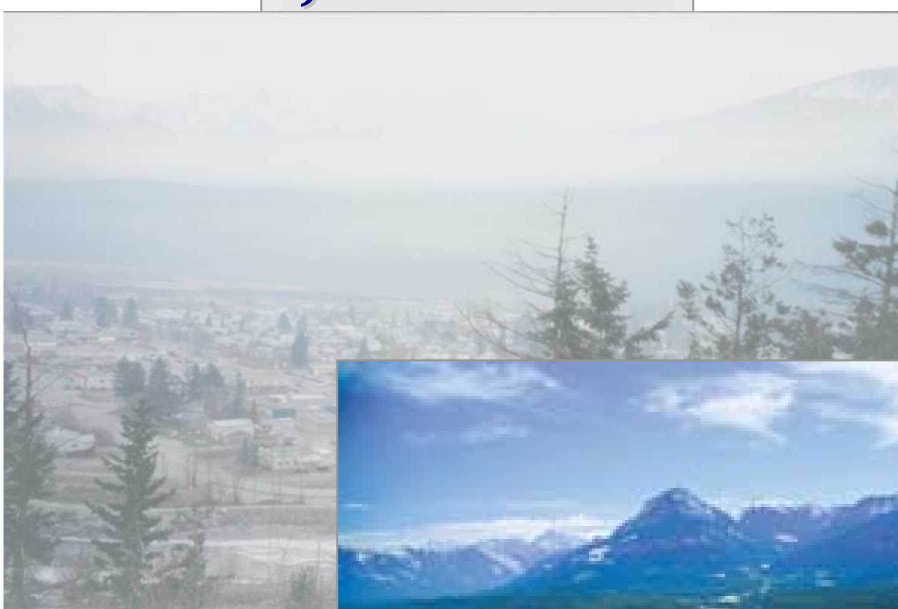
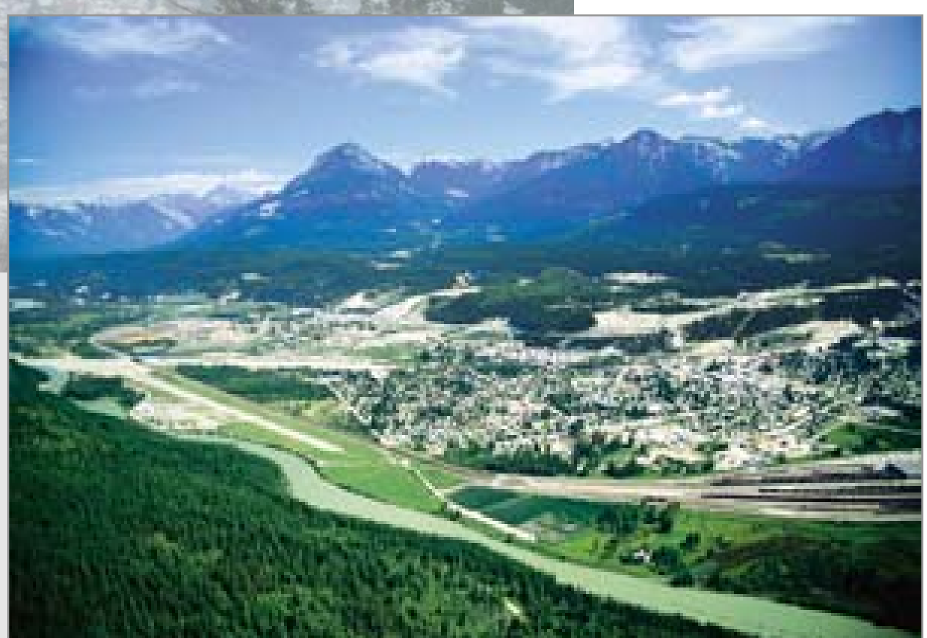
British Columbia
Ministry of Environment
Kootenay and Okanagan Regions

Particulate Matter Source Apportionment in Golden, British Columbia





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[1] This report was written when the ministry name was "Water, Land, and Air Protection" (WLAP). However, as of June 2005, the name changed to the "Ministry of Environment" (MoE).

Preface

The ultimate goal of a Source Apportionment Study in Golden is to add to the knowledge base of the air quality in the airshed and to aid the development of strategies as part of an Airshed Management Plan. The intent of this report is to provide a broad summary of the science of source apportionment, and specifically how this science will be applied in Golden.

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'Pristine' Golden, courtesy Golden and District Chamber of Commerce http://www.goldenchamber.bc.ca/

Particulate Matter Source Apportionment in Golden, British Columbia

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January 2006

Executive Summary

There is mounting evidence that airborne particulate matter (PM) poses a significant health concern. The Ministry of Environment[2] (MoE) has instituted a network to monitor airborne particulate matter throughout the province, including continuous measurements in Golden. Recognizing that better understanding of the sources of particulate matter was needed to develop strategies for improving air quality, MoE undertook the development of a provincial particulate matter speciation and source apportionment program. Golden's particulate matter levels are the highest of Kootenay communities and consistently rank as one of the highest in British Columbia. For this reason, among others, the Golden airshed was chosen as the province's first so-called "supersite" to conduct a two year study on the chemical constituency of sampled air.

At the heart of this study are two over-arching goals:

- Identification of which anthropogenic pollutants – and therefore human-generated sources – are found in the Golden airshed so that a resultant Airshed Management Plan can be optimized.

- Establishment of guidelines for particulate matter speciation to which all future provincial studies can adhere; at least at some high level.

Proactively, the Town of Golden and its residents support MoE's interest in this large-scale study. A stakeholder partnership, including major local industry, has been established to facilitate the study and to provide input to the process. Following the completion of the study, new airshed management strategies will be generated, and monitoring will continue, to determine the effectiveness of the strategies with respect to the reduction of particulate matter levels in Golden. This report describes the science of Source Apportionment in general terms and details how the science will be applied to the Golden airshed type.

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[2] Formerly the "Ministry of Water, Land and Air Protection," until June 2005.

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1.0 Introduction: Source Apportionment, Speciation, Receptor Modelling

1.1 Background

A receptor model[3] is a technique to identify the sources of emissions, and the quantities from those sources. These models start by collecting and measuring ambient PM at a receptor (a location in the community), and work backwards to determine the sources.

Two key components of a receptor model are ***speciation*** and ***source apportionment***. Speciation utilizes the physical and/or chemical characteristics of ambient pollutants to identify the sources (e.g., black carbon typically indicates incomplete combustion, from sources such as diesel engines and wood burning). Source apportionment is the process of "apportioning" ambient air pollutants at a receptor site to their respective source(s). Used together, source apportionment and speciation determine the amount of the PM from the different sources. Meteorological data (e.g., wind speed and direction) are also needed in a receptor model to apportion the PM.

Receptor models have been used extensively since the 1980's and have proven useful in targeting sources for emission reduction programs. In the past decade, receptor models have been applied to increasingly more complex air quality scenarios. As the ability to analyze particulate matter and its chemical constituents has improved, the models to support the data have grown in complexity and accuracy.

Receptor models are developed using a variety of data. Typically, when a greater quantity and variety of chemical species is collected, the model is more robust, and the easier it is to apportion between similar sources (e.g. woodstoves versus wildfires; gasoline versus diesel combustion).

There are two basic types of receptor models: 1) a single variable or sample type (e.g., Chemical Mass Balance - CMB), or 2) a multivariate/multi-sample type (e.g., Principal Component Analysis (PCA), Positive Matrix Factorization (PMF), and UNMIX target transformation factor analysis.)

1.2 Why do we need to understand the sources of PM?

Airborne fine particulate matter (PM) is a diverse mixture of dust, pollen, smoke, soot and fine aerosols. The smallest of these particles (smoke and aerosols) can penetrate deep into the air sacs of the lungs and pose a serious threat to human health.

A report released by the Ministry of Environment, Lands and Parks in 1995[4] estimated that in British Columbia fine particulate (PM_{10}) in outdoor air caused 148 hospitalizations and 82 premature deaths per year due to various lung and heart disorders.

[3] Statistics-based software tools that equate empirical relationships between ambient data and emissions sources.

[4] http://www.env.gov.bc.ca/air/particulates/heoipifb.html

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Airborne fine particulate matter … poses a serious threat to human health.

Understanding the sources of PM allows air quality managers and community stakeholders to pinpoint emission sources for Airshed Management Plans[5]. Further information on the relative contribution of each source to air pollution allows planners to develop effective pollution reduction schemes to protect human health.

