodium	**0.562334**	0.157939	**-0.537618**	0.122333	0.089424
Sulphur	0.110745	**-0.888604**	0.005445	0.014824	0.077103
Titanium	-0.110529	-0.11622	**0.463147**	0.225067	**0.369104**
Eigenvalue	2.304538	1.848237	1.433655	1.066018	1.021766
% Total Variance	19.2	15.4	11.95	8.88	8.51
Cumulative %	19.2	34.61	46.55	55.44	63.95

For explanation see Table 9

TABLE 8: PCA Eigenvalues and Primary Factors: Episode 2- 950328 Van Bien

Factor	1 Road Dust Quartz	2 Industrial Sulphur Source	3 Road Dust K-Feldspar	4 Road Dust Magnesium oxide	5 Other
Aluminum	0.153863	0.036381	**0.803332**	**0.372885**	0.107824
Calcium	0.045965	**-0.869732**	0.010075	0.120626	0.060865
Carbon	**0.574705**	-0.005825	**-0.513817**	0.052518	**-0.371143**
Chlorine	0.194407	0.033108	-0.081463	-0.036582	**-0.543152**
Magnesium	0.054522	-0.055603	0.059933	**0.922348**	0.055081
Potassium	-0.075571	-0.095033	**0.790296**	-0.125613	-0.184386
Silicon	**-0.951602**	0.153075	-0.101285	-0.192867	0.103602
Sodium	**0.699934**	0.106182	-0.025201	**-0.52856**	0.175348
Sulphur	0.023844	**-0.88714**	0.049579	-0.036429	0.002101
Titanium	-0.133577	0.021733	0.144873	0.012077	**-0.736164**
Eigenvalue	1.995771	1.842872	1.383276	1.153286	1.023791
% Total Variance	19.96	18.43	13.83	11.53	10.24
Cumulative %	19.96	38.39	52.22	63.75	73.99

For explanation see Table 9

TABLE 9: PCA Eigenvalues and Primary Factors: Episode 2- 950328 Lakewood

Factor	1 Industrial Sulphur Source	2 Road Dust K-Feldspar	3 Road Dust Quartz	4 Road Dust Magnesium oxide	5 Other
Aluminum	0.136887	**-0.826459**	-0.059002	0.316788	0.090247
Calcium	**-0.94134**	0.021429	0.052582	0.056728	0.017515
Carbon	0.100148	**0.447099**	**0.744414**	0.116865	-0.259745
Iron	0.021788	-0.066254	0.098305	-0.100455	**-0.812693**
Magnesium	0.110187	-0.305522	0.137335	**0.762944**	0.021247
Potassium	-0.037221	**-0.757115**	-0.020129	-0.123181	-0.169614
Silicon	0.23072	0.123921	**-0.958216**	-0.016155	-0.079616
Sodium	0.069311	-0.014701	**0.363964**	**-0.631931**	**0.536441**
Sulphur	**-0.944168**	0.041793	0.081524	0.004299	0.003244
Titanium	-0.194997	0.207133	0.06828	**0.488286**	0.217018
Eigenvalue	2.194023	1.731547	1.452894	1.236898	1.036339
% Total Variance	21.94	17.32	14.53	12.37	10.36
Cumulative %	21.94	39.26	53.78	66.15	76.52

For explanation see Table 9

TABLE 10: PCA Eigenvalues and Primary Factors: Episode 3 - 960227 Plaza

Factor	1 Combustion	2 Road Dust Ca-Feldspar	3 Industrial Sulphur Source	4 Salt NaCl	5 Road Dust K-Feldspar
Aluminum	**-0.669079**	**0.353685**	-0.129359	0.138659	0.104945
Calcium	0.283588	**0.507162**	0.25692	0.06577	-0.138604
Carbon	**0.845678**	-0.059346	0.061193	0.14652	0.201046
Chlorine	-0.051145	0.064577	-0.023708	**-0.796057**	-0.055152
Iron	-0.07124	-0.038879	**0.6786**	0.117714	-0.298203
Magnesium	-0.128912	**0.831944**	-0.078309	-0.023309	0.027674
Phosphorus	**0.327685**	0.079385	-0.137055	0.104206	-0.068458
Potassium	**-0.493391**	-0.142129	0.205348	0.237889	**0.322505**
Silicon	**-0.596592**	**-0.347463**	**-0.328618**	**0.344754**	-0.263678
Sodium	0.040019	**-0.546338**	0.013722	**-0.682405**	0.06786
Sulphur	0.026716	0.074087	**0.782872**	-0.082874	0.199069
Titanium	0.005732	0.02983	0.040393	-0.011922	**-0.798411**
Eigenvalue	2.136813	1.693778	1.240174	1.141119	1.013245
% Total Variance	17.81	14.42	10.34	9.51	8.44
Cumulative %	17.81	31.92	42.26	51.77	60.21

