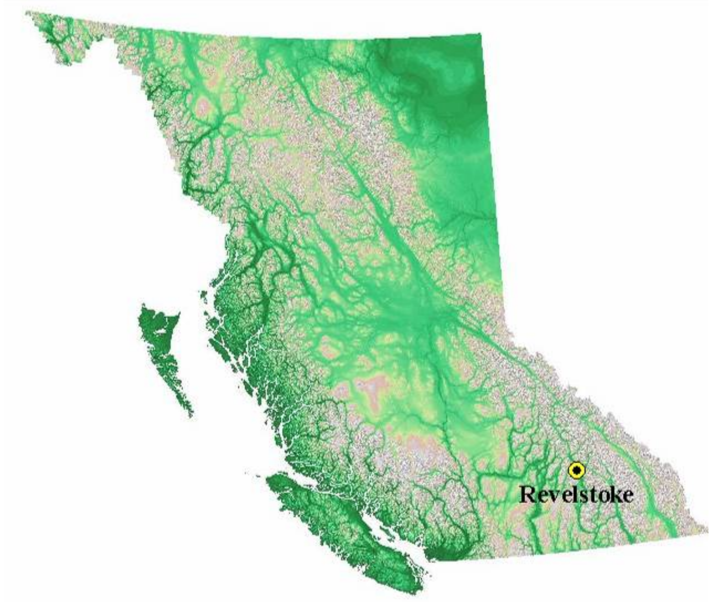
Ministry of Environment
KOOTENAY REGION

Ambient Air Quality Monitoring Report
Revelstoke, British Columbia

Particulate Matter - 1993 to 2008

Preface

This report is one in a series of air quality reports that are being issued by the Kootenay Regional Office for all communities in the region where air quality is monitored. It is the intention of the Regional Office of the Ministry of Environment to publish air quality reports on our website (http://www.env.gov.bc.ca/epd/regions/kootenay/aq_reports/index.htm) in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding air quality management can be made.



Acknowledgements

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Cover Photo:
Revelstoke Chamber of Commerce

ENVIRONMENTAL QUALITY

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Revelstoke, British Columbia

Particulate Matter - 1993 to 2008

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ENVIRONMENTAL QUALITY

Executive Summary

A vast amount of evidence exists to support the concern that airborne particulate matter poses a significant health risk to humans. In response to such a concern, the Ministry of Environment (MoE) has implemented air quality monitoring programs in various communities throughout British Columbia. The following report provides an assessment of the results of the monitoring program established in Revelstoke. The report was prepared by the MoE in an effort to inform the public, local government, and industry on the air quality conditions within the Revelstoke airshed based on particulate matter (PM) data collected during the years of 1993 to 2008. The purpose of the report is to provide insight on how to effectively manage the local air quality conditions of Revelstoke.

The Revelstoke airshed is generally defined by mountain ridgelines and passes. The airshed extends 30 km north and south of Revelstoke, confined by ridgelines 10 km on either side of the Columbia River. The airshed also extends 30 km west to Eagle Pass and 55 km east to the summit of Rogers Pass.

Primary emission sources within this airshed include fugitive dust from highways and streets, natural sources (biogenic emissions), vehicle emissions, railway operations, and smoke from woodstoves, slash burning, forest fires, and industrial point sources. The latter includes emissions from the combustion processes involved with Downie Timber Ltd. (cedar products) and Joe Kozak Sawmill Ltd.

Long-term monitoring of PM in Revelstoke has been done by a "Hi-Vol" manual sampler (every sixth day) located in the downtown area at the Fire Hall, and has been in operation since 1993. Continuous sampling (daily) of PM_{10} began in 2002, and manual sampling (every sixth day) of $PM_{2.5}$ began in 2003. More recently (mid-year 2007), the continuous monitor was changed to sample $PM_{2.5}$.

The results of the monitoring indicate that inhalable PM (PM_{10}) levels in Revelstoke have been trending downward in the decade prior to the turn of the century, except for 1997 and 1998, when major forest fires caused elevated concentrations. While the levels are within provincial guidelines, they are comparable to levels found in more industrial areas of the province. Although the annual mean PM levels appear to be satisfactory, more detailed analyses showed some noteworthy differences.

As with the inhalable PM, the respirable PM ($PM_{2.5}$) levels have been trending downward. Still, annual means of $PM_{2.5}$ rank among the highest in BC and threaten to exceed established health outcome thresholds.

PM levels are higher in the months of February and March, reflecting the effects of road traction materials and smoke from wood-burning appliances in winter. PM levels are

ENVIRONMENTAL QUALITY

also higher in August, a result of smoke from summer wild fires. PM concentrations are also strongly influenced by wind, with the quiet winds of winter resulting in higher levels (especially during inversion events), and the stronger winds of summer dispersing PM, resulting in lower levels.

Unlike PM_{10}, the $PM_{2.5}$ levels in winter are higher on weekends, and lower in mid-week. In spring, summer, and fall, no clear trend is evident. A possible explanation is that because Revelstoke is a tourist destination in the winter season (e.g., skiing, snow-mobiling), traffic volumes on the weekends and/or weekdays as part of 'long' weekends, are elevated with a corresponding rise in fine particulate emissions. This disparity may also well reflect the higher usage of wood stoves on the weekends when residents spend more time at home.

Finally, although the annual, monthly, and day of the week means indicate satisfactory air quality overall, Revelstoke has experienced several days per year of fair or poor air quality, as measured by the National Ambient Air Quality Objectives (NAAQO) Exceedance health indicator. Even if the air quality is good for most of the year, a few days of poor air quality may have serious health impacts.

Therefore, the MoE has some concern regarding air quality in the Revelstoke airshed due to the risk of high concentrations during thermal inversions and forest fire episodes. Because health care professionals have determined that even low levels of PM have an impact on human health, the public, government agencies, and industry should always be working together to adopt effective airshed management strategies, with the goal of improving the air quality for the community of Revelstoke.

Table of Contents

ENVIRONMENTAL QUALITY

Figures and Tables

ENVIRONMENTAL QUALITY

1.0 Introduction

There is mounting evidence that airborne **particulate matter** (PM) poses a significant health concern and thus the Ministry of Environment (MoE) has instituted a network of monitoring for airborne PM. The data resulting from this monitoring has been compiled and analysed by the MoE for this report to inform the public, local government, and industry about PM levels in the Revelstoke **airshed**[1]. This document will also discuss trends in air quality data and some possible actions to maintain or improve air quality. By providing such information in a readily understood format, it is hoped that local air quality conditions can be better understood and that better-informed decisions regarding air quality management can be made.

Many air pollutants are known to have detrimental effects on human and environmental health. The common ones monitored in B.C. are: nitrogen dioxide, sulphur dioxide, total reduced sulphur, carbon monoxide, ozone, formaldehyde, and PM. However, in most Kootenay Region communities, including Revelstoke, PM is the most serious health concern. As such, this was the primary monitoring focus and this report will deal only with the assessment of PM.

"Particulate matter" may sound like a scientific expression, but it breaks down into simple concepts. Particulates are tiny solid or liquid particles that come in many shapes and sizes, and are from many different sources.

The majority of particulates that have a negative effect on human health are 10 micrometres or less in diameter (PM_{10}). A micrometre (µm) is a millionth of a metre, so PM_{10} is roughly the same size as bacteria. Like bacteria, PM_{10} is invisible to the naked eye and small enough to be breathed into our lungs.

Fine particulate matter is small enough to enter our airways and lungs as we breathe.

Figure 1 demonstrates that PM comes in a wide range of sizes and differs in chemical composition, source, and behaviour in the air. Collectively, PM_{10} includes the **coarse fraction** ($PM_{10-2..5}$), the fine **fraction** ($PM_{2.5-0.1}$), and the **ultrafine** fraction ($PM_{<0.1}$).

The fine fraction ($PM_{2.5}$) is comprised of particles smaller than 2.5 µm that generally are formed by chemical reactions. $PM_{2.5}$ is often generated directly through combustion or burning; however, $PM_{2.5}$ also may be created indirectly from reactions in the atmosphere (secondary PM). Common sources of $PM_{2.5}$ include smoke from burning of yard waste, slash burning, residential woodstoves, exhaust from automobiles, and industrial smoke

[1] A geographic area that, because of topography, meteorology, and/or climate, is frequently affected by the same air mass.

stacks. In addition to sources associated with human activities, $PM_{2.5}$ is also generated through natural processes such as forest fires.