Particulate matter is generally designated into three size classifications: $PM_{2.5}$ (known as "fine fraction" PM) consisting of particles less than 2.5 microns[6], $PM_{10-2.5}$ (known as "coarse fraction" PM) consisting of particles between 2.5 and 10 microns, and PM_{10} consisting of particles less than 10 microns (i.e., coarse and fine fractions combined).

$PM_{2.5}$ is largely composed of particulates from combustion sources such as vehicle exhaust, wood and coal burning. $PM_{10-2.5}$ is largely composed of crustal material that has been crushed or ground by natural or anthropogenic processes down to sizes where it is entrained and suspended in the atmosphere. Examples include road, drilling and construction dust. Sea salt, soot, pollen and fly ash are other common sources of the coarse fraction.

[5] An area- or airshed-based process undertaken to identify the sources and impacts of certain air pollutants, and to develop a strategy to minimize those emissions. Refer to: http://www.env.gov.bc.ca/air/airquality/pdfs/int_aq_rep_may04.pdf

[6] 1 micron is one millionth of a metre. For reference the diameter of a human hair is typically 50 – 60 microns.

1.3 Receptor Studies in B.C.

Receptor modelling has had limited application in B.C.. Several site-specific studies have been performed across the province. However, given the types of resources available and the variability of the study objectives, most of these studies utilized different chemical and statistical analysis methods. These studies include REVEAL[7] in 1994 and REVEAL II in 1999, which analysed the sources of $PM_{2.5}$ in the Fraser Valley. In Prince George, a PCA study utilizing PM_{10} morphology[8], metals and ions was performed to determine the sources of PM_{10} in the Prince George airshed. In Quesnel, particulate morphology was used to fingerprint sources of PM during winter.

Provincial interest in using source apportionment to support local Airshed Management Plans has risen over the past few years. To address this, the province intends to use the Golden study to develop standard criteria for provincial source apportionment studies. The study in Golden will not only serve the needs of this particular airshed but should also improve guidelines to which all provincial studies can adhere; at least at a higher level. Individual airshed studies will vary somewhat, reflecting differences in local concerns, climate and emission sources. Lessons learned from the Golden study and any subsequent study should be applied to the provincial receptor modelling guidelines to improve their standard of excellence. The Golden study is envisioned to help B.C. communities and air quality planners design source

[7] REgional Visibility Experimental Assessment in the Lower Fraser Valley.

[8] Morphology refers to the particulate shape (e.g., spherical, oval, rounded or irregular) which is used to denote the source of that particle.

apportionment studies for their airshed (i.e. required instrumentation, operational support, data analysis and data management) for the purpose of supporting Airshed Management Plans.

1.4 Influences on Air Quality: Emissions

To characterize particulate matter levels in British Columbia, the Ministry of Environment has been monitoring particulate matter levels throughout the province for several years. While the earliest monitoring dates back to 1985, the large-scale monitoring effort began in 1989.

The sources of particulate matter vary from community-to-community and from season-to-season. Based on the year 2000 provincial emissions inventory[9], an estimated 850 thousand tonnes of particulate matter (see Appendix II: Primary Pollutant) were released into the atmosphere. Note that this estimate is only for emissions that result from human activities.

Though provincial summaries may not reflect relative source contributions in individual communities such as Golden, they are useful as a benchmark for comparison.

As summarized in Figures 1a and 1b, these are the key points from the 2000 Emission Inventory with regard to particulate matter outside the Lower Mainland:

PM_{10}

- ❖ Point sources contribute 45% of PM_{10} emissions, with 23% coming from the wood industry and 11% coming from the pulp and paper industry.
- ❖ Area sources are collectively responsible for 46% of PM_{10} emissions; 25% are from prescribed burning, 11% are from agricultural practices and 9% are from residential fuel wood combustion.

$PM_{2.5}$

- ❖ Point sources contribute 40% of $PM_{2.5}$ emissions, with 20% from the wood industry and 12% the from the pulp and paper industry.
- ❖ Area sources account for almost half (49%) of $PM_{2.5}$ emissions, with significant contributions from prescribed burning (33%) and residential fuel wood combustion (13%).

For both PM_{10} and $PM_{2.5}$, the contributions from area sources (e.g. fireplaces, wood stoves and backyard burning), mobile sources (e.g. diesel trucks and railroad activity), and road dust are important to local air quality. Area sources are numerous and/or widespread and are located in close proximity to the community.

[9] MWLAP (2004) *2000 Emission Inventory Analysis Report*. Note that the estimates contained in this report include neither natural sources such as wildfires and biogenic emissions, nor fugitive road dust.

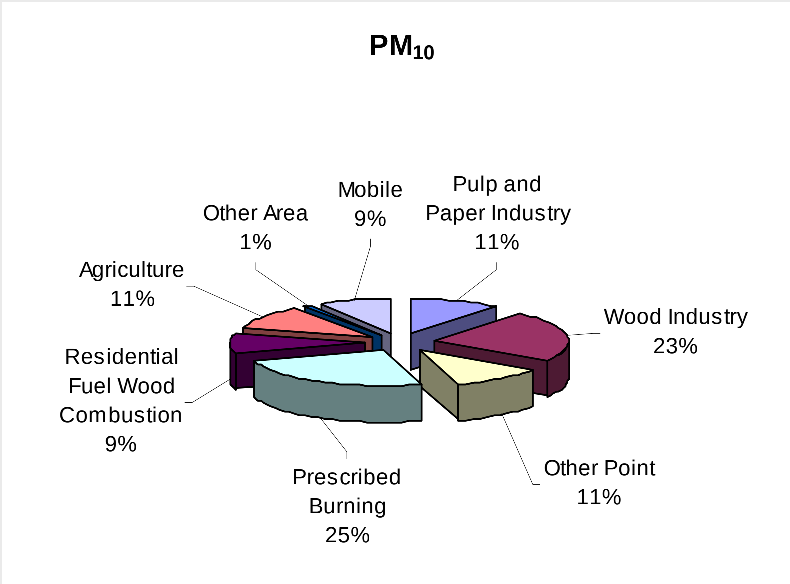

Figure 1a: Summary of PM_{10} Emissions Outside Lower Mainland

Source: *2000 Emission Inventory Analysis Report*, MWLAP. 2004. This estimate does not include natural sources, such as wildfires or biogenic emissions, or fugitive road dust.

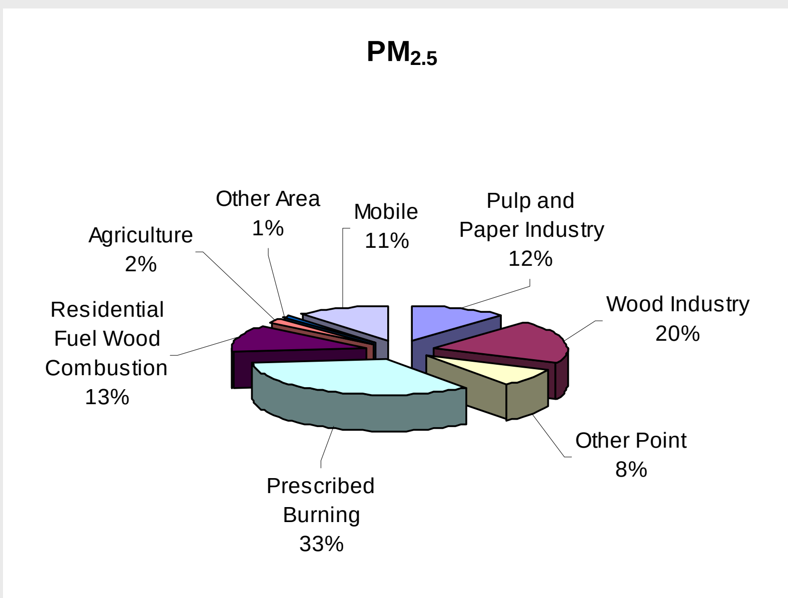

Figure 1b: Summary of $PM_{2.5}$ Emissions Outside Lower Mainland

Source: *2000 Emission Inventory Analysis Report*, MWLAP. 2004. This estimate does not include natural sources, such as wildfires or biogenic emissions, or fugitive road dust.

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Secondary particles[10] were not considered in the emission inventory estimates, although studies limited to the Lower Fraser Valley indicate that they comprise up to 50% of the fine particulate matter collected during the summer. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), various hydrocarbons, and ammonia (NH_3) are important gases involved in the formation of secondary particles[11, 12].

Major sources of SO_2 include the cement, pulp and paper, and petroleum industries, as well as motor vehicles[13]. Approximately 75% of NO_x emissions are from motor vehicles and marine vessels. Motor vehicles, solvent usage and vegetation contribute to over 70% of hydrocarbon emissions, and agriculture is the dominant source of NH_3.