For explanation see Table 9

TABLE 11: PCA Eigenvalues and Primary Factors: Episode 3 - 960227 Van Bien

Factor	1 Road Dust Magnesium oxides	2 Industrial Sulphur Source	3 Other	4 Road Dust Quartz	5 Other	6 Road Dust K-Feldspar
Aluminum	**-0.339831**	0.138536	0.188444	-0.14148	0.051002	**-0.70965**
Calcium	-0.135407	**-0.804698**	-0.019536	-0.125388	0.102481	0.032867
Carbon	0.06461	0.145716	-0.086199	**0.7461**	-0.089412	**0.362661**
Chlorine	0.101691	-0.165331	0.007295	0.027763	**-0.777398**	0.019735
Iron	-0.117258	0.11895	-0.009628	0.000783	**-0.747684**	-0.052241
Magnesium	**-0.840207**	-0.063192	-0.040191	0.133443	0.010648	-0.038745
Manganese	-0.240116	-0.092131	-0.000464	0.249142	0.097556	-0.067649
Phosphorus	-0.042369	0.060429	**0.856545**	0.024275	-0.00401	0.027602
Potassium	0.044524	-0.051639	-0.11519	0.01442	-0.076041	**-0.846489**
Silicon	-0.039336	0.14106	-0.080828	**-0.939632**	0.038916	0.08305
Sodium	**0.73196**	0.027335	0.028834	**0.394435**	0.128427	0.114092
Sulphur	0.01424	**-0.821612**	0.03103	0.227488	-0.157919	-0.0045
Titanium	0.091606	-0.070027	**0.836744**	-0.009387	0.006118	-0.038391
Eigenvalue	2.186647	1.628453	1.516118	1.262686	1.183442	1.038543
% Total Variance	16.82	12.53	11.66	9.71	9.1	7.99
Cumulative %	16.82	29.35	41.01	50.72	59.83	67.81

For explanation see Table 9

TABLE 12: PCA Eigenvalues and Primary Factors: Episode 3 - 960227 Lakewood

Factor	1 Road Dust Quartz	2 Industrial Sulphur Source	3 Road Dust K-Feldspar	4 Road Dust Magnesium oxide	5 Road Dust Titanium	6 Other
Aluminum	0.178383	-0.091393	**-0.823052**	0.202965	-0.021682	0.120635
Barium	0.044333	**0.772248**	0.059966	0.012271	0.045319	0.057641
Calcium	-0.034068	**0.444555**	-0.04404	-0.022595	**-0.652171**	-0.078406
Carbon	**-0.71264**	-0.180917	0.275301	-0.117905	-0.057385	0.132692
Iron	-0.059109	-0.02842	0.036934	-0.07084	0.009187	**0.538107**
Magnesium	0.129378	-0.004039	-0.108534	**0.67829**	-0.296082	0.287447
Manganese	-0.022263	0.046236	0.008659	0.070578	0.072879	**0.743997**
Potassium	0.006702	-0.010868	**-0.812528**	-0.18343	0.081808	-0.180977
Silicon	**0.909085**	-0.096956	0.214041	-0.193323	0.149632	-0.183625
Sodium	**-0.760947**	0.138795	0.16132	-0.049473	0.188303	-0.134115
Sulphur	-0.09419	**0.839281**	0.02438	-0.006517	-0.088558	-0.039263
Titanium	0.015421	-0.120323	0.089486	0.027703	**-0.820643**	-0.047731
Eigenvalue	2.189174	1.666525	1.456901	1.277486	1.095427	1.047173
% Total Variance	16.84	12.82	11.21	9.83	8.43	8.06
Cumulative %	16.84	29.66	40.87	50.69	59.12	67.17

For explanation see Table 9

TABLE 13: PCA Eigenvalues and Primary Factors: Non-Episode 1 - 960122 Plaza

Factor	1 Industrial Sulphur Source	2 Road Dust K-Feldspar	3 Road Dust Mica	4 Road Dust Iron oxide
Aluminum	-0.311196	0.302924	**0.706255**	-0.156129
Calcium	**0.830579**	0.184324	0.056948	-0.029799
Carbon	-0.1733	**-0.920888**	0.013616	0.243563
Iron	0.014024	0.028795	-0.004335	**-0.695994**
Magnesium	0.302634	-0.027655	**0.487465**	**-0.346553**
Potassium	0.258067	**0.63058**	0.008447	**0.437476**
Silicon	**-0.650368**	**0.610525**	0.082888	0.090711
Sodium	-0.139656	0.212556	**-0.79621**	**-0.387918**
Sulphur	**0.944649**	0.125787	0.016788	0.06418
Eigenvalue	2.322892	1.814044	1.370271	1.033842
% Total Variance	25.81	20.16	15.23	11.49
Cumulative %	25.81	45.97	61.19	72.68

For explanation see Table 9

TABLE 14: PCA Eigenvalues and Primary Factors: Non-Episode 1 - 960122 Van Bien

Factor	1 Industrial Sulphur Source	2 Road Dust Mica or Feldspar	3 Road Dust Magnesium oxide	4 Other
Aluminum	0.062672	**0.804204**	-0.039147	0.059089
Calcium	**-0.884279**	-0.126819	0.069688	0.140658
Carbon	**0.448712**	**-0.544702**	0.231346	**0.647537**
Iron	0.023517	0.007562	0.021432	-0.158511
Magnesium	-0.057236	-0.08967	**-0.867188**	0.029624
Manganese	0.05934	0.055306	**-0.73178**	0.08096
Potassium	**-0.838432**	0.192184	0.121123	0.127232
Silicon	0.064381	**0.906122**	0.103985	-0.051668
Sodium	0.1639	-0.121312	0.07698	**-0.945512**
Sulphur	**-0.775425**	**-0.371681**	**-0.354779**	-0.057813
Eigenvalue	2.435205	2.0146	1.461276	1.296782
% Total Variance	24.35	20.15	14.61	12.97
Cumulative %	24.35	44.5	59.11	72.08