Secondary PM is formed through atmospheric reactions involving oxides of nitrogen, sulphur dioxide, volatile organic compounds, and/or ammonia from natural (*e.g.*, tree metabolism, wildfires) or human-caused emissions (*e.g.*, industrial processes, vehicles). High concentrations of secondary PM can produce an effect known as blue **haze**. Blue hazes impair visibility of scenic landscapes and can be economically detrimental to communities with high tourism values such as Revelstoke. Secondary PM of the fine fraction may remain suspended in the atmosphere for extended periods of time (depending on meteorological conditions) resulting in prolonged periods of poor air quality.

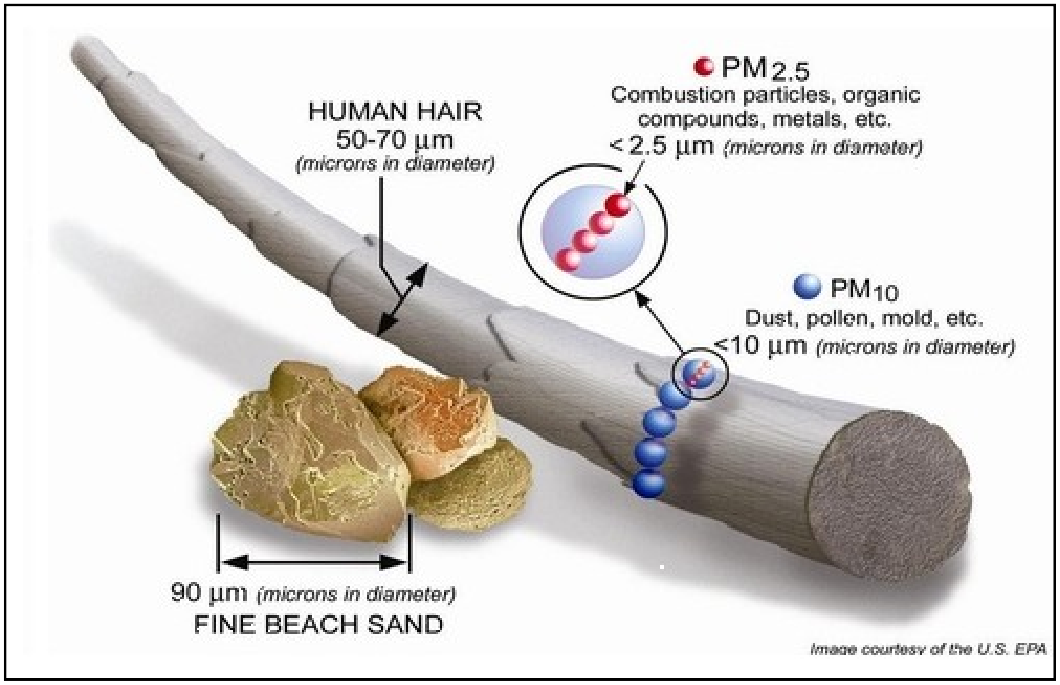


Figure 1: Relative sizes of particulate matter.

The coarse fraction consists of particles between 2.5 µm and 10 µm in diameter. Particles of this size often assume the form of **fugitive dust**, which consists of finely ground rock and clay, and come from both human and natural sources. The most common source of fugitive dust caused by human activity is unpaved roads, or paved roads that have had sand and salt applied for winter travelling. In spring, when the roads are no longer frozen or wet, traffic grinds up the gravel into finer and finer particles. These are then either thrown into the air by passing traffic, or picked up by strong winds. Other sources of coarse fraction PM include industrial emissions (e.g., fly-ash) and sea salt. Depending on meteorological conditions, it is possible for the particles to stay suspended for hours or days, resulting in poor air quality. Natural sources of fugitive dust are river, lake, and reservoir banks and dust storms, problems that affect communities like Revelstoke when water levels are low.

1.1 Particulate Matter and Health Effects

PM is the air pollutant of greatest concern in the Revelstoke airshed and throughout the Kootenay Region. There are two main reasons for the concern over this pollutant: 1) these particles are small enough to enter our airways and lungs as we breathe, and 2) the emission sources typically found in interior BC tend to produce significant amounts of PM.

Two types of PM exist that produce adverse health effects in people: inhalable PM and respirable PM. **Inhalable particulate matter**, also known as PM_{10}, is composed of particles small enough to be carried into our airways. However, some of these particles are large enough to get trapped in the larger airways and do not reach the smallest cavities within our lungs. **Respirable particulate matter** consists of the fine and ultra-fine fractions of PM (also termed as $PM_{2.5}$) and is composed of particles small enough to travel into the deepest parts of our lungs.

PM can cause a range of health effects in people, from annoying symptoms such as a runny nose to increased premature mortality in extreme cases. Recent studies have associated PM with longer-term health effects such as lung cancer.

Based on evidence from epidemiological studies, the effects of exposure to PM_{10} and $PM_{2.5}$ concentrations are reflected in:

- Increases in mortality due to cardiorespiratory diseases.
- Increases in hospitalization due to cardiorespiratory diseases.
- Decreases in lung function in children and asthmatic adults.
- Increases in respiratory stresses that can lead to absenteeism from work or school and a restriction in activities.
- Chronic effects including increased development of chronic bronchitis and asthma in some adults, and reduced survival.

Particulate matter can cause a range of effects … from annoying symptoms to premature mortality.

ENVIRONMENTAL QUALITY

Those most susceptible to PM-related health impacts are children, the elderly, asthmatics, and people with pre-existing cardiorespiratory diseases.

Previous medical studies have determined that no apparent safe lower threshold for adverse health effects exists for PM[2]. Such a finding has prompted governments to review and strengthen air quality criteria for PM in order to reduce the risks to Canadians[3].

[2] http://www.env.gov.bc.ca/epd/bcairquality/reports/phoannual2003.html
[3] WGAQOG (1999) *National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document.* A report by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines. Minister, Public Works and Government Services.

2.0 Air Quality Objectives/Standards

To evaluate air quality, objectives and standards have been introduced that provide what are considered to be acceptable levels of PM_{10} and $PM_{2.5}$ in British Columbia.

2.1 Provincial Objectives

Recognizing the threat that PM_{10} poses to human health, the MoE established an air quality objective for PM_{10} of 50 µg/m^3 (24-hour average) in 1995. This level is comparable to the maximum acceptable level in the **National Ambient Air Quality Objective** (NAAQOs) system[4] or a provincial Level B objective.

More recent health evidence suggests that $PM_{2.5}$ poses a greater health risk than do the coarser fractions. In response to this concern, the MoE has established (in the spring of 2008) a 24-hour average air quality objective for $PM_{2.5}$ of 25 µg/m^3 and an annual average objective of 8 µg/m^3.[5]

The 24-hour and annual air-quality objectives (AQOs) are the primary air management tool, used to guide decisions on environmental impact assessments and authorizations, airshed planning efforts and regulatory development. The 24-hour AQO is also used to guide decisions on whether or not to issue an air quality advisory.

The $PM_{2.5}$ planning goal of 6 µg/m^3 (annual average) is intended as a voluntary target to guide airshed planning efforts and encourage communities to maintain good air quality in the face of economic growth and development.

2.1.1 Air Quality Index

The **air quality index** (AQI[6]) is the most familiar indicator of air quality to British Columbians, providing the public with a meaningful measure of outdoor air quality via daily reports available on the Internet. It is determined by comparing air quality measures for contaminants such as ozone, carbon monoxide, and PM to levels established by the federal or provincial governments. In provincial AQI calculations, PM_{10} levels are

[4] For more information about NAAQO, see: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/naaqo-onqaa/particulate_matter_matieres_particulaires/summary-sommaire/98ehd220.pdf
[5] http://www.bcairquality.ca/regulatory/pm25-objective.html.
[6] A numerical index of particulate matter, ozone and other common air pollutants. From the AQI, we can effectively rate air quality as "Good", "Fair", "Poor", or "Very Poor". For guidance on how to calculate the AQI, see http://a100.gov.bc.ca/pub/aqiis/air.info.