The Ministry of Environment has implemented a number of programs to reduce the amount of particulate matter emitted into the atmosphere. Regulations have been passed to reduce smoke from land-clearing fires and wood stoves[14]. A model bylaw[15] has been developed to assist local governments in restricting backyard burning. Beehive burners are being phased out, beginning in the most smoke-sensitive areas of the province.

Common sources of fine particulate matter ($PM_{2.5}$) are: smoke from burning of wood waste or garden refuse, slash burning, residential woodstoves, exhaust from car and truck engines, as well as industrial smoke stacks. In addition to sources that come from human activities, $PM_{2.5}$ is also produced by natural processes.

Depending on meteorological conditions, it is possible for particles to stay suspended in the air for long periods of time, resulting in poor air quality. For particles in the $PM_{2.5}$ size fraction, this can allow particles to travel over hundreds of kilometres over time spans of days to weeks.

The larger particles that make up the rest of the coarser particulate matter (PM_{10}) usually consist of finely ground rock and clay. They come from both human and natural sources and are often called fugitive dust.

[10] Particles that are not directly emitted into the atmosphere, but are produced by chemical and physical processes. See Appendix II: Secondary Particle.

[11] Lowenthal D.H., D. Wittorff, and A.W. Gertler (1994) *CMB Source Apportionment During REVEAL - Final Report*. Air Resources Branch, British Columbia Ministry of Environment, Lands and Parks.

[12] Pryor S.C. and D. Steyn (1994) *Visibility and ambient aerosols in south-western British Columbia during REVEAL*. British Columbia Ministry of Environment, Lands and Parks.

[13] ARB (1994) *1990 British Columbia Emissions Inventory of Common Air Contaminants*, Air Resources Branch, British Columbia Ministry of Environment, Lands and Parks, Victoria, B.C., December.

[14] http://www.qp.gov.bc.ca/statreg/reg/W/WasteMgmt/302_94.htm , http://www.env.gov.bc.ca/air/particulates/agttobsc.html

[15] http://www.env.gov.bc.ca/air/particulates/pdfs/bylaw.pdf

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The most common source of fugitive dust caused by human activity is from unpaved roads or paved roads that have had gravelled tractional material applied for winter travelling. When B.C. Interior roads thaw and dry in the spring, traffic grinds the gravel into finer and finer particles. These are then either mixed into the air by passing traffic, or picked up by strong winds.

1.5 Influences on Air Quality: Weather and Topography

Besides emission sources, both human-caused and naturally occurring, there are other factors that play an important role in the ambient air conditions. Of primary importance are the influences of complex terrain (i.e., valleys and hills) and weather conditions.

Winds in the airshed generally are aligned with the valley orientation (north-northwest to south-southeast). This may be the result of either valley channelling or diurnal valley flows (see Figure 2). Thus, the Town of Golden is more susceptible to particulate matter emissions from either of these directions.

An airshed is often bounded by natural topographic features. In the case of the Golden airshed, the Purcell Mountain Range and the Rocky Mountain Trench play a large role in determining the containment and/or dispersion of air pollutants. The steep valley walls make Golden more susceptible to a higher frequency of temperature inversions.

Temperature inversions are common in communities located in mountain valleys or nestled up against a mountain range. Cold air sinks to the valley floor or base of the mountains and because it is denser than the warmer air, it remains there. These stagnant conditions prevent upward mixing of the air, keeping pollutants near the surface. This is most prevalent during the night (Figure 2 illustrates valley flows over a daily period), but can also occur during the day, especially during the winter season when daylight hours are reduced.

… steep valley walls make Golden more susceptible to … temperature inversions.

Unfortunately, air quality suffers during an inversion because pollutants like dust, smoke and vehicle emissions are trapped close to the ground by the warm layer of air above. The warm air acts like a lid and prevents pollutants from rising and dispersing (Figure 3). Prolonged periods of inversions can aggravate severe health effects, especially on those with respiratory problems, children and the elderly.

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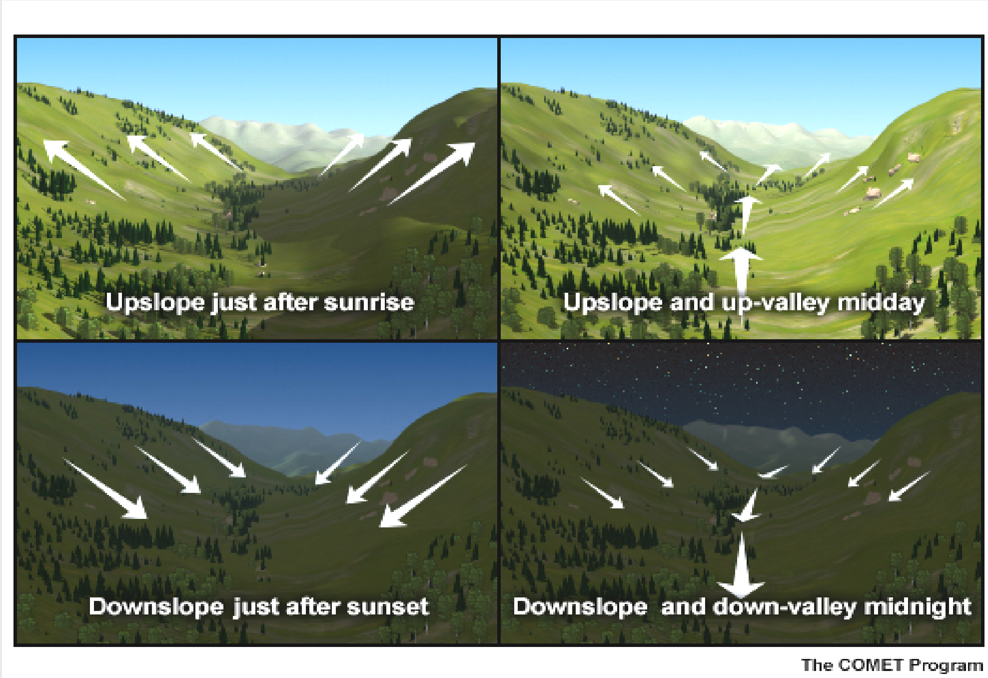

Figure 2: Diurnal Valley Flow. Airflow during the daytime tends to be towards upslope and up-valley. During the nighttime this tendency reverses and denser, cooler air pools in valley bottoms. *The source of this material is the Cooperative Program for Operational Meteorology, Education, and Training (COMET®) Web site at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR), funded by the National Weather Service. ©2002, UCAR. All Rights Reserved.*

Figure 3: Diagram of a Temperature Inversion. The warm layer of air on top of the cold layer creates an inversion layer that traps emissions close to the ground. *Graphic courtesy of Environment Waikato, Government of New Zealand.*

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2.0 Framework for Source Apportionment Studies

When an area experiences high concentrations of particulate matter, particularly when the concentrations are in exceedance of the standard, research and analysis are needed to determine the possible sources of PM and PM precursors leading to the high concentrations[16]:

- Monitoring staff should know whether their sampling and analysis setup is adequate to identify the PM and precursor species that are critical for identifying potential sources in their area.
- Analysts should be able to identify potential sources and meteorological conditions to assist policy makers and modellers in developing control strategies.
- Modellers should know how well current emission inventories and dispersion models represent the ambient conditions so that they can model future control scenarios and the effect on PM concentrations.
- Policy makers should know what sources are the principal contributors to PM so that appropriate controls on PM and precursor emissions can be developed and implemented. Also, policy makers need to understand which fraction of the PM is changing in response to controls or other emission changes.

A complete understanding of the atmospheric environment and a thorough assessment of possible particulate matter (PM) management strategies are only possible when information from receptor methods, emission inventories, and chemical transport models (CTMs) are combined. This corroborative, or "weight of evidence," approach provides the strongest scientific basis for specific emission controls. Through this approach decisions can be made with greater confidence in their positive outcome when considering air-quality management options and costs in relation to other societal needs[17].

… identification of sources which are the most harmful to health.

At the heart of this information need are two over-arching outcomes:

1. Identification of which anthropogenic pollutants in the airshed – and therefore which human-related sources – are the most harmful to health and/or are most strongly implicated in other environmental issues (e.g., visibility impairment);

2. Identification of which emission reduction strategies will result in the greatest health and environmental benefits.

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[16] Main and Roberts. *$PM_{2.5}$ Data Analysis Workbook*, Sonoma Technology Inc, 2001.