For explanation see Table 9

TABLE 15: PCA Eigenvalues and Primary Factors: Non-Episode 1 - 960122 Lakewood

Factor	1 Industrial Sulphur Source	2 Road Dust K-Feldspar	3 Combustion	4 Road Dust Iron oxide	5 Road Dust Magnesium oxide
Aluminum	**-0.569951**	**0.530886**	0.305935	0.269809	0.03219
Calcium	**0.791484**	0.287477	-0.082392	-0.148085	0.124054
Carbon	-0.034505	**-0.859681**	**0.419698**	-0.180087	0.121311
Iron	0.069839	0.058952	0.085881	**0.718402**	**0.548899**
Magnesium	0.285821	0.0825	0.19387	**0.513046**	**-0.699081**
Potassium	**0.363559**	**0.627014**	0.178045	**-0.42214**	0.124823
Silicon	**-0.697441**	**0.576407**	0.145678	-0.188943	-0.098925
Sodium	**-0.325738**	-0.003647	-0.193049	0.083806	0.044175
Sulphur	**0.91173**	0.197008	-0.086193	0.122348	-0.056725
Titanium	0.078315	0.139598	0.13655	0.069029	**0.479547**
Eigenvalue	2.601143	1.897521	1.234147	1.147135	1.081648
% Total Variance	26.01	18.98	12.34	11.47	10.82
Cumulative %	26.01	44.99	57.33	68.8	79.62

For explanation see Table 9

TABLE 16: PCA Eigenvalues and Primary Factors: Non-Episode 2 - 960304 Plaza

Factor	1 Combustion	2 Road Dust Iron oxide	3 Industrial Sulphur Source	4 Salt NaCl	5 Road Dust Titanium
Aluminum	**-0.615036**	**0.335953**	-0.140493	0.310137	-0.113652
Calcium	0.20028	0.199963	0.144292	-0.07228	**-0.64276**
Carbon	**0.85714**	-0.025208	-0.309298	**0.32853**	0.003094
Chlorine	0.07389	0.157915	-0.112843	**-0.744845**	-0.179117
Iron	-0.013878	**0.742947**	-0.029695	-0.012003	**0.331177**
Magnesium	-0.037428	**0.78357**	0.069134	0.003435	-0.295482
Potassium	-0.159089	-0.010132	**0.817777**	0.215552	0.033345
Silicon	**-0.821743**	-0.127956	-0.187696	0.293149	0.133698
Sodium	0.088749	**-0.415465**	0.165109	**-0.721417**	0.316972
Sulphur	0.216661	0.025984	**0.822631**	-0.222393	-0.124832
Titani				0.025733	**-0.655572**
Eigenv				1.134402	1.031171
% Total V				10.31	9.37
Cumulat				60.88	70.25

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TABLE 1

ode 2 960227 Van Bien

Fact	4 Other	5 Industrial Sulphur Source	6 Other
Alumi	0.006447	0.266835	-0.285115
Bari	**-0.728839**	0.032749	0.048946
Calc	0.055788	-0.131472	**0.339926**
Carl	0.212269	-0.158311	-0.256685
Chlo	0.061142	**0.823178**	0.136286
Iro	**-0.721785**	-0.083031	-0.069277
Magn	-0.087301	0.074628	-0.070226
Potas	0.135917	-0.184769	0.046881
Sili	0.105971	-0.102519	0.116415
Sod	-0.148921	0.146332	0.137354
Sulp	0.031411	**-0.40777**	**0.389063**
Tita	0.014467	0.12885	**0.765721**
Eiger	1.154473	1.045531	1.028826
% Total	9.62	8.71	8.57
Cumul	51.74	60.45	69.02

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TABLE 18: PCA Eigenvalues and Primary Factors: Non-Episode 2 - 960304 Lakewood

Factor	1 Salt NaCl	2 Road Dust Mica or Feldspar	3 Road Dust K-Feldspar	4 Combustion	5 Road Dust Iron oxide	6 Industrial Sulphur Source
Aluminum	0.248927	**-0.643683**	**-0.450415**	-0.283126	-0.076404	-0.133501
Calcium	0.126556	-0.112602	0.16049	-0.066599	0.129296	**-0.805672**
Carbon	0.06056	0.139053	0.135358	**0.876935**	0.004045	-0.010224
Chlorine	**-0.804837**	-0.063691	0.174964	-0.207167	0.039343	0.00591
Chromium	-0.015918	**-0.674857**	-0.004131	0.093409	0.04157	0.193395
Copper	0.089491	-0.176589	0.196665	0.209341	0.292001	0.285695
Iron	0.07909	-0.277732	0.133242	0.065734	**-0.613991**	0.05261
Magnesium	0.019017	**-0.700779**	0.187954	-0.109878	-0.228189	-0.192549
Potassium	0.062914	0.03359	**-0.894545**	-0.045436	0.093994	0.015507
Silicon	**0.578149**	**0.341635**	0.161461	**-0.646563**	0.079505	0.165633
Sodium	**-0.839499**	0.258467	-0.055949	0.231235	0.052216	0.030147
Sulphur	-0.133844	0.102252	-0.203323	0.274691	-0.046603	**-0.497892**
Titanium	0.011352	0.029764	-0.007066	-0.00783	**-0.820121**	0.031156
Eigenvalue	2.281444	1.742222	1.297393	1.196282	1.051901	1.028203
% Total Variance	17.55	13.4	9.98	9.2	8.09	7.91
Cumulative %	17.55	30.95	40.93	50.13	58.22	66.13

For explanation see Table 9

TABLE 19: PCA Eigenvalues and Primary Factors: Non-Episode 3 - 960509 Plaza

Factor	1 Combustion	2 Road Dust Ca-Feldspar	3 Industrial Sulphur Source	4 Copper	5 Road Dust Iron oxide
Aluminum	**-0.373558**	**0.599175**	**-0.370437**	0.038807	0.172581
Calcium	0.117609	**0.368709**	**0.66596**	0.138537	-0.119758
Carbon	**0.824742**	-0.025373	0.253878	0.077608	0.064122
Copper	-0.004826	0.019995	0.085219	**-0.889949**	-0.019892
Iron	0.135445	0.064485	-0.118856	-0.263867	**-0.724288**
Magnesium	0.002829	**0.745112**	0.135847	0.066196	0.090417
Potassium	**-0.735875**	-0.068405	0.098329	0.074338	0.060721
Silicon	**-0.46963**	0.08968	**-0.710002**	0.131841	-0.127404
Sodium	-0.158703	**-0.813902**	0.047238	0.152453	0.107846
Sulphur	**-0.399414**	-0.263266	**0.682903**	-0.201809	0.039471
Titanium	0.149582	0.136119	-0.137669	-0.297738	**0.648476**
Eigenvalue	2.162114	1.878504	1.319593	1.055617	1.01326
% Total Variance	19.66	17.08	12	9.6	9.2
Cumulative %	19.66	36.73	48.73	58.33	67.54