ENVIRONMENTAL QUALITY

compared to reference levels of 25, 50, and 100 µg/m^3 (comparable to provincial reference Levels A, B and C, respectively). For $PM_{2.5}$, these same Levels A, B, and C correspond to 15, 25, and 50 µg/m^3.[7]

The data analysis of this report uses the reference levels of the AQI system to count the number of days in a year that each level is exceeded and reports the percentage of days that each level is exceeded. Along with these guidelines, British Columbia also references other national standards described below.

2.2 National Ambient Air Quality Objectives (NAAQOs)[8]

The NAAQOs identify benchmark levels of protection for people and the environment. NAAQOs guide federal, provincial, territorial and regional governments in making risk-management decisions, playing an important role in air quality management. Local source permitting, air quality index calculations, and the development of provincial objectives and standards all make use of the NAAQOs.

The NAAQO system defines three objectives: a maximum desirable level, a maximum acceptable level, and a maximum tolerable level. With the exception of the maximum tolerable objective, the NAAQOs are viewed as effects-based long-term air quality goals (i.e., goals determined by the epidemiological effects on peoples' health as established by statistical analysis).

2.2.1 Federal Reference Levels

Although negative health effects can occur at any level of PM, the CEPA/FPAC[9] Working Group on Air Quality Objectives and Guidelines recommended reference levels of 25 µg/m^3 (24 hour average) for PM_{10} and 15 µg/m^3 (24 hour average) for $PM_{2.5}$. These levels were intended to represent estimates above which there are demonstrated (i.e., statistically significant) effects on human health and the environment. They were not intended to be used as enforceable air quality objectives, but as the basis for establishing goals for long-term air quality management.[10]

2.2.2 Exposure Estimates

[7] The calculation used to establish the AQI for PM_{10} is [AQI = PM], where "PM" is the recorded value. For $PM_{2.5}$, the calculation is [If PM <= 15, AQI=PM*5/3. If PM > 15 and PM <= 25, AQI = 25 + (PM-15). If PM > 25, AQI=50 + (PM-25)*2]

[8] National Ambient Air Quality Objectives: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/index-eng.php

[9] Canadian Environmental Protection Act Federal-Provincial Advisory Committee

[10] CEPA/FPAC Working Group on Air Quality Objectives and Guidelines (1999) *National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document.* Minister, Public Works and Government Services.

ENVIRONMENTAL QUALITY

British Columbia | Ministry of Environment

Risk to human health is believed to increase linearly with PM concentrations. Hence, a simple estimate of exposure, and therefore risk, can be estimated by summing the concentration above a threshold or reference level over a specific period of time. The method used in this report to calculate exposure is explained in Appendix G.

2.3 Canada-wide Standards (CWS) Agreement

Under the Canada-wide Accord on Environmental Harmonization, the Canadian Environment Ministers (with the exception of Quebec) ratified the Canada-wide Standards (CWS) for PM and ozone in July 2000[11]. The CWS process is expected to provide new tools for the management of environmental issues of national interest.

The standards for particulates are based on daily average $PM_{2.5}$ measurements over three consecutive calendar years. The 98[th] percentile is often used in analyses and comparisons because it reduces the bias caused by a single extremely high reading. For each year, the 98th percentile of the daily averages is determined, then averaged for the last three calendar years. This value, referred to the **CWS Indicator**, can then be compared to the standard and to other communities.

The adopted standard for $PM_{2.5}$ is 30 $\mu g/m^3$. Although there was no standard or objective set by the CWS for PM_{10}, the previously described "CWS Indicator" is used to analyze historical trends in ambient air quality in this report.[12]

2.4 World Health Organization (WHO) Guidelines

The PM targets defined by NAAQO are useful in determining whether daily averages of PM are complying with air quality objectives. However, when examining the long term trends in ambient air PM concentrations, air quality data is converted to yearly means (rather than using daily means for trend analysis). NAAQO PM target levels are intended for daily average values and are not applicable to yearly mean values; therefore, yearly means are compared to air quality guidelines designated by the **World Health Organization** (WHO)[13].

WHO has defined long-term guidelines for both PM_{10} and $PM_{2.5}$. To minimize health issues related to PM, WHO recommends maintaining average yearly fine PM levels at concentrations below 10 $\mu g/m^3$. Similarly, WHO recommends that yearly averages of PM_{10} should not exceed 20 $\mu g/m^3$. The PM guidelines defined by WHO are used in the

[11] Canada-wide Standards Agreement: http://www.ccme.ca/ourwork/air.html?category_id=99
[12] The B.C provincial government has an objective for PM_{10}, and the federal government has a standard for $PM_{2.5}$. but there is no common objective or standard for both pollutants.
[13] For more information on WHO air qualityguidelines, refer to http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf

ENVIRONMENTAL QUALITY

current report for statistical analysis to determine whether yearly PM means exceed guidelines. WHO also defines 24-hour guidelines for $PM_{2.5}$ (25 μg/m^3) and PM_{10} (50 μg/m^3), which are the same as the provincial objectives.

Table 1: World Health Organization (WHO) objectives for PM.

PM Type	Coarseness of Particulate	WHO Objective
PM_{10}	Coarse	20 μg/m^3
$PM_{2.5}$	Fine	10 μg/m^3

ENVIRONMENTAL QUALITY

2.5 Comparison of Provincial, Federal and International Air Quality Criteria

To consolidate the types of criteria used to evaluate air quality, Table 2 summarizes the provincial, federal, and international objectives, reference levels, standards, and guidelines for PM.

Table 2. Comparison of provincial, federal, and international air quality criteria for particulate matter

	$PM_{2.5}$			**PM_{10}**		
	Concentration ($\mu g/m^3$)	Averaging	Type of criteria	Concentration ($\mu g/m^3$)	Averaging	Type of criteria
Provincial	25	24 hour	interim objective	50	24 hours	objective
	8	annual	interim objective			
Federal	15	24 hours	reference level	25	24 hours	reference level
	30	annual 98 percentile	Canada-wide Standard			
Inter-national	10	annual	guideline	20	annual	guideline
	25	24 hours	guideline	50	24 hours	guideline

Table 3. Air quality index (AQI) rating scale. Concentrations of pollutants are transformed to a common unit-less scale to indicate health implications. Note for PM_{10}, the AQI equals the concentration ($\mu g/m^3$).

Level	Description	AQI Rating	Equivalent PM_{10} Concentration	Equivalent $PM_{2.5}$ Concentration	Equivalent federal objective
A	Provide long term protection	Good – up to 25	up to 25 $\mu g/m^3$	up to 15 $\mu g/m^3$	Maximum desirable
B	Adequate protection, but may affect personal comfort.	Fair – 25 to 50	25 to 50 $\mu g/m^3$	15 to 25 $\mu g/m^3$	Maximum acceptable
C	Appropriate action required to protect human health	Poor – 50 to 100	50 to 100 $\mu g/m^3$	25 to 50 $\mu g/m^3$	Maximum tolerable

Note: the **Level** is the federal reference level for determining health effects.

ENVIRONMENTAL QUALITY

3.0 Air Quality Monitoring in Revelstoke

PM levels are measured to determine the concentrations to which people in B.C. communities are exposed. Monitoring enables regulators and policymakers to identify the air quality impacts of current sources and to determine the impacts of new sources or emission control measures. Monitoring over long periods of time allow communities to assess trends that will show if air quality is getting better or worse. It also allows comparison with standards and objectives to assess how Revelstoke's air quality is doing in relation to health standards. Comparisons can also be done between the air quality in Revelstoke and in other B.C. communities for which air quality is monitored.

To characterize particulate matter levels in B.C., MoE has been monitoring PM levels throughout the province for a number of years. Figure 2 displays the locations where air quality monitoring is done in the Kootenays, and the types of pollutants sampled. While the earliest monitoring dates back to the early 1970's, the large-scale monitoring effort began in 1989.

Several different types of air quality monitors are used across the province. In Revelstoke three samplers were used to collect PM data used for this report.

In 1993, a high-air volume (Hi-Vol) manual, non-continuous sampler (Figure 3) started monitoring PM_{10} at the Fire Hall. This sampler was in operation until mid-2007, providing a 14-year record of PM_{10} in Revelstoke. In mid-2007, a Partisol sampler, also measuring PM_{10}, replaced it.