[17] Brook, JR, et al. *Particulate Matter Science for Policy Makers: A NARSTO Assessment*. February, 2003. http://narsto.org/ - see PM Science & Assessment

3.0 Golden Airshed Study Overview

3.1 Airshed Description

In general, an ***airshed*** is a three-dimensional geographical area denoting that body of air in which management strategies of any individual emission source can have a discernible effect. For example, a backyard burning bylaw in Golden could likely positively influence the air throughout the Town of Golden and in the surrounding areas but will likely not affect air quality in Revelstoke or Invermere. However, this definition is complicated by that fact that fine PM can travel thousands of kilometres. But for airshed management purposes, the Golden airshed refers roughly to the elongated airmass running along the axis of the Columbia River which runs from SSE to NNW. The airshed extends from ridgeline to ridgeline (under summer conditions; in winter with the inversion cap the mixing is contained well below the ridgelines) and the valley is about 12 km wide. Emission influences along the valley axis extend about 30 km either side of Golden. The airshed is approximately 600 km^2 (Figure A1).

3.2 Golden Emission Inventory

The Town of Golden and the regional district are subject to frequent high levels of particulate matter (PM). Major emission sources in this airshed have been identified as:

- **Lumber/Plywood Mill** (operated by Louisiana Pacific Inc. herein known as 'LP', 24hr continuous wood combustion)
- **Canadian Pacific Railway (CPR) switching yards** (diesel exhaust, fugitive dust)
- **Vehicle Traffic**
  - Idling and mobile trucks (diesel)
  - Gas powered local and highway traffic
- **Wood Burning Stoves** (residential)
- **Forest Fires**

- **Slash Burning** (Forest industry, ski development)

- **Natural Sources**
  - Crustal sources (e.g., road dust, lake beds, river beds during low water levels, agricultural tilling)
  - Gaseous and particle emissions from trees.

Figures A1 and A2 show an aerial view and a topographical view of Golden and the locations of monitoring stations and stationary emission sources. Note the NW/SE valley orientation. The channelling of winds and mountain/valley wind flow are evidenced by the weather data collected. As with any airshed there exists a significant challenge in the identification of emissions and sources. However, this airshed is relatively simple, as there are a limited number of emission sources and types; only one major single emission point (LP Mill), a few line sources (TransCanada highway, Provincial Highway 95, CPR), and some area sources (Husky Truck Stop, residential heating, slash burning, forest fires, crustal sources, CPR switching yard). The orientation of these sources to the present monitoring station is generally favourable (LP and CPR on opposite sides of Golden but both in line with prevailing NW/SE wind orientation).

A preliminary Emission Inventory (EI) for this airshed has built upon the provincial EI and updated by some sources with more detailed data and emission factors. This Golden EI will be released after updated source emission data has been included and the document has completed an in-house review, followed by a stakeholder review.

3.3 *Monitoring Support: Pre-Speciation*

Data collection in Golden has a fairly solid archive dating back to 1992. However, the data collection to date has been limited to particulate matter (PM) and meteorological parameters; and it has been only since 1998 that continuous sampling of PM_{10} has occurred. In April, 2002, a NAPS[18] TEOM[19] $PM_{2.5}$ sampler was collocated with the PM_{10} sampler (Figure 4). The MoE ambient monitoring site is located adjacent to Golden Hospital at Durand Manor (denoted in Figure A1 as the grey flagpole). Less than two blocks to the southwest is located a standard MoE weather station (on top of Lady Grey Elementary School).

Figure 4: Twin TEOMs currently in operation above the Durand Manor. (Photo by Garry Bell, WLAP)

[18] National Air Pollution Survey.

[19] Tapered element oscillating microbalance – an instrument to measure PM2.5

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The recent formation of an air quality advocacy group has been key in gathering political will and public support for creating partnerships to operate Ministry (TEOM PM_{10} and meteorological station) and NAPS (TEOM $PM_{2.5}$ installed April 2002) monitoring equipment. At present, the support from the municipal entities, the industrial stakeholders (LP, CPR), the Columbia Basin Trust, and the Golden District Golf and Country Club for a Speciation Study is strong.

In summary, air quality monitoring in Golden prior to the initiation of the speciation study consisted of:

- A meteorological station downtown monitoring wind speed, wind direction, temperature and relative humidity since 2000.
- Continuous PM_{10} monitoring downtown since 1999.
- Continuous $PM_{2.5}$ monitoring downtown since 2001.
- NAPS speciation instrumentation downtown (Dichot[20] and speciation monitor[21], see figure 6) since spring, 2004. This station does 1 in 3 day sampling., and filters are analysed for mass, major ions (NH_4, NO_3, SO_4, Cl, K etc…), carbon (EC[22]/OC[23]), and metals. The NAPS program is covering the instrumentation and analysis costs for this equipment.

All instruments are located downtown at the Central Hub (see Figure A2) and are treated as one site for air quality analysis. For the list of instrumentation for the speciation study, refer to section, "Speciation Study Design".

[20] Short for "Dichotomous Partisol-Plus Sequential Air Sampler" which is a multi-filter sequential sampler (up to 16 filter sets) for the simultaneous collection of the fine (PM-2.5) and coarse particles contained in PM_{10}.

[21] A flexible Partisol sampling platform for the collection of particulate matter and gases from ambient air for analysis in a laboratory.

[22] Elemental Carbon – EC, also known as "black carbon", is formed by incomplete combustion of hydrocarbons. Its major sources are biomass and fossil fuel burning. It is a good indicator of primary anthropogenic emission sources as it is relatively inert.

[23] Organic Carbon – OC is formed by a variety of processes, including combustion and secondary organic aerosol formation. Organic carbon (OC) in particles can be emitted from primary emission sources (primary OC), biogenic sources, and in situ chemical reactions among reactive organic gases (e.g. toluene, xylenes etc…) in the atmosphere (secondary OC).

3.4 Why Golden?

There is strong community support for the development of an Airshed Management Plan in Golden.

The National Air Pollution Surveillance program (NAPS) is currently undertaking source apportionment/receptor modelling work across the country. Golden was one of three sites in British Columbia (Abbotsford and Burnaby are the others) that NAPS chose to locate speciation equipment. The GVRD/FVRD is working with Environment Canada at the Lower Mainland sites. In Golden, the operation of the speciation monitor and the analysis of data is a joint venture between the NAPS program (which has supplied the additional instrumentation) and the B.C. MoE (which is responsible for instrument operation and maintenance).

Historical PM_{10} and $PM_{2.5}$ levels in Golden are well above the provincial average

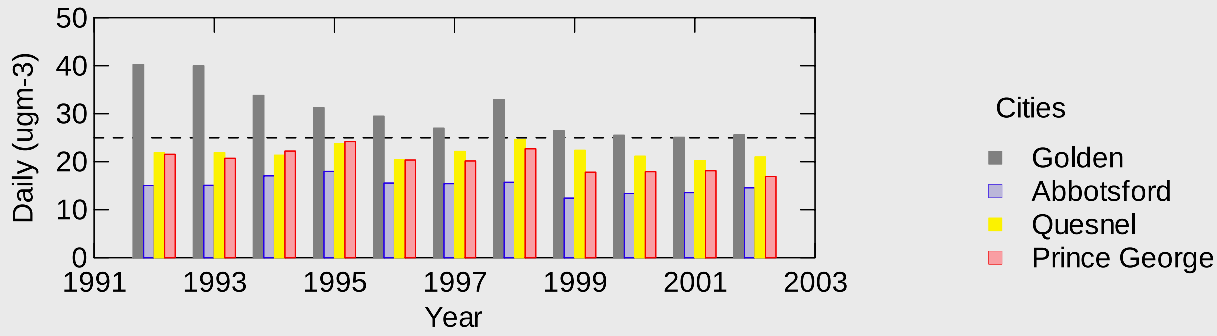
Golden is a suitable site for the development of a model source apportionment study for several reasons.

1. Its topography (i.e., valley bottom), climate and meteorological characteristics are typical of numerous interior B.C. communities (see Figure A1).