For explanation see Table 9

TABLE 20: PCA Eigenvalues and Primary Factors: Non-Episode 3 960509 Van Bien

Factor	1 Road Dust Mica or Feldspar	2 Industrial Sulphur Source	3 Road Dust Iron oxide	4 Combustion
Aluminum	**0.730878**	-0.127119	-0.019484	-0.279701
Calcium	0.197117	**0.892817**	0.017316	0.030285
Carbon	-0.090658	-0.058461	0.068013	**0.849249**
Iron	0.01776	-0.023518	**-0.92388**	0.036098
Magnesium	**0.705173**	0.065328	-0.078726	0.204914
Potassium	-0.106064	0.113214	0.056007	**-0.614811**
Silicon	0.209434	**-0.415547**	0.113641	**-0.706599**
Sodium	**-0.831907**	-0.145307	-0.022351	0.059442
Sulphur	-0.061455	**0.931989**	0.012933	-0.06984
Titanium	0.047716	0.007045	**-0.92476**	0.021009
Eigenvalue	2.059628	1.983915	1.776504	1.375565
% Total Variance	20.6	19.84	17.77	13.76
Cumulative %	20.6	40.44	58.2	71.96

For explanation see Table 9

TABLE 21: PCA Eigenvalues and Primary Factors: Non-Episode 3 - 960509 Lakewood

Factor	1 Road Dust Mica or Feldspar	2 Road Dust Quartz	3 Industrial Sulphur Source	4 Road Dust Iron oxide	5 Other
Aluminum	**0.77901**	0.215037	0.078073	-0.207599	0.060575
Calcium	0.067649	-0.201232	-0.151101	-0.085808	**-0.619303**
Carbon	-0.049398	**-0.901904**	0.109322	0.045625	0.012745
Copper	0.118702	-0.318164	0.009842	0.191434	0.08958
Iron	0.009145	0.020502	0.080285	**-0.846887**	0.083895
Magnesium	**0.476193**	-0.00917	-0.010936	**-0.525607**	**-0.439579**
Phosphorus	-0.084611	0.136381	0.152287	0.123646	**-0.754064**
Potassium	0.08594	**0.342353**	**-0.667389**	0.204935	-0.072325
Silicon	0.100778	**0.755351**	0.038307	0.262055	**0.356257**
Sodium	**-0.803751**	0.259186	0.136716	0.077626	0.097116
Sulphur	-0.093572	-0.106862	**-0.83029**	-0.062483	0.046195
Titanium	**0.546872**	0.024966	0.079859	0.260396	0.048033
Eigenvalue	2.09496	1.898634	1.268884	1.170133	1.016936
% Total Variance	17.46	15.82	10.57	9.75	8.48
Cumulative %	17.46	33.28	43.85	53.61	62.08

For explanation see Table 9

TABLE 22: PCA Eigenvalues and Primary Factors: BCR Episode 940408

Factor	1 Road Dust Quartz	2 Road Dust Magnesium oxide	3 Industrial Sulphur Source	4 Road Dust K-Feldspar	5 $CaCl_2$
Aluminum	-0.116213	-0.128651	0.074032	**-0.836713**	-0.003897
Barium	-0.034778	-0.023076	**-0.840187**	0.062786	0.121355
Calcium	0.018698	0.019138	-0.182504	0.003581	**-0.797564**
Carbon	**0.708902**	-0.095443	0.116949	**0.32279**	0.020236
Chlorine	-0.009827	-0.120859	0.065706	-0.049626	**-0.651261**
Iron	0.100426	-0.17104	0.039252	-0.01679	0.142328
Magnesium	-0.036764	**-0.833526**	0.003165	-0.12847	-0.144884
Phosphorus	-0.008918	0.091647	0.054999	0.063366	**-0.323328**
Potassium	0.000594	0.117911	0.004878	**-0.746222**	0.077823
Silicon	**-0.869953**	0.212178	0.195447	**0.321782**	0.167242
Sodium	**0.69397**	**0.392793**	-0.036902	0.14309	0.200334
Sulphur	0.074954	**0.41772**	**-0.872803**	0.001596	-0.125083
Titanium	-0.004084	**-0.66705**	-0.025255	0.150512	0.127649
Eigenvalue	1.934896	1.691515	1.465909	1.363065	1.182974
% Total Variance	14.88	13.01	11.28	10.49	9.1
Cumulative %	14.88	27.9	39.17	49.66	58.76