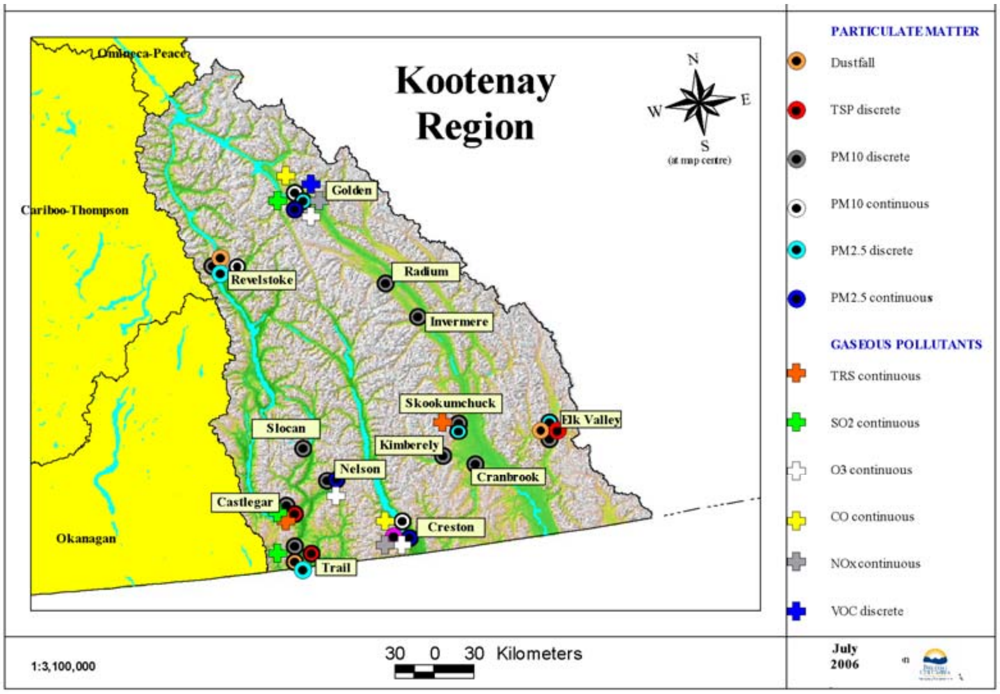
To supplement the Hi-Vol sampler, two additional monitoring systems were installed on the roof of Mt. Begbie School in February, 2002; a continuous TEOM[14] PM_{10} sampler and a complete weather station. Because of the continuous data collection and reporting in near real-time, data are available to the public and ministry and health professionals within hours of the sampling. The resultant Air Quality Index reading provides an additional tool to determine when health advisories should be issued.

One year after the TEOM installation, in February, 2003, another non-continuous sampler, a so-called low-volume Partisol (Figure 4), was installed at Mt. Begbie School to measure $PM_{2.5}$. This added the ability to differentiate the potentially more harmful fine PM. In mid-year 2007, the TEOM sampling head was also switched to measure $PM_{2.5}$. After approximately a year of co-located $PM_{2.5}$ sampler operation (needed for quality assurance), the network will be reassessed and any identified needs will be addressed.

ENVIRONMENTAL QUALITY

[14] Tapered element oscillating microbalance

Figure 2. Air quality monitoring sites in Kootenay Region (as of January 1, 2006)



Manual samplers (Hi-Vol and Partisol) draw air through a pre-weighed filter for a specified period (usually 24 hours) at a known flow rate. The filter is then removed and sent to a laboratory to determine the gain in filter mass due to particle collection. Ambient PM concentration is calculated on the basis of the increase in filter mass, divided by the product of sampling period and sampling flow rate. Different size sampling head inlets allow for the measurement of very coarse, coarse, or fine PM. Additional analysis can also be performed on the filter to determine the chemical composition of the sample, but is not done routinely. These samplers are set to take one sample of PM every sixth day (60 or 61 samples per year) and thus are considered non-continuous samplers.

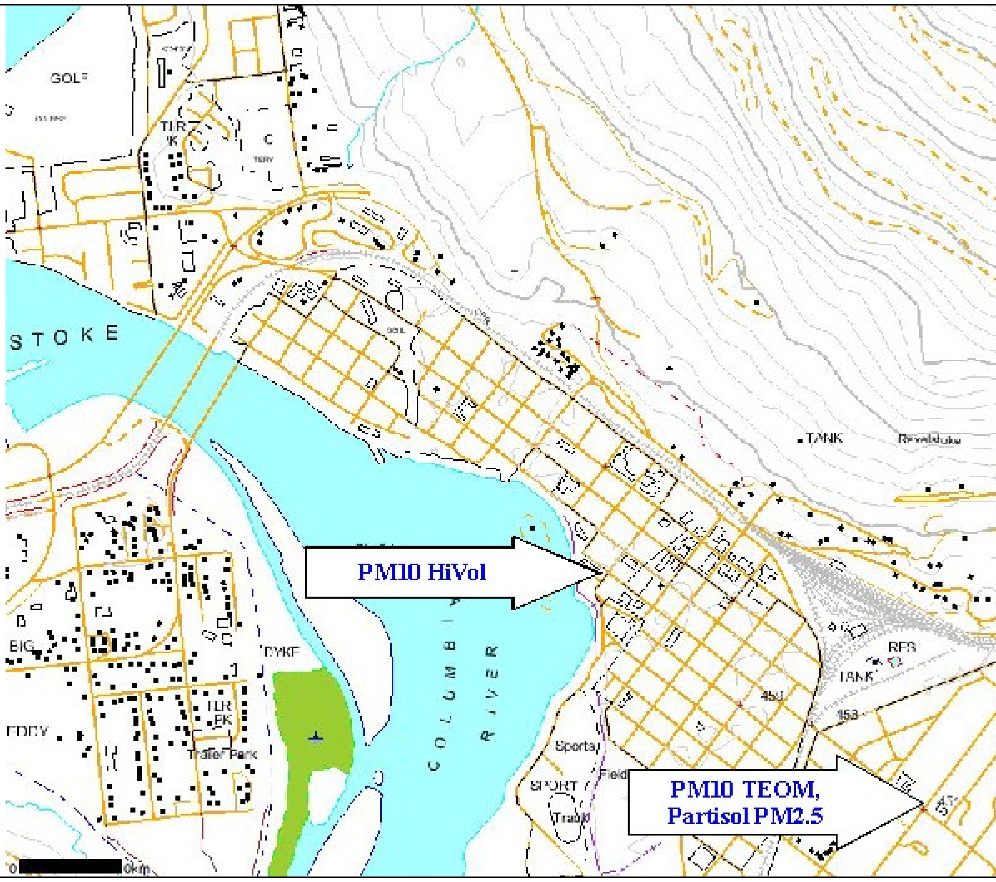
Continuous samplers (TEOM) draw air through a filter at a known flow rate, and the increased mass of the filter changes the frequency of an oscillating tube. Because this frequency is measured continuously, the amount of PM in the air is measured immediately, allowing results to be available quickly. (Typically, results are averaged over a one-hour period.) The TEOM requires the air sample to be heated, which affects the readings slightly, so they are not directly comparable to data from manual samplers, though cross calibrations are possible.

Figure 3. Periodic maintenance is performed on the high-volume (Hi-Vol) manual sampler on the roof of the Fire Hall. It collected a sample over a 24-hour period every sixth day, until July, 2007

Figure 4. This Partisol sampler was installed at Mt. Begbie Elementary School in 2003 to measure $PM_{2.5}$. Like the Hi-Vol, it takes one sample every sixth day. Located at the same site are a TEOM that measured PM_{10}, (until it was recently changed to measure $PM_{2.5}$) and a meteorological station.

[15]

Figure 5. Location of air quality (PM) sampling instruments in Revelstoke.