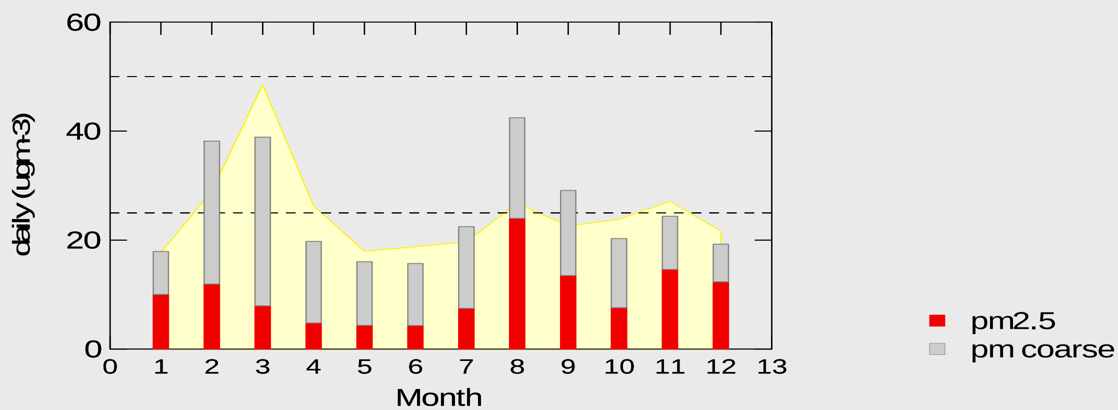
2. Historical PM_{10} and $PM_{2.5}$ levels are well above the provincial average. (see Figure 5)

3. Predominant emission sources (wood stoves, open burning, transportation, rail yards, wood processing, and road dusting) are typical for interior communities.

4. There is strong community support for the development of an Airshed Management Plan.



a) Yearly comparison of Golden PM_{10} with other communities.
NAAQO health reference level for PM_{10} is 25 µg/m^3.



b) Year 2003 data compared with previous years average.
NAAQO health reference level for PM_{10} is 25 µg/m^3
Actual PM_{10} is the total of red and grey portions of bar.
Yellow profile is PM_{10} average from all previous years.
Note that 2003 July, August, and September levels were biased by high degree of wildfire activity.

Figure 5: Summary of Ambient Conditions of PM_{10} for Golden, British Columbia.

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3.5 Study Objectives

- The ultimate goal of a $PM_{2.5}$ Source Apportionment Study in Golden is to add to the knowledge base of the airshed and to provide a baseline for the development of strategies as part of an Airshed Management Plan.

- The study in Golden should not only serve the needs of this particular airshed but should also improve guidelines that all provincial studies can adhere to at a general level. Individual airshed studies will vary somewhat, reflecting local concerns and environment.

3.6 Receptor Model Requirements

Positive Matrix Factorization (PMF - a multivariate receptor model) is the model likely to be used with the Golden data. PMF requires numerous ambient data samples (minimum 65 - 100) to estimate source contributions and create source profiles. The advantage of this model over single variable models, such as CMB, is that it does not require the collection and speciation of source emissions. Only the receptor data is required.

For the Golden study, PM species including metals, ions and carbon constituents will be derived from 24hr filters running on a 1 in 3 day cycle over 2½ years. Data from continuous monitoring of SO_2, NO_x, CO, $PM_{2.5}$ and PM_{10} will be used in combination with and/or separate from the filter data in the receptor model. Meteorological data will also be collected continuously. This continuous data will be crucial in determining both diurnal (i.e., day vs night air quality) and directional (i.e., direction of plumes) factors associated with poor air quality.

3.7 Speciation Study Design

The current NAPS speciation network in Golden provides a minimal understanding of Golden's $PM_{2.5}$ sources. It does not provide the required detail to differentiate between similar sources such as diesel truck versus gasoline vehicle emissions or wood stove versus open burning emissions. Furthermore, it does not speciate coarse fraction particulates. As this study is intended to provide criteria for a provincial source apportionment guideline, it was felt that the current NAPS instrumentation would not adequately address the diverse range of air quality concerns experienced by interior communities. To develop a more robust receptor model, the PM Speciation Working Group has proposed that further instrumentation and analysis be added to the current network.

The resultant design for the Golden study consists of a series of components that have unique functions. However, all of them also build upon existing instrumentation to add robustness and broader capability to the study. These components are grouped into four levels, with Level 1 being the core requirements needed to meet source apportionment objectives and Levels 2-4 successively adding more components. Figure 11 is a conceptual diagram of the plan.

3.7.1 Level 1: Core Speciation

Figure 6: R&P Partisol Speciation Sampler.
http://www.rpco.com/products/ambprod/amb2300/index.htm

Level 1 consists of the minimum core components required for source apportionment in Golden. All the instrumentation in this level is located at the so-called "Central Hub" (downtown on the Golden and District Hospital grounds). It includes MoE monitoring equipment currently in place and equipment provided by NAPS, as well as:

1. Continuous gas monitoring provided by the mobile provincial trailer. NO_x, SO_2, CO, and possibly O_3. These measures of primary gaseous pollutants serve as tracers for emission source types and assist analysts in identifying the sources with greater confidence. These are currently in place in the mobile unit (see Figure 7) which moved to Golden in summer 2004; however, the SO_2 and the CO units may have inadequate detection limits and may need to be replaced.

2. Carbon analysis in the coarse fraction ($PM_{10\text{-}2..5}$). Current NAPS instrumentation and analysis in Golden is limited to metals characterization of the coarse fraction. Coarse fraction carbon (OC/EC) is not accounted for. Carbon analysis of the coarse fraction will be performed using a second dichotomous sampler collocated with the other dichotomous sampler. This could run on a 1-in-3 schedule like $PM_{2.5}$ or could run consecutively over episodic periods (e.g., March – April).

3. An hourly aethalometer[24] for black carbon (BC) measurements (see Figure 8). This will provide additional support for the identification of combustion sources in the Golden airshed, particularly in combination with the SO_2, NO_x and meteorological data.

Figure 7: WLAP Mobile Monitoring Station will be deployed at one of the Anchor sites. (photo by Steve Josefowich, WLAP)

24 An aethalometer continuously measures the "black" or "elemental" carbon components of aerosols in ambient air.

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Figure 8: **An Aethalometer.**
http://www.mageesci.com/

3.7.2 Level 2: Spatial Resolution

Level 2 consists of all components in Level 1 with the following additional instrumentation:

1. Additional monitoring site(s) south and/or north of current Central Hub site. These are the northern and southern anchor sites (see Figure A2). Continuous PM and surface meteorological monitoring at one or both of these stations are providing data for a better temporal and spatial understanding of PM in the Golden airshed. These two stations are providing additional information about PM emissions from the two principal point sources in Golden – the fibreboard manufacturing plant and the railyard. The site has:

a. TEOM $PM_{2.5}$/PM_{10} mass
b. Surface meteorology (temperature, RH, WS, WD)

3.7.3 Level 3: Enhanced Spatial Resolution

Level 3 consists of all components in Level 2 with the following additional instrumentation:

1. A second aethalometer at one of the anchor sites (south or north). This instrument serves as a backup to the Central Hub site and when both instruments are operating can be rotated between the two anchor sites. This allows for a spatially broader time-resolved characterization of combustion sources in the valley.

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3.7.4 Level 4: Spatial and Temporal Variations of PM

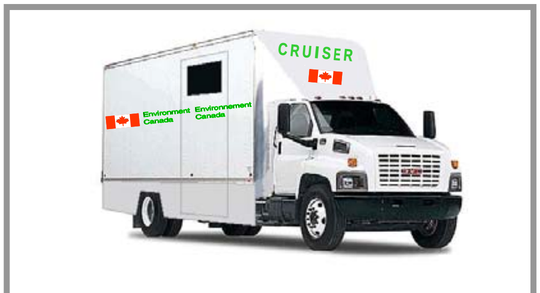

Figure 9: CRUISER.

Canadian Regional and Urban Investigation System for Environmental Research mobile monitoring station.

To increase the spatial and temporal (area and time) aspects of monitoring, Level 4 consists of all components in Level 3 with additional instrumentation and analysis from a three-week visit from Environment Canada's mobile monitoring stations (see Figure 9 and Figure 10). These shorter data collection periods were split between establishing source profiles from the major emission sources and adding to the existing PM speciation data collection at the Central Hub.

The "CRUISER" (Canadian Regional and Urban Investigation System for Environmental Research) has an impressive suite of instrumentation including the following:

1) **Mass and chemical characterization** using an Aerodyne Aerosol Mass Spectrometer (AMS) and a Proton-Transfer Reaction Mass Spectrometer (PTRMS). The PTRMS is used for near real-time measurement of gas phase organics. Some of the currently planned target compounds are: benzene, toluene, xylene, acetaldehyde, isoprene and PAN. Both the AMS and PTRMS are state-of-the-art research instruments.

2) **Atmospheric aerosol scanning** was used to augment and validate measurements taken at the Central Hub.

The mobile laboratory known as RASCAL (or Rapid Acquisition Scanning Aerosol Lidar) employs a laser beam which is reflects off a series of mirrors before it arcs out to scan the lower atmosphere for particulate matter. Using powerful telescopes, the team is then able to observe the beam as it reflects off any airborne matter it encounters. Since the beam continually sweeps the horizon in incremental steps, the reflected signals will follow air contaminants both spatially and temporally.