For explanation see Table 9

TABLE 23: PCA Eigenvalues and Primary Factors: BCR Episode 940923

Factor	1 Road Dust K-Feldspar	2 Road Dust Iron oxide	3 Road Dust Quartz	4 Industrial Sulphur Source	5 Road Dust Magnesium oxide
Aluminum	**0.885355**	0.026337	-0.029581	0.117901	0.07957
Calcium	0.008092	-0.014351	-0.072434	**-0.716916**	0.291719
Carbon	**-0.617431**	0.02017	**-0.541509**	-0.000179	0.074171
Iron	0.083174	**-0.881844**	0.001057	0.041691	0.065911
Magnesium	0.067834	0.0013	-0.09236	0.02248	**0.880364**
Potassium	**0.690018**	-0.04738	0.039909	-0.085301	0.037557
Silicon	0.040897	0.085655	**0.953305**	0.159711	-0.219647
Sodium	-0.03472	0.169625	**-0.659987**	0.18851	**-0.507344**
Sulphur	-0.014271	0.01626	0.020604	**-0.788386**	-0.231893
Titanium	-0.044132	**-0.890518**	0.009752	-0.04008	-0.026361
Eigenvalue	2.075907	1.665057	1.352332	1.237871	1.051046
% Total Variance	20.76	16.65	13.52	12.38	10.51
Cumulative %	20.76	37.41	50.93	63.31	73.82

For explanation see Table 9

TABLE 24: PCA Eigenvalues and Primary Factors: BCR Episode 950316

Factor	1 Road Dust K-Feldspar	2 Other	3 Road Dust Quartz	4 Road Dust MgCl	5 Road Dust Iron oxide
Aluminum	**-0.859888**	0.014208	-0.071016	0.032192	0.160278
Calcium	0.06466	**-0.7037**	0.009111	0.554235	0.012012
Carbon	0.235255	0.123093	**0.645346**	0.2686	-0.12552
Chlorine	0.150707	-0.181141	-0.003738	**0.765661**	-0.113679
Iron	-0.145478	0.06853	0.00401	0.009984	**0.779355**
Magnesium	**-0.424381**	0.189143	0.073067	**0.544219**	0.301279
Phosphorus	-0.087147	**-0.822301**	0.028987	-0.023405	0.030654
Potassium	**-0.73068**	-0.14501	-0.166401	-0.155519	-0.195174
Silicon	0.228412	0.151789	**-0.901519**	-0.182457	-0.139369
Sodium	**0.407981**	-0.114132	**0.608595**	**-0.372623**	0.008247
Sulphur	0.061092	0.025321	**0.420387**	-0.100468	-0.074201
Titanium	0.285576	-0.208182	-0.14666	-0.058167	**0.486988**
Eigenvalue	2.202918	1.868981	1.459653	1.060521	1.001251
% Total Variance	18.35	15.58	12.16	8.84	8.34
Cumulative %	18.35	33.93	46.1	54.93	63.28

For explanation see Table 9

TABLE 25: PCA Eigenvalues and Primary Factors: BCR Episode 950328

Factor	1 Road Dust Quartz	2 Industrial Sulphur Source	3 Road Dust K-Feldspar	4 Road Dust Iron oxide	5 Road Dust Magnesium oxide
Aluminum	0.170372	-0.013018	**0.818859**	-0.11765	-0.21353
Calcium	0.020909	**0.743375**	-0.037639	0.126449	**-0.372638**
Carbon	**-0.731276**	-0.088116	-0.241874	-0.030514	-0.081796
Iron	0.026397	0.045082	0.00135	**0.899356**	0.017937
Magnesium	0.051717	0.063157	0.29662	-0.191844	**-0.731468**
Manganese	-0.05372	0.087365	**0.421909**	0.010921	0.233449
Phosphorus	-0.002026	0.161837	-0.2478	0.098097	-0.71021
Potassium	0.058588	-0.198052	**0.595967**	**0.415643**	-0.086055
Silicon	**0.862908**	-0.191847	**-0.347107**	0.039133	0.258573
Sodium	**-0.735926**	-0.014405	-0.126235	0.042871	**0.379761**
Sulphur	-0.055086	**0.850635**	0.031412	-0.07565	0.103913
Titanium	0.089052	0.143832	-0.02758	-0.123195	0.197436
Eigenvalue	2.009675	1.876671	1.465056	1.091274	1.037338
% Total Variance	16.75	15.64	12.21	9.09	8.65
Cumulative %	16.75	32.39	44.6	53.69	62.33

For explanation see Table 9

TABLE 26: PCA Eigenvalues and Primary Factors: BCR Episode 950831

Factor	1 Road Dust Quartz	2 Road Dust Mica or Feldspar	3 Road Dust K-Feldspar	4 Road Dust Titanium
Aluminum	0.25755	0.153652	**-0.821492**	0.055209
Calcium	-0.007766	**0.337386**	0.076462	**-0.615282**
Carbon	**-0.899348**	0.002158	0.279442	0.139599
Iron	-0.04115	0.141896	-0.200247	-0.156874
Magnesium	0.025467	**0.755379**	0.018037	-0.268917
Potassium	0.01553	-0.106499	**-0.864268**	0.003362
Silicon	**0.920586**	0.024704	0.052155	0.153178
Sodium	-0.018221	**-0.795521**	0.134658	-0.27751
Titanium	0.008372	0.208838	0.067237	**0.684392**
Eigenvalue	2.106702	1.407532	1.213829	1.052668
% Total Variance	23.71	15.64	13.49	11.7
Cumulative %	23.71	39.05	52.53	64.23