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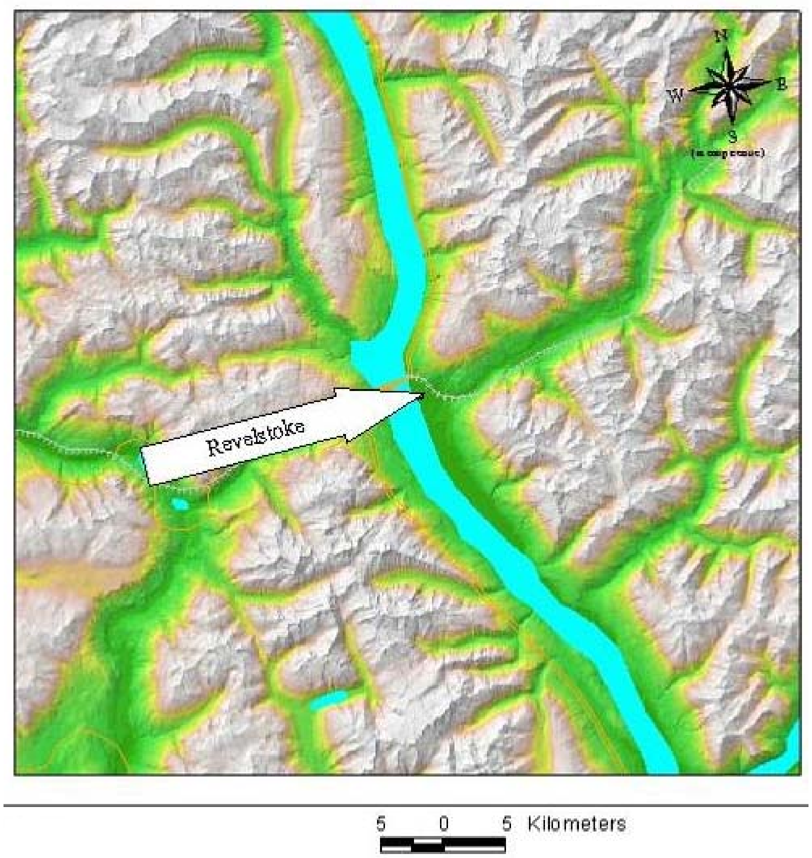
[15] The instrument head on the Mt Begbie TEOM was changed to sample $PM_{2.5}$ on June 28, 2007. The Fire Hall site instrumentation changed on October 15, 2009 from a HiVol PM_{10} to a Partisol $PM_{2.5}$. The Partisol $PM_{2.5}$ at Mt Begbie was changed to a Partisol PM_{10} on October 15, 2009.

4.0 Airshed Description

In general, an **airshed** is that body of air in which management strategies of any individual emission source can have an effect. For example, the backyard burning bylaw in Revelstoke likely has a positive influence to the air throughout Revelstoke and surrounding areas, but will likely not affect air quality elsewhere. For airshed management purposes, the Revelstoke airshed is defined by10 km to ridgelines on either side of the Columbia River and along its axis 30 km to the south and 30 km to the north. The airshed also extends 20 km to the west along the Eagle Pass Valley that splits the Monashee Mountains and 20 km to the east along the Illecillewaet River Valley to the summit of Rogers Pass in the Selkirk Mountains. (Figure 6).

Figure 6. Revelstoke airshed



The steep mountains around Revelstoke confine the flow of air masses, influencing air quality.

ENVIRONMENTAL QUALITY

4.1 Influences on Air Quality: Emissions

4.1.1 Provincial Overview

The sources of PM vary from community-to-community and from season-to-season. Based on the year 2000 provincial **emissions inventory**[16], an estimated 850 thousand tonnes of PM were released into the atmosphere as **primary pollutants**[17]. Note that this estimate is only for emissions that result from human activities (i.e., **anthropogenic** emissions).

Though provincial summaries may not reflect relative source contributions in individual communities such as Revelstoke, they are useful as a benchmark for comparison. For both PM_{10} and $PM_{2.5}$, the contributions from **area sources**[18] (e.g., fireplaces, wood stoves and backyard burning), **mobile sources** (e.g., diesel trucks), and road dust are important to local air quality. Area sources are numerous and/or widespread and are located in close proximity to where we live.

Point sources[19] of PM in the Kootenay Region include industrial operations, such as mining and metals smelting, and wood and pulp mills.

As summarized in Figures 7 and 8, these are the key points from the 2000 Emissions Inventory with regard to PM in the B.C. Interior:

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.

$PM_{2.5}$

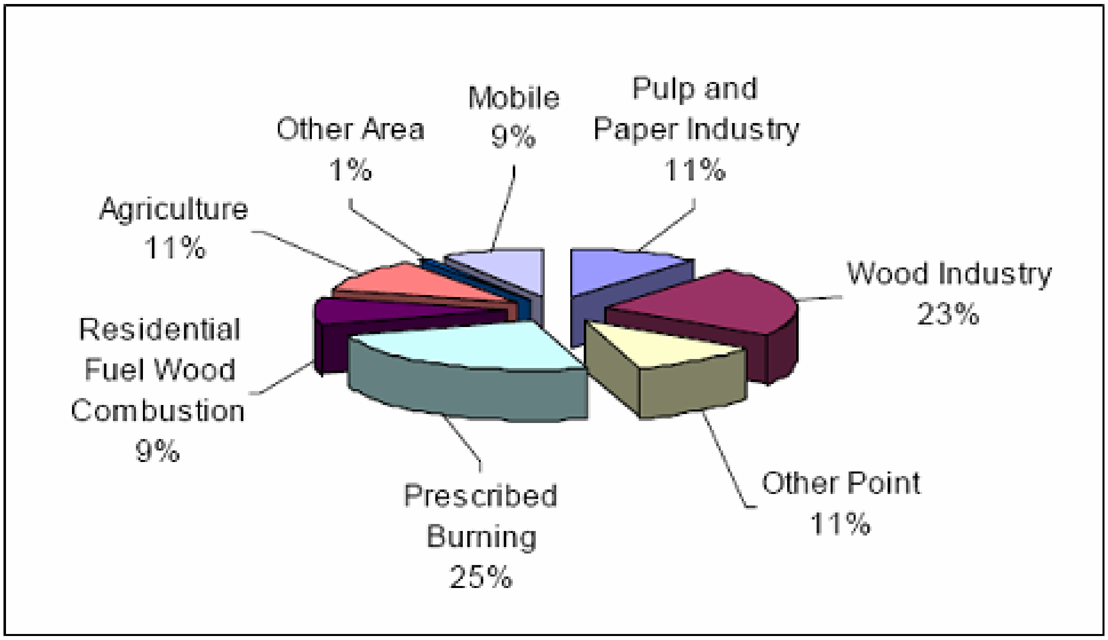
- Area sources account for almost half (49%) of $PM_{2.5}$ emissions, with significant contributions from prescribed burning (33%) and residential fuel wood combustion (13%).
- Point sources contribute 40% of $PM_{2.5}$ emissions, with 20% from the wood industry and 12% the from the pulp and paper industry.

[16] MWLAP (2004) *2000 Emissions 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.
[17] Primary pollutants are the chemicals that are emitted directly into the atmosphere. Secondary pollutants are the result of primary pollutants reacting chemically or physically to form different compounds.
[18] An emission source of pollutants that covers a large, and sometimes poorly defined, area.
[19] An emission source of pollutants that is a small identifiable area.

Secondary particles[20] were not considered in the emissions inventory estimates, although studies limited to the Lower Fraser Valley indicate that they comprise up to 50% of the fine PM 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[21,22]. Major sources of SO_2 include the cement, pulp and paper, and petroleum industries, as well as motor vehicles[23]. Approximately 75% of NO_x emissions are from motor vehicles and marine vessels. Motor vehicles, solvent usage and vegetation[24] contribute to over 70% of hydrocarbon emissions. Agricultural use of fertilizers is the dominant source of NH_3.

Figure 7. Human-caused sources of inhalable particulate matter (PM_{10})
The figure displays information for areas outside the Lower Mainland, and exclude natural sources, such as wildfires or **biogenic** emissions, and fugitive road dust.