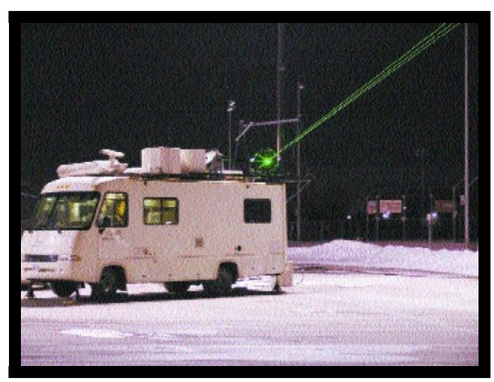

Figure 10: RASCAL

Rapid Acquisition Scanning Aerosol Lidar mobile monitoring station.

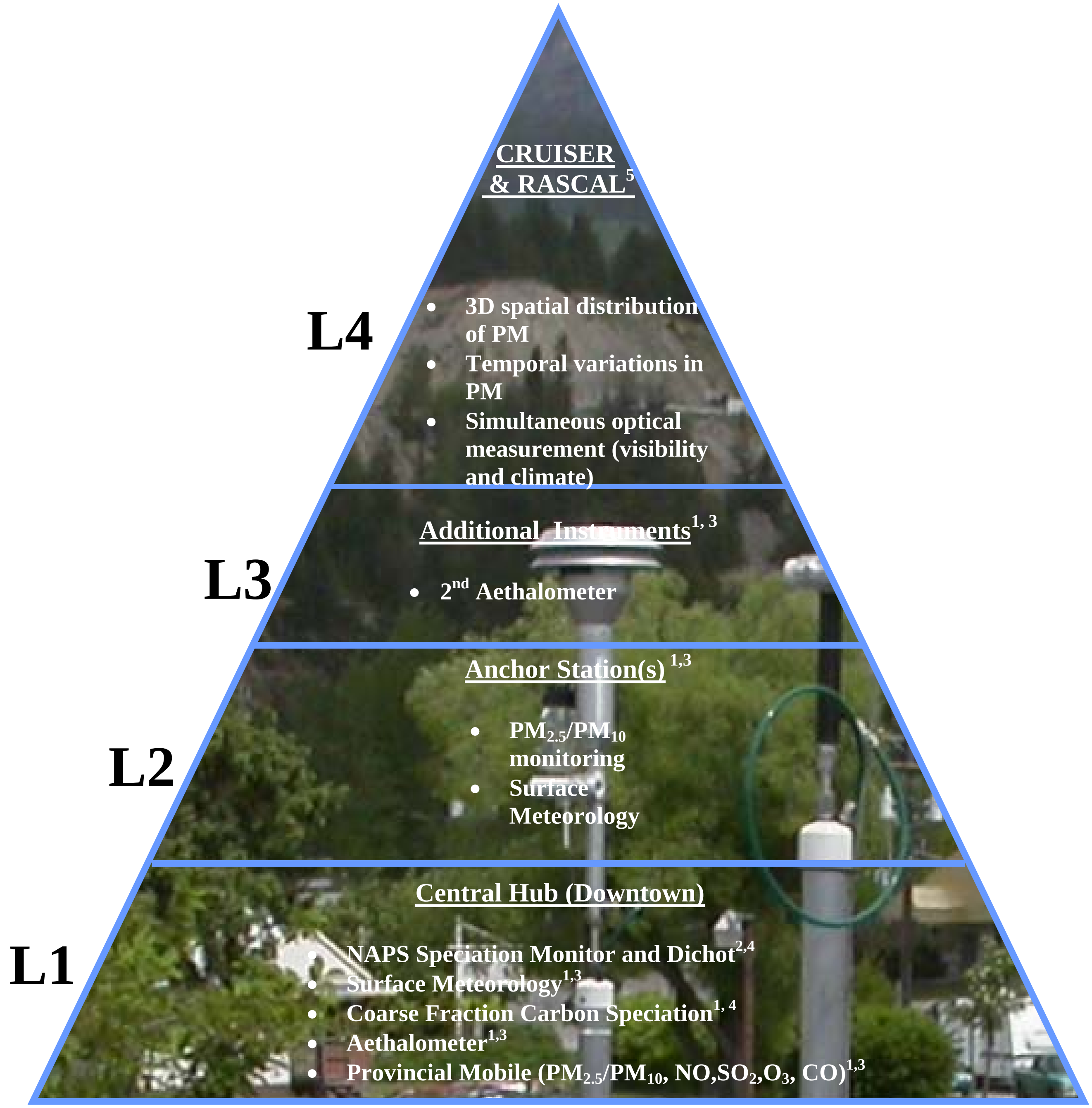

Figure 11: Instrumentation Network Hierarchy

[1] Instrumentation, maintenance and analysis supplied by MoE
[2] Instrumentation and analysis supplied by EC, maintenance supplied by MoE
[3]1-hr, daily
[4]24hr, 1-in-3
[5]Instrumentation and analysis supplied by EC. Continuous measurements over a short-term.

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3.8 Provincial Co-Benefits

In addition to providing criteria for performing receptor modelling studies in B.C., there are several other benefits this study provides to the province. These include:

- The development of a provincial mobile "speciation trailer" outfitted with appropriate instrumentation for source apportionment work. This trailer could be moved to other communities in the province performing source apportionment studies in the future.
- The development of valuable in-house MoE knowledge in using and applying receptor models (e.g., PMF).
- The development of criteria for applying source apportionment results to airshed management plans.

3.9 Budget

The requirement to minimize the level of uncertainty inherent with source apportionment studies comes with a significant cost. For the complete two and a half year term of the data collection phase, there will be close to $700K worth of instrumentation and staffing invested. Budget for the data analysis phase has yet to be determined.

3.10 Timeline

Collection and analysis of NAPS speciation filters began in June 2004. Full initiation of Levels 2 and 3 was realized in October, 2004. Level 4 monitoring occurred during a three-week period in February, 2005. It is anticipated that the data collection phase of the study (Levels 1,2,3) will end in the spring of 2007. Following this phase, data analysis will begin in earnest. Recommendations that arise from this analysis will be brought forward to local and provincial policy makers, and will provide the heart of the resultant Airshed Management Plan.

3.11 Further Monitoring

Although the current monitoring system will provide a useful receptor model for the Golden airshed, future provincial speciation studies may want to include more specialized equipment. Adding to the data volume with more specialized sampling will lead to more effective receptor models, and hence better policy decisions. However, there is a significant financial burden that comes with receptor modelling and the design of any study must reflect available resources.

1. **Size distribution instrumentation** (OPC[25] and CPC[26]) will provide further understanding of the coarse ($PM_{10-2.5}$) and fine ($PM_{2.5}$) aerosols. Correlated with continuous meteorological

[25] Optical Particle Counter – counts particles > 0.1 µm to 25 µm.

[26] Condensation Particle Counter – for size distribution of ultrafine particles (<1µm to 0.003µm).

and gas monitoring data, the particle size distribution data would be used to determine sources of aerosol by size classification (e.g. dust storms are associated with particles smaller than 2.5µm while diesel sources are dominated by particles smaller than 1µm).

2. **If carbon or nitrate/sulphate** are significant species, specialty monitors would focus on them. If OC is determined by filter analysis to be a primary component of PM2.5, a continuous OC/EC monitor would collect day/night detail of OC/EC ratio. A continuous ion monitor would analyze nitrate/sulphate species.