For explanation see Table 9

TABLE 27: PCA Eigenvalues and Primary Factors: BCR Episode 960304

Factor	1 Industrial Sulphur Source	2 Road Dust K-Feldspar	3 Combustion	4 Road Dust Iron oxide	5 Other	6 Road Dust MgCl
Aluminum	0.156891	**-0.828536**	0.06932	-0.010294	0.193203	-0.137406
Calcium	**-0.812466**	0.069415	-0.091024	0.026855	0.117662	-0.251123
Carbon	0.067095	0.229364	**-0.933245**	0.050232	0.066619	0.095566
Chlorine	0.030155	0.070528	0.056723	0.106729	-0.198466	**-0.805194**
Iron	0.044417	0.090842	0.017112	**-0.753724**	0.0079	-0.030703
Magnesium	-0.259538	-0.083195	-0.132761	-0.209605	**0.370989**	**-0.645605**
Potassium	-0.058659	**-0.779524**	0.031912	0.017051	-0.075829	0.13808
Silicon	0.316745	0.295661	**0.720364**	0.087901	**0.411028**	0.285751
Sodium	0.027648	0.081211	-0.062628	-0.012346	**-0.958522**	-0.041261
Sulphur	**-0.903401**	0.013122	0.29887	0.011051	-0.071224	0.108865
Titanium	-0.018485	-0.081104	-0.008969	**-0.737808**	-0.005784	0.028967
Eigenvalue	2.044786	1.604454	1.386594	1.201355	1.069471	1.059244
% Total Variance	18.59	14.59	12.61	10.92	9.72	9.63
Cumulative %	18.59	33.17	45.78	56.7	66.42	76.05

For explanation see Table 9

TABLE 28: PCA Eigenvalues and Primary Factors: BCR Episode 960813

Factor	1 Road Dust Iron oxide	2 Industrial Sulphur Source	3 Road Dust Quartz	4 Road Dust Magnesium oxide	5 Road Dust K-Feldspar	6 Other
Aluminum	-0.075912	0.07267	0.036587	-0.317677	**0.806312**	0.191203
Calcium	0.046055	**-0.844205**	0.07539	-0.067192	0.012817	-0.337602
Carbon	-0.008083	0.164938	**0.688297**	0.058754	**-0.459147**	-0.118246
Chromium	0.22448	-0.129632	0.076789	-0.30356	0.023114	**0.57795**
Iron	**0.951618**	-0.022844	0.008173	-0.171604	0.042725	0.175939
Magnesium	0.017457	0.055569	0.095149	**-0.853489**	0.028618	0.040777
Phosphorus	0.055979	-0.229158	0.085558	-0.22128	0.005749	**-0.736259**
Potassium	0.16883	0.058469	-0.108405	0.214757	**0.698977**	-0.184444
Silicon	-0.023343	0.251131	**-0.946157**	0.127438	-0.117781	0.003678
Sodium	-0.085275	0.042371	**0.54897**	**0.611191**	-0.045614	0.179609
Sulphur	-0.035092	**-0.872753**	0.026025	0.090617	-0.096868	0.138095
Titanium	**0.949216**	0.018653	-0.020882	0.086073	0.046691	-0.060411
Eigenvalue	2.158042	1.94937	1.62457	1.383851	1.141864	1.011289
% Total Variance	17.98	16.25	13.54	11.53	9.52	8.43
Cumulative %	17.98	34.23	47.77	59.3	68.81	77.24

For explanation see Table 9

TABLE 29: PCA Eigenvalues and Primary Factors: BCR Non-Episode 960122

Factor	1 Industrial Sulphur Source	2 Road Dust Mica or Feldspar	3 Combustion	4 Road Dust Iron oxide
Aluminum	0.038549	**-0.842177**	0.077704	-0.021569
Calcium	**0.665316**	0.22237	0.053537	-0.001944
Carbon	**-0.373754**	0.275311	**-0.846558**	0.005701
Chlorine	-0.039867	0.130986	-0.315598	-0.174401
Copper	0.00403	-0.024258	-0.005002	**0.360893**
Iron	-0.060228	0.075651	0.097198	**0.886276**
Magnesium	**0.536459**	-0.109009	-0.124436	0.111317
Potassium	**0.574067**	-0.091322	0.147943	-0.176843
Silicon	-0.254805	**-0.842827**	0.142114	0.015003
Sodium	**-0.433103**	**0.402928**	**0.735462**	-0.189618
Sulphur	**0.835593**	**0.385114**	0.148886	-0.019167
Eigenvalue	2.322876	1.806744	1.389726	1.019127
% Total Variance	21.12	16.42	12.63	9.26
Cumulative %	21.12	37.54	50.18	59.44

For explanation see Table 9

TABLE 30: PCA Eigenvalues and Primary Factors: BCR Non-Episode 960509

Factor	1 Road Dust Mica or Feldspar	2 Industrial Sulphur Source	3 Road Dust Quartz	4 Industrial Sulphur Source
Aluminum	**0.812654**	0.181611	-0.032364	-0.199114
Calcium	0.009944	**-0.850908**	0.13511	-0.083556
Carbon	-0.263436	0.122082	**0.655151**	**0.384773**
Iron	0.137671	0.035065	0.098563	0.255091
Magnesium	**0.762797**	-0.047257	0.213192	0.21378
Phosphorus	-0.039929	**-0.656641**	-0.077905	0.175562
Potassium	0.167009	0.229859	-0.018811	**-0.778907**
Silicon	-0.024355	0.21072	**-0.938969**	0.077426
Sodium	**-0.736013**	0.256461	**0.341435**	-0.083286
Sulphur	-0.040753	**-0.491689**	0.253178	**-0.506493**
Titanium	-0.118164	-0.014295	0.021239	0.004543
Eigenvalue	2.100938	1.74972	1.294827	1.169554
% Total Variance	19.1	15.91	11.77	10.63
Cumulative %	19.1	35.01	46.78	57.71

For explanation see Table 9

Appendix H : ANOVA RESULTS for Quantitative and Qualitative/Morphological Analysis

TABLE 31: Krustal Wallis ANOVA results for Qualitative Chemical Analyses: Sources