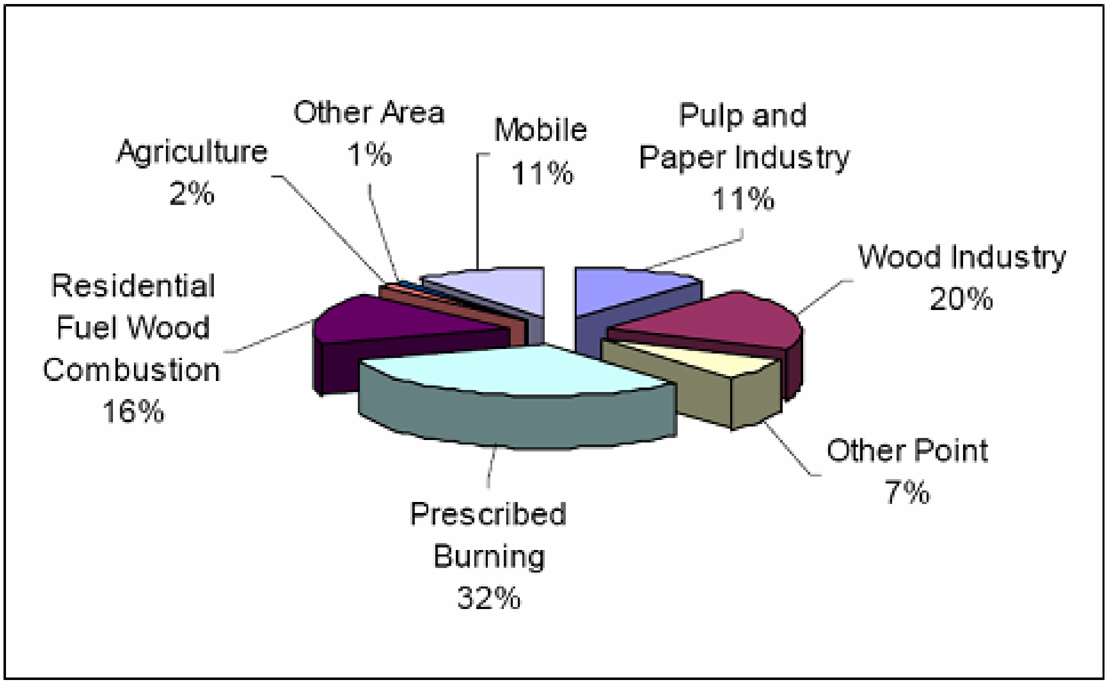
Source: 2000 Emissions Inventory Analysis Report, MWLAP. 2004.



[20] Particles that are not directly emitted into the atmosphere, but are produced by chemical and physical processes. See Appendix A: Secondary Pollutant.
[16] 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.
[22] 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.
[23] 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.
[24] "Biogenic" sources are a subset of natural sources and include only those sources that result from biological activity. Biogenic emissions represent a significant portion of the natural source emissions. VOC, NOx, and the greenhouse gases can all be emitted from biogenic sources.

Figure 8. Human-caused sources of respirable (fine) particulate matter ($PM_{2.5}$)
The figure displays information for areas outside the Lower Mainland, and exclude natural sources, such as wildfires or **biogenic** emissions, and fugitive road dust.

Source: 2000 Emissions Inventory Analysis Report, MWLAP. 2004.



Of course, each airshed will have a unique mix of emissions and sources. While a rigorous emissions inventory has not been produced for the Revelstoke airshed it is clear that the sources will be somewhat different than those indicated by the graphics in Figures 7 and 8. The main difference relates to the industrial base in Revelstoke, where two lumber mills (Downie Timber Ltd.[25] (cedar products) and Joe Kozak Sawmill Ltd.[26] dominated and there are no pulp and paper operations. Other primary emission sources in Revelstoke are residential heating, mobile sources (including resultant road dust), prescribed (including 'slash') burning, exposed lake/river beds, and wild fires. The reader is encouraged to view the emissions inventory that was completed for the Town of Golden, British Columbia[27]. Golden's emissions and airshed are very similar to those of Revelstoke.

[25] Downie Timber Ltd. ceased operation of its silo burner in 2007.
[26] This mill's silo burner ceased operating in the summer of 2008.
[27] The Emissions Inventory for Golden is available at:
http://www.env.gov.bc.ca/epd/bcairquality/reports/air_emiss_golden.html

ENVIRONMENTAL QUALITY

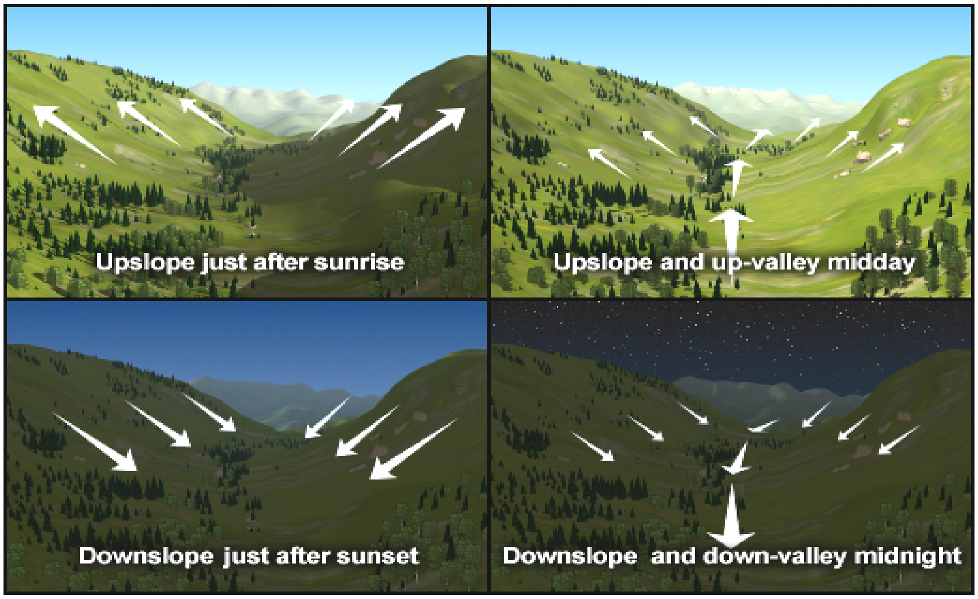
The provincial government has implemented a number of programs to reduce the amount of PM emitted into the atmosphere. Regulations have been passed to reduce smoke from land-clearing fires and wood stoves[28]. A model bylaw[29] has been developed to assist municipal governments in designing regulations restricting burning of yard waste on residential property. In addition, efforts to phase out beehive burners (large domed incinerators used by lumber mills to burn wood waste) are in process, initially focusing on the most smoke-sensitive areas of the province.

4.2 Influences on Air Quality: Weather and Terrain

Besides emission sources, both human-caused and naturally occurring, there are other factors that play an important role in ambient air conditions. Of primary importance are the influences of complex terrain (i.e., deep valleys) and weather conditions. Winds in the airshed generally are aligned with the valley orientation (north-south), which may be the result of either valley channelling or diurnal valley flows (Figure 9). However, the Mt Begbie site is strongly affected by the diurnal upslope and downslope flows from the Illecillewaet River Valley to the northeast of the station, so the wind directions at Mt. Begbie are primarily northeast or southwest, instead of the general north-south flows of the main airshed. This is especially true in winter when cold air descends from higher elevations and pools in the valley bottom at night and early mornings. (See Appendix F for detailed information about wind direction and speed in Revelstoke.)

[28] *Environmental Management Act* http://www.env.gov.bc.ca/epd/main/ema.htm
A Guide to the Open Burning and Smoke Control Regulation
http://www.bcairquality.ca/reports/agttobsc.html
[29] Model burning bylaw: http://www.env.gov.bc.ca/epd/bcairquality/topics/municipal-smoke-bylaws.html

Figure 9. Daily cycle of air flows in valleys



Airflow during the day tends to be upslope and up-valley. During the night this tendency reverses and denser, cooler air pools in valley bottoms.

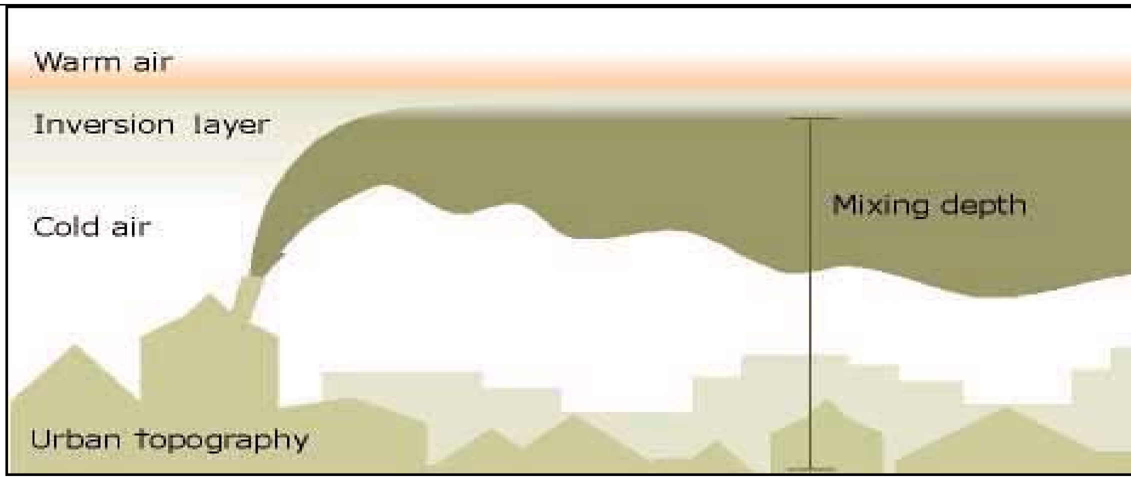
Source: The Cooperative Program for Operational Meteorology, Education, and Training (COMET®) Web site at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR), funded by the National Weather Service. ©2002, UCAR. All Rights Reserved.