For Further Information

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Public Feedback is Welcomed

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Appendix I: Golden Airshed

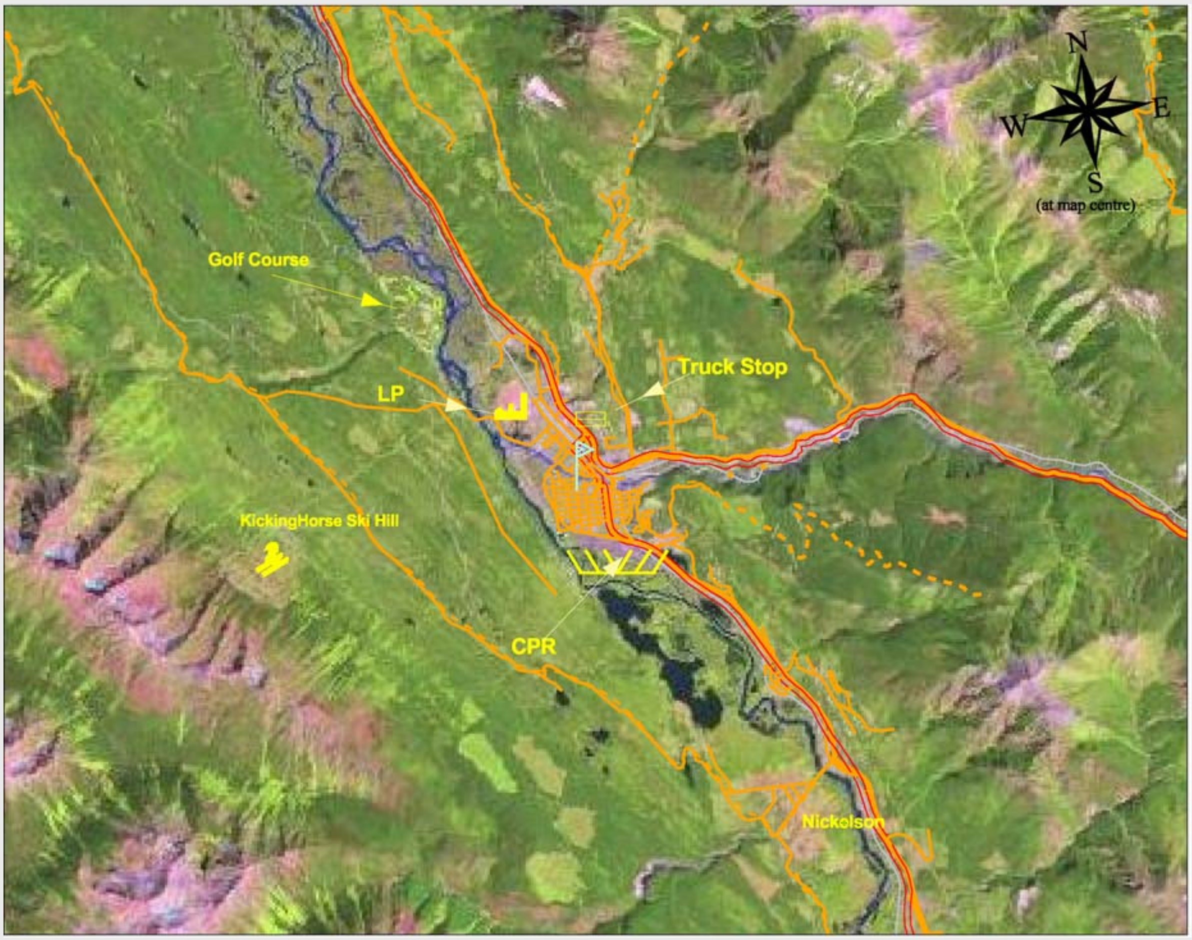

Figure A1: Golden Airshed, with major air quality features.

Scale: 1:130,000. June 2002, air photo image.

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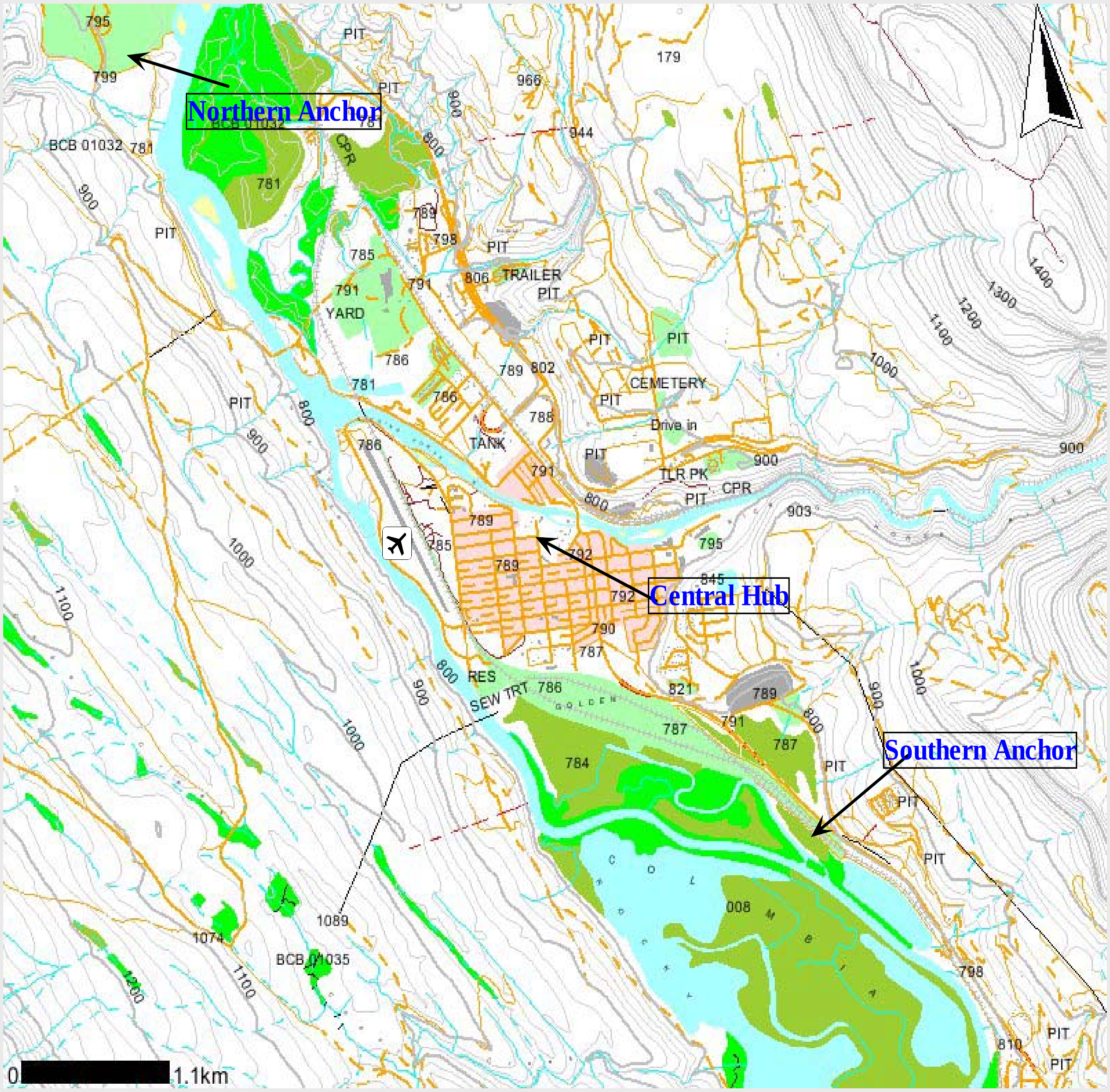

Figure A2: Monitoring Component Locations

Appendix II: Glossary and Abbreviations

Aerosol A particle of solid or liquid matter that can remain suspended in the air because of its small size (generally under one micron).

Aethalometer An air sampler that continuously measures the "black" or "elemental" carbon components of aerosols in ambient air**.**

Air parcel A volume of air that tends to move as a single entity.

Air pollution Degradation of air quality resulting from unwanted chemicals or other materials occurring in the air.

Airshed A geographic area that, because of topography, meteorology, and/or climate, is frequently affected by the same air mass. In general, it is that body of air in which management strategies of any individual emission source can have a discernible effect.

Air Quality Index (AQI) Reports levels of ozone, particulate matter, and other common air pollutants. Higher AQI ratings for a pollutant indicate higher levels of contaminants in an airshed. For guidance on how to compute the AQI, see http://wlapwww.gov.bc.ca:8000/pls/aqiis/air.info .

Airshed Management Plan [Planning] An area- or airshed-based process undertaken to identify the sources and impacts of certain air pollutants, and to develop a strategy to minimize those emissions.

AMS Aerodyne Aerosol Mass Spectrometer. The AMS is used for size and chemical composition of particles in the range from 30-1000 nm. Time-resolved measurements of sulfate, nitrate, ammonium and organic carbon can be obtained relatively routinely. Environment Canada's CRUISER is equipped with this technology.

Anthropogenic Produced by human activities.

Anthropogenic pollutant Emissions from human-made sources as opposed to natural (biogenic) sources.

ARB Air Resources Branch, Ministry of Environment

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Attenuation The diminution of quantity. In the case of visibility, attenuation or extinction refers to the loss of image-forming light as it passes from an object to the observer.

Biogenic Having to do with living organisms as sources. For example, major sources of biogenic emissions in the Kootenay Region are trees.

Carbon monoxide (CO) A colourless, odourless, poisonous gas, produced by incomplete burning of carbon-based fuels.

CMB Chemical Mass Balance model

CO See Carbon monoxide

Coarse fraction Particulate matter with diameter between 2.5 and 10 microns ($PM_{10-2.5}$). Also referred to as "inhalable particulate matter."