Element	Sources
Aluminum	H(3,n=399)= 44.40, p=0.0000
Barium	N/A
Calcium	H(3,n=399)= 3.03, p=0.3865
Carbon	H(3,n=399)= 112.96, p=0.0000
Chlorine	H(3,n=399)= 3.04 p=0.3859
Chromium	N/A
Copper	N/A
Iron	H(3,n=399)= 8.31, p=0.0401
Magnesium	H(3,n=399)= 6.26, p=0.0997
Manganese	N/A
Potassium	H(3,n=399)= 8.85, p=0.0313
Phosphorus	N/A
Silicon	H(3,n=399)= 45.38, p=0.0000
Sodium	H(3,n=399)= 14.87, p=0.0019
Sulphur	N/A
Titanium	H(3,n=399)= 1.10, p=0.7777

TABLE 32: Krustal Wallis ANOVA results for Qualitative Analyses: Bowl Episodes

Element	Episode 1	Episode 2	Episode 3	Total Episodes
Aluminum	H(2,n=899)= 24.36, p=0.0000	H(2,n=900)= 52.29, p=0.0000	H(2,n=899)= 5.78, p=0.0555	H(2,n=2698)= 1163.05, p=0.000
Barium	H(2,n=899)= 3.99, p=0.1354	N/A	H(2,n=899)= 2.01, p=0.3659	H(2,n=2698)= 1.99, p=0.3703
Calcium	H(2,n=899)= 32.32, p=0.0000	H(2,n=900)= 0.75, p=0.6869	H(2,n=899)= 32.11, p=0.0000	H(2,n=2698)= 73.25, p=0.000
Carbon	H(2,n=899)= 51.81, p=0.0000	H(2,n=900)= 4.79, p=0.0911	H(2,n=899)= 5.05, p=0.0802	H(2,n=2698)= 655.05, p=0.000
Chlorine	N/A	H(2,n=900)= 16.12, p=0.0003	H(2,n=899)= 0.40, p=0.8171	H(2,n=2698)= 14.38, p=0.0008
Chromium	N/A	N/A	N/A	N/A
Copper	H(2,n=899)= 2.01, p=0.3659	N/A	N/A	H(2,n=2698)= 2.16, p=0.3395
Iron	H(2,n=899)= 4.38, p=0.1122	H(2,n=900)= 13.58, p=0.0011	H(2,n=899)= 7.30, p=0.0260	H(2,n=2698)= 2.32, p=0.3134
Magnesium	H(2,n=899)= 1.88, p=0.3898	H(2,n=900)= 18.07, p=0.0001	H(2,n=899)= 6.06, p=0.0484	H(2,n=2698)= 525.59, p=0.000
Manganese	N/A	N/A	H(2,n=899)= 2.00, p=0.3672	H(2,n=2698)= 6.04, p=0.0489
Potassium	H(2,n=899)= 10.40, p=0.0055	H(2,n=900)= 0.57, p=0.7517	H(2,n=899)= 0.32, p=0.8530	H(2,n=2698)= 64.94, p=0.000
Phosphorus	N/A	H(2,n=900)= 4.00, p=0.1352	H(2,n=899)= 2.00, p=0.3672	H(2,n=2698)= 2.71, p=0.2575
Silicon	H(2,n=899)= 24.81, p=0.0000	H(2,n=900)= 23.18, p=0.0000	H(2,n=899)= 12.22, p=0.0022	H(2,n=2698)= 768.03, p=0.000
Sodium	H(2,n=899)= 10.95, p=0.0042	H(2,n=900)= 27.83, p=0.0000	H(2,n=899)= 1.32, p=0.5173	H(2,n=2698)= 279.31, p=0.000
Sulphur	H(2,n=899)= 46.35, p=0.0000	H(2,n=900)= 8.43, p=0.0148	H(2,n=899)= 38.82, p=0.0000	H(2,n=2698)= 143.75, p=0.000
Titanium	H(2,n=899)= 8.02, p=0.0181	H(2,n=900)= 0.25, p=0.8844	H(2,n=899)= 0.73, p=0.6926	H(2,n=2698)= 3.22, p=0.1997

TABLE 33: Krustal Wallis ANOVA results for Qualitative Analyses: Bowl Non-Episodes

Element	Non-Episode 1	Non-Episode 2	Non-Episode 3	Total Non-Episodes
Aluminum	H(2,n=899)= 1.46, p=0.4808	H(2,n=900)= 31.13, p=0.0000	H(2,n=900)= 3.87, p=0.1443	H(2,n=2677)= 703.11, p=0.000
Barium	N/A	H(2,n=900)= 2.02, p=0.3638	N/A	H(2,n=2677)= 2.07, p=0.3554
Calcium	H(2,n=899)= 17.33, p=0.0002	H(2,n=900)= 31.93, p=0.0000	H(2,n=900)= 4.43, p=0.1093	H(2,n=2677)= 45.12, p=0.000
Carbon	H(2,n=899)= 0.93, p=0.6276	H(2,n=900)= 3.19, p=0.2029	H(2,n=900)= 10.96, p=0.0042	H(2,n=2677)= 527.21, p=0.000
Chlorine	N/A	H(2,n=900)= 11.83, p=0.0027	N/A	H(2,n=2677)= 60.61, p=0.000
Chromium	N/A	H(2,n=900)= 2.02, p=0.3638	N/A	H(2,n=2677)= 2.07, p=0.3554
Copper	H(2,n=899)= 4.00, p=0.1354	H(2,n=900)= 2.02, p=0.3638	H(2,n=900)= 1.01, p=0.6028	H(2,n=2677)= 0.41, p=0.8129
Iron	H(2,n=899)= 8.10, p=0.0174	H(2,n=900)= 0.57, p=0.7533	H(2,n=900)= 0.41, p=0.8130	H(2,n=2677)= 8.17, p=0.0169
Magnesium	H(2,n=899)= 9.55, p=0.0084	H(2,n=900)= 7.04, p=0.0296	H(2,n=900)= 5.19, p=0.0748	H(2,n=2677)= 165.38, p=0.000
Manganese	H(2,n=899)= 2.01, p=0.3659	N/A	N/A	H(2,n=2677)= 2.07, p=0.3554
Potassium	H(2,n=899)= 9.24, p=0.0098	H(2,n=900)= 22.76, p=0.0000	H(2,n=900)= 2.27, p=0.3212	H(2,n=2677)= 24.24, p=0.000
Phosphorus	N/A	N/A	H(2,n=900)= 2.02, p=0.3638	H(2,n=2677)= 2.07, p=0.3554
Silicon	H(2,n=899)= 4.58, p=0.1013	H(2,n=900)= 27.66, p=0.0000	H(2,n=900)= 22.04, p=0.0000	H(2,n=2677)= 528.31, p=0.000
Sodium	H(2,n=899)= 5.89, p=0.0526	H(2,n=900)= 62.85, p=0.0000	H(2,n=900)= 2.97, p=0.2263	H(2,n=2677)= 5.21, p=0.0740
Sulphur	H(2,n=899)= 23.06, p=0.0000	H(2,n=900)= 85.22, p=0.0000	H(2,n=900)= 25.21, p=0.0000	H(2,n=2677)= 199.09, p=0.000
Titanium	H(2,n=899)= 2.01, p=0.3659	H(2,n=900)= 0.005, p=0.9974	H(2,n=900)= 3.26, p=0.1964	H(2,n=2677)= 5.22, p=0.0734