Wind speed and direction are important drivers of ambient air pollutant levels. Generally, low winds speeds, like those often encountered during stagnant winter conditions, impede the ability of the atmosphere to disperse pollutants. Of course, wind direction dictates whether pollutants from any one source are being carried towards or away from an air quality sampler, or a populated area.

Natural topographic features often bound an airshed. In the case of the Revelstoke airshed, the Selkirk and Monashee Mountains play a large role in determining the containment and/or dispersion of air pollutants. The steep valley walls that define the airshed make Revelstoke susceptible to temperature **inversions**, which 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 trapped by the warm air above. These stagnant conditions prevent upward mixing of the air, allowing pollutant levels to increase near the surface, as shown in Figure 10. This is most prevalent during the night but can also occur during the day, especially in the winter season when daylight hours are reduced.

In Revelstoke, these prolonged periods of inversions can have serious health effects, especially for those with respiratory problems, as well as children and the elderly. Thus, air quality in Revelstoke remains a concern for the Ministry because of pollutant concentrations during inversions.

Figure 10. Temperature inversion conditions

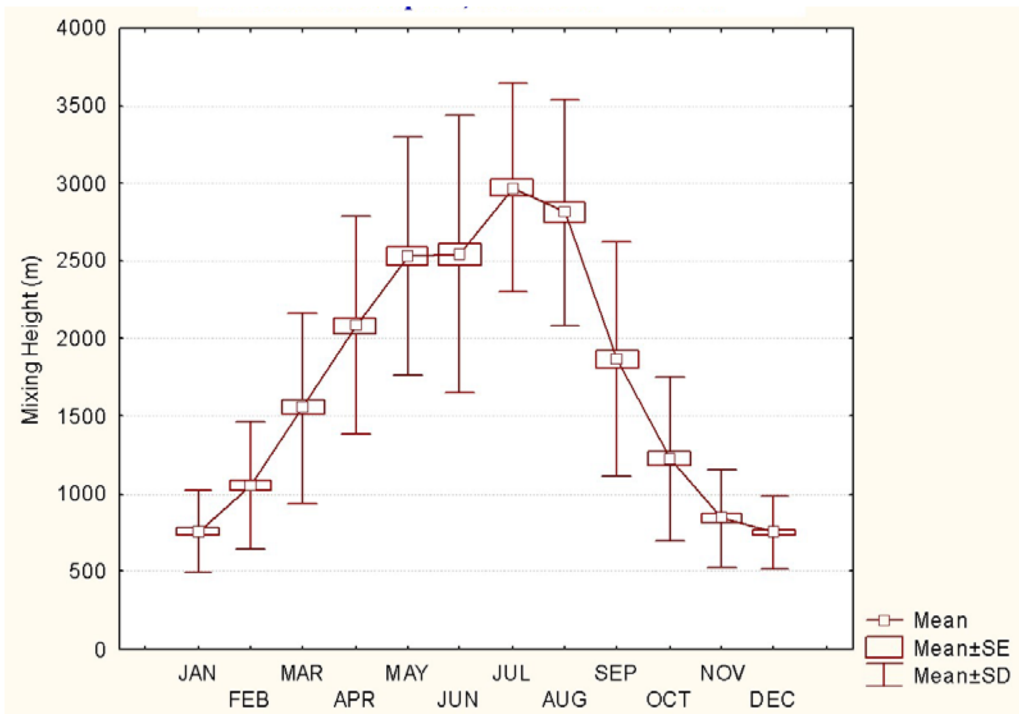


The warm layer of air on top of the cold layer creates an inversion layer. Because the cold air is denser than the warm air, it does not circulate vertically. The stagnant cold air can accumulate contaminants for several days, resulting in high levels of pollutants.

Graphic courtesy of Environment Waikato, Government of New Zealand.

The distance between the surface and the inversion layer is called the "mixing depth", and it has a major influence on the dispersion capability of the atmosphere. (The analogous term "mixing height" is used for the height above sea level.) The greater the mixing depth or height, the greater the volume of air in which pollution emitted at the ground can mix, resulting in lower concentrations. The height of this mixing layer is driven primarily by hours of sunlight and is therefore seasonal in nature. Figure 11 demonstrates that the long hours of sunlight in summer cause a much greater mixing height, and the winds are capable of dispersing pollution well. Conversely, in winter, the small amount of sunlight results in very low mixing heights, so pollution does not get dispersed, and PM concentrations can rise.

Figure 11. Annual cycle of mixing heights at Revelstoke airport (elevation 443 m.)



The meteorological station at Revelstoke Airport provides data for wind direction and speed. To move particulate emissions away from the human habitations in Revelstoke, the wind must carry them both horizontally and vertically. This graph shows how much vertical movement of air (mixing height) occurs in Revelstoke in each month of the year. Starting from a base elevation of 443 m (metres above sea level), the mean mixing height in winter (December and January) is about 750 m (or only 307 m above ground level), compared to almost 3000 m (about 2600 m above ground level) in July and August. The vertical bars represent the statistical standard deviation of the mixing heights, indicating that approximately 68% of mixing heights are within the range of the bars..

Source: GEM-Scribe VI model output data from Jan 2002 to June 2007, courtesy of Environment Canada, Pacific Yukon Region. “SE” refers to “standard error”. “SD” refers to “standard deviation”.

5.0 Air Quality in Revelstoke

As mentioned above, there were three air quality samplers located in Revelstoke during the period covered by this report. From 1993 until 2008, the MoE operated an inhalable PM (PM_{10}) high volume (Hi-Vol) sampler at the Fire Hall, which provided a substantial amount of data to assess air quality trends in Revelstoke. Table 4 summarizes the results of the PM_{10} monitoring since the operation of the Hi-Vol began.

The continuous TEOM sampler has been in operation only since 2002, and the manual Partisol sampler since 2003, so the data from them are very limited. Because of this, most trends analysis of this report is based on the long-term PM_{10} data from the Fire Hall.

5.1 Manual (Hi-Vol) PM_{10} Results and Trends

Each Hi-Vol (and Partisol) filter sample is reported as an average of the PM_{10} concentration for a 24-hour period. The results of these samples (a maximum of 60 or 61 per year – one sample every six days) are analyzed to calculate the **mean** (arithmetic average), **median** (value closest to the centre of the range of readings), 98th percentile and maximum. Because of equipment failures or problems with laboratory analysis, data are not obtained for every sampling day. The data capture rate reflects the annual availability of data and therefore a measure of the representativeness of the data for a particular year. Appendix D has a discussion of data completeness and adjustments relevant to this report.

Table 4. Summary of annual inhalable particulate matter (PM_{10}) in Revelstoke (Fire Hall site) from 1993 to 2008

Year	Data Capture (%)	Mean (ug/m^3)	Median (ug/m^3)	98th Percentile (ug/m^3)	Fair Days (%)	Poor Days (%)	Very Poor Days (%)	Exposure Indicator	CWS Indicator (ug/m^3)
1993	96.7	20.9	19.0	54.0	25.4	3.2	0	156	
1994	85.2	18.6	14.0	54.0	16.4	3.3	0	144	
1995	80.3	16.7	14.2	51.0	13.1	3.3	0	84	53
1996	85.2	16.6	15.0	41.0	11.5	1.6	0	72	49
1997	88.5	23.2	19.9	62.0	24.6	8.2	0	239	51
1998	95.1	23.3	22.0	51.0	33.9	3.2	0	218	51
1999	95.0	22.2	21.0	58.0	26.7	5.0	0	213	57
2000	96.7	21.3	19.0	84.0	19.7	1.6	1.6	180	64
2001	88.5	17.3	16.0	39.0	11.3	0	0	59	60
2002	85.2	20.1	19.0	44.4	27.9	0	0	144	56
2003	83.6	20.1	17.0	63.0	18.0	4.9	0	174	48
2004	88.5	19.5	18.7	56.0	19.4	3.2	0	159	55
2005	59.0	16.8	15.5	34.3	14.8	0	0	60	51
2006	90.2	16.6	14.6	52.0	8.1	3.2	0	77	47
2007	78.3	15.5	15.0	44.0	6.7	0	0	43	43
2008	88.5	12.6	10.0	33.0	10.9	0	0	51	43

Data Capture is the percentage of samples collected in a year, compared to the maximum possible number of samples (60 or 61 per year). The **Mean** is the calculated arithmetic average of readings for each day sampled. The **Median** is the middle reading of the range of readings[30]. The **98th Percentile** is the near-maximum reading in each year (the absolute maximum reading is not used for analysis because an unusually high reading can distort the analysis unduly). Concentrations (Mean, Median, and 98th Percentile) are measured in micrograms per cubic metre (µg/m^3).