Condensation The process by which molecules in the atmosphere collide and adhere to small particles.

Condensation Particle Counter (CPC) Counter for size distribution of ultrafine particles (<1µm to 0.003µm).

CPR Canadian Pacific Railway

CRUISER Canadian Regional and Urban Investigation System for Environmental Research

Dichot Short for "Dichotomous Partisol-Plus Sequential Air Sampler" which is a multi-filter sequential sampler (up to 16 filter sets) for the simultaneous collection of the fine fraction($PM_{2.5}$) and particles contained in $PM_{10-2.5}$.

Elemental carbon (EC) Also known as "black carbon" or "soot", is formed by incomplete combustion of hydrocarbons. Its major sources are biomass and fossil fuel burning. It is a good indicator of primary anthropogenic emission sources as it is relatively inert.

EC Environment Canada or elemental carbon

Emission Inventory (EI) A list of air pollutants emitted into a community's atmosphere in amounts (commonly tonnes) per day or year, by type of source.

Emission factor A measure of an average rate of emission of a pollutant for a defined activity rate.

EPA US Environmental Protection Agency

Exceedance A measured level of an air pollutant higher than the national or provincial ambient air quality standard.

Fine fraction Particulate Matter with diameter less than 2.5 microns; $PM_{2.5}$. Also referred to as "respirable particulate matter".

FVRD Fraser Valley Regional District

GVRD Greater Vancouver Regional District

Haze (hazy) Atmospheric aerosol of sufficient concentration to be visible. The particles are so small that they cannot be seen individually but are still effective at attenuating light and reducing visual range.

Inversion An increase in temperature with height. The reverse of the normal cooling with height in the atmosphere. Temperature inversions minimize vertical air movement, trapping atmospheric pollutants in the lower troposphere, resulting in higher concentrations of pollutants at ground levels than would usually be experienced.

LFV Lower Fraser Valley

LP Louisiana Pacific Inc.

Mean The total of all values divided by the number of samples.

MoE B.C. Ministry of Environment. (formerly Ministry of Water, Land, and Air Protection).

MELP B.C. Ministry of Environment, Lands and Parks**.** (predecessor to WLAP).

µg/m³ Micrograms per cubic metre (concentration)

µm Micrometres (10^{-6} m) (diameter)

Mobile sources Motor vehicles and other moving objects that release pollution; mobile sources include cars, trucks, buses, planes, trains, motorcycles, and gasoline-powered lawn mowers. Mobile sources are divided into two groups: road vehicles, which include cars, trucks, and buses, and non-road vehicles, which includes trains, planes, and lawn mowers.

Multivariate analyses Statistical procedures that can be used to infer a mix of emission sources impacting a receptor location.

NAPS National Air Pollution Surveillance Network. NAPS was established by Environment Canada to monitor and assess the air quality in Canadian urban regions.

National Ambient Air Quality Objectives (NAAQO) Health-based pollutant concentration objectives, developed by Environment Canada and used as enforcement standards in B.C.

National Ambient Air Quality Standards (NAAQS) Health-based pollutant concentration limits established by the EPA (United States) that apply to outside air.

Nitrates (NO_{3-}) Those gases and aerosols that have origins in the gas-to-aerosol conversion of nitrogen oxides, e.g., NO_2; of primary interest are nitric acid and ammonium nitrate.

Nitrogen oxides ($NO_{x)}$ Gases formed mainly from atmospheric nitrogen and oxygen when combustion takes place under conditions of high temperature and high pressure; considered a major air pollutant and precursor of ozone.

NO_x NO + NO_2 + poorly defined fraction of other NO_y species (given conventional analyzers).

O_3 Ozone ; a major component of smog. Ozone is not emitted directly into the air but is formed by the reaction of volatile organic compounds (VOCs) and NO_x in the presence of heat and sunlight.

Optical Particle Counter (OPC) Instrumentation that counts particles from less than 0.1 µm up to 25 µm in size.

Organic carbon (OC) Consists of hundreds of separate compounds that contain > C20. OC is formed by a variety of processes, including combustion and secondary organic aerosol formation. Organic carbon in particles can be emitted from primary emission sources (primary OC), biogenic sources, and in situ chemical reactions among reactive organic gases.

Particulate matter (PM) A generic term referring to liquid or solid particles suspended in the air.

Partisol A filter-based ambient sampler operated at low volume input that can be configured to measure $PM_{2.5}$ or $PM_{10.}$

PCA Principal Component Analysis – a statistical model that analyses emissions over time and space, which is then used in receptor modeling.

$PM_{2.5}$ Particulate matter less than 2.5 microns in diameter: the fine fraction of PM. Tiny solid or liquid particles, generally soot and aerosols. The size of the particles (2.5 microns or smaller, about 0.0001 inches or less) allows them to easily enter the air sacs deep in the lungs where they may cause adverse health effects; $PM_{2.5}$ also causes visibility reduction.

PM_{10} Particulate matter less than 10 microns in diameter, and includes both coarse and fine fractions. Tiny solid or liquid particles of soot, dust, smoke, fumes, and aerosols. The size of the particles (10 microns or smaller, about 0.0004 inches or less) allows them to easily enter the respiratory system where they may be deposited, resulting in adverse health effects. PM_{10} also causes visibility reduction and is a criteria air pollutant.

$PM_{10\text{-}2..5}$/PM_{coarse} Particulate matter between 2.5 and 10 microns in diameter; the coarse fraction of PM. Particles that are typically generated by mechanical grinding or crushing (e.g. road dust) but can include soot, ash and pollen (biogenic) particles. These particles are less likely to enter the air sacs of the lungs but instead are trapped by the mucous membranes and other lung defenses. Coarse particles are not deemed as dangerous to human health as $PM_{2.5}$ but are, nevertheless, associated with inflammatory symptoms such as asthma and other respiratory ailments.

PMF Positive Matrix Factorization; PMF is a multivariate (more than one variable) receptor model that can be used to determine source profiles based on the ambient data

Precursor Compounds that change chemically or physically after being emitted into the air and eventually become secondary pollutants. For example, sulphur and nitrogen oxides are precursors for particulate matter.

Primary particle The fraction of PM_{10} and $PM_{2.5}$ that is directly emitted from combustion and fugitive dust sources.

Primary pollutant The emissions discharged from a source that either retain their form or are transformed into secondary pollutants.

PTRMS Proton-Transfer Reaction Mass Spectrometer. The PTRMS is used for near real-time measurement of gas phase organics and is included in the instrumentation aboard the CRUISER.

QA Quality assurance; a set of external tasks to provide reasonable certainty that the quality control system is satisfactory. These tasks include independent performance audits, on-site system audits, inter-laboratory comparisons, and periodic evaluations of internal quality control data.

QC Quality control; a set of internal tasks performed to provide accurate and precisely measured ambient air quality data. These tasks address sample collection, handling, analysis, and reporting (e.g., periodic calibrations, routine service checks, instrument-specific monthly quality control maintenance checks, and duplicate analyses on split and spiked samples).

Receptor model Statistics-based software tools that equate empirical relationships between ambient data for emissions collected at a receptor (in the community) and the sources of those emissions.

Relative humidity The ratio of the partial pressure of water to the saturation vapor pressure, also called saturation ratio; often expressed as a percentage.

REVEAL Regional Visibility Experimental Assessment in the Lower Fraser Valley.

Secondary particle The fraction of PM_{10} and $PM_{2.5}$ that is formed in the atmosphere. Secondary particles are products of the chemical reactions between primary pollutant gases, such as nitrates, sulphur oxides, ammonia, and organic products.

SO_2 See Sulphur dioxide

Source apportionment Process of determining the types and amounts of ambient pollutants that came from emissions sources.

Speciation The process of characterizing the chemical/physical properties of particulate matter for the purpose of performing source apportionment.

Speciation profile Listing of individual chemical species emitted by a specific source category

Speciation sampler Flexible Partisol sampling platform for the collection of particulate matter and gases from ambient air for analysis in a laboratory.

Stationary source A place or object from which pollutants are released and which does not move around. Stationary sources include power plants, gas stations, incinerators, houses, etc.

Sulphur dioxide (SO_2) A pungent, colourless gas formed as a byproduct of the combustion of fossil fuels.

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TEOM Tapered element oscillating microbalance. A method for the continuous measurement of PM.

UBC University of British Columbia

UNMIX A multivariate receptor modeling package that inputs observations of particulate composition and seeks to find the number, composition, and contributions of the contributing sources or source types.

WLAP B.C. Ministry of Water, Land and Air Protection (formerly Ministry of Environment, Lands and Parks (ELP), and now the Ministry of Environment (MoE)).

WD Wind direction

WS Wind speed