TABLE 34: Krustal Wallis ANOVA results for Qualitative Analyses: BCR Episodes / Non-Episodes

Element	BCR Episode	BCR Non-Episode	BCR Episode versus Non-Episode
Aluminum	H(6,n=2099)= 14.85, p=0.0215	H(1,n=599)= 306.68, p=0.0000	H(1,n=2698)= 369.95, p=0.0000
Barium	H(6,n=2099)= 6.01, p=0.4216	N/A	N/A
Calcium	H(6,n=2099)= 25.86, p=0.0002	H(1,n=599)= 1.69, p=0.1933	H(1,n=2698)= 5.73, p=0.0166
Carbon	H(6,n=2099)= 165.85, p=0.00	H(1,n=599)= 155.85, p=0.0000	H(1,n=2698)= 66.81, p=0.0000
Chlorine	H(6,n=2099)= 15.11, p=0.0195	H(1,n=599)= 0.99, p=0.3202	H(1,n=2698)= 0.31, p=0.5781
Chromium	H(6,n=2099)= 6.01, p=0.4216	N/A	N/A
Copper	N/A	H(1,n=599)= 0.99, p=0.3202	H(1,n=2698)= 3.68, p=0.0551
Iron	H(6,n=2099)= 10.75, p=0.0966	H(1,n=599)= 0.20, p=0.6512	H(1,n=2698)= 0.79, p=0.3747
Magnesium	H(6,n=2099)= 19.76, p=0.0031	H(1,n=599)= 68.75, p=0.0000	H(1,n=2698)= 103.88, p=0.0000
Manganese	H(6,n=2099)= 6.01, p=0.4216	N/A	N/A
Potassium	H(6,n=2099)= 20.04, p=0.0027	H(1,n=599)= 0.34, p=0.5604	H(1,n=2698)= 0.94, p=0.3330
Phosphorus	H(6,n=2099)= 7.73, p=0.2586	H(1,n=599)= 1.02, p=0.3137	H(1,n=2698)= 0.66, p=0.4152
Silicon	H(6,n=2099)= 8.53, p=0.2017	H(1,n=599)= 282.34, p=0.0000	H(1,n=2698)= 220.82, p=0.0000
Sodium	H(6,n=2099)= 90.42, p=0.00	H(1,n=599)= 122.72, p=0.0000	H(1,n=2698)= 255.61, p=0.0000
Sulphur	H(6,n=2099)= 43.49, p=0.0000	H(1,n=599)= 59.48, p=0.0000	H(1,n=2698)= 118.94, p=0.0000
Titanium	H(6,n=2099)= 4.90, p=0.5572	H(1,n=599)= 1.02, p=0.3137	H(1,n=2698)= 2.92, p=0.0874

TABLE 35: Krustal Wallis ANOVA results for Morphological /:Qualitative Analyses Bowl Episodes / Non-Episodes

Element	Episodes	Non-Episodes
Aluminum	H(7,n=2698)= 106.47, p=0.0000	H(7,n=2699)= 39.84, p=0.0000
Calcium	H(7,n=2698)= 57.51, p=0.0000	H(7,n=2699)= 15.99, p=0.0138
Carbon	H(7,n=2698)= 74.73, p=0.0000	H(7,n=2699)= 22.46, p=0.0010
Copper	H(7,n=2698)= 59.09, p=0.0000	N/A
Magnesium	H(7,n=2698)= 56.99, p=0.0000	H(7,n=2699)= 21.08, p=0.0018
Silicon	H(7,n=2698)= 67.61, p=0.0000	H(7,n=2699)= 20.58, p=0.0022
Sodium	H(7,n=2698)= 61.56, p=0.0000	N/A
Sulphur	H(7,n=2698)= 43.77, p=0.0000	H(7,n=2699)= 28.28, p=0.0001

TABLE 36: Krustal Wallis ANOVA results for Morphological / Qualitative Analyses: BCR Episodes / Non-Episodes

Element	Episodes	Non-Episodes
Calcium	H(4,n=2099)= 11.13, p=0.0252	N/A
Carbon	H(4,n=2099)= 17.29, p=0.0017	H(4,n=599)= 10.91, p=0.0276
Sodium	H(4,n=2099)= 31.17, p=0.0000	H(4,n=599)= 10.98, p=0.0269