The percent of days with Fair, Poor, and Very Poor air quality are measures of **exceedances** of NAAQO levels, showing the percentage of days where PM_{10} exceeded Level A (25 µg/m^3), Level B (50 µg/m^3), and Level C (100 µg/m^3), respectively. The **Exposure Indicator** is a cumulative factor of the time exposed to PM_{10} above a reference health level of 25 µg/m^3 (see Appendix G for the method of calculation). The **CWS indicator** adopts the algorithm for the Canada-wide Standards for $PM_{2.5}$, which uses the three-year running average of the 98th percentile

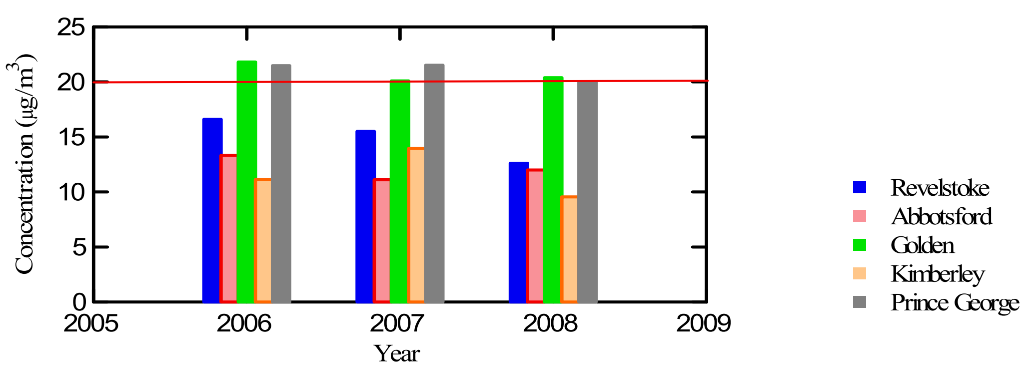
[30] The arithmetic mean (or arithmetic average), geometric mean, and median are statistical terms describing methods of determining the **central tendency** of a set of data. Though they are considered to be "averages" they are often not the same. The use of the term "average" without a descriptive qualifier (such "arithmetic") in this report is more qualitative and suggests what a "typical" air quality reading would be for that weekday/month/year. More on this topic can be found in Appendix C.

5.1.1 Comparisons of Communities

To put air quality in Revelstoke in perspective, PM concentrations for Revelstoke were compared with those of other B.C. communities. Sites were selected based on the use of similar samplers over the same time periods.

PM_{10} for Abbotsford, Golden, Kimberley, and Prince George were chosen to compare to Revelstoke, as shown in Figure 12, to demonstrate a range of geographic locations and air quality differences. Over the period from 2000 to 2008, Revelstoke's air quality was within an acceptable range based on the annual mean PM_{10}. While air quality (as measured by the PM_{10} sampler) has improved only slightly for Golden and Prince George, Revelstoke has seen a fairly significant improvement.

Figure 12. Comparison of PM_{10} in Revelstoke (Fire Hall), Abbotsford, Golden, Kimberley, and Prince George from 2006 to 2008



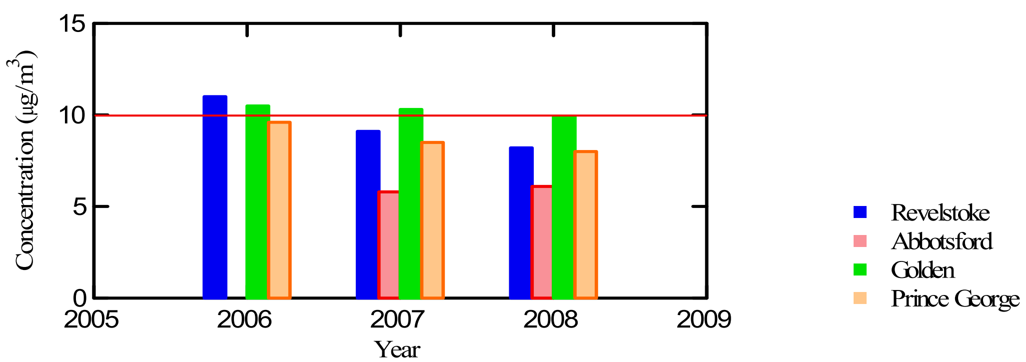
Mean annual PM_{10} concentrations for Revelstoke and four other B.C. communities from 2000 to 2006. The line at 20 μg/m^3 is the guideline established by the World Health Organization.

$PM_{2.5}$ data from Abbotsford, Golden and Prince George were used to compare with Revelstoke in Figure 13. Because $PM_{2.5}$ has only been monitored recently, data are limited and long-term trends are not identifiable yet.

Revelstoke's $PM_{2.5}$ levels, like those of PM_{10}, have shown general improvement since the start of sampling for this contaminant. Yet, the annual means are among the highest in the province and hover near the WHO guideline of 10 ug/m^3. By comparison, both Prince George and Golden have seen similar improvements while Abbotsford's two-year record show levels that are fairly constant and low.

It is interesting to note that all three communities that have shown improvements in air quality have implemented airshed management plans that vary in program start-date and methodology. But before one concludes these programs have demonstrated success, it has to be recognized that for the years 2007 and 2008, atmospheric conditions during the winter season (when dispersion of pollutants is the most challenging) resulted in few long stagnant periods than previous years.

Figure 13. Comparison of $PM_{2.5}$ in Revelstoke (Mt. Begbie), Abbotsford, Golden, and Prince George from 2006 to 2008



Mean annual $PM_{2.5}$ concentrations for Revelstoke (Mt. Begbie site) and three other B.C. communities from 2006 to 2008. The line at 10 µg/m^3 is the WHO guideline for mean $PM_{2.5}$ concentration (see section 2.4).

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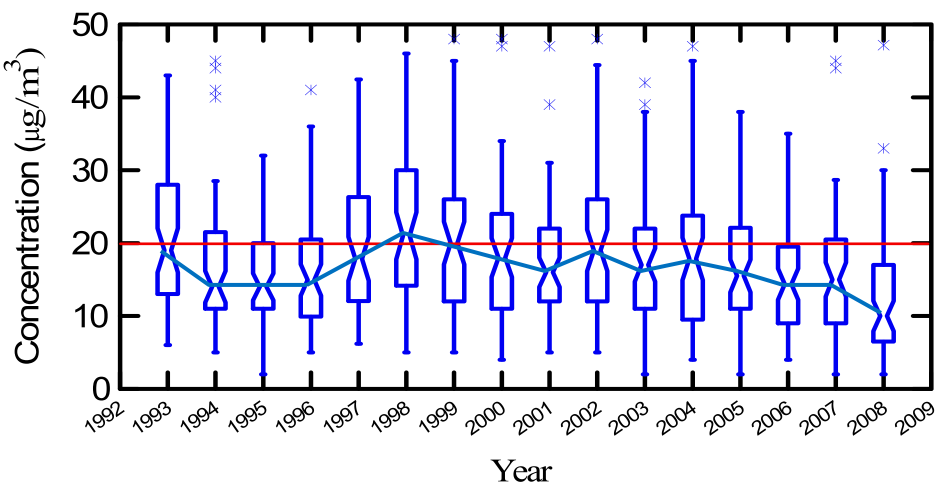
5.1.2 Annual Comparisons

The operation of the Hi-Vol sampler has provided a set of data covering the years from 1993 to 2008 and beyond, allowing year-by-year comparisons for that period. The results of the monitoring indicate that there was a decreasing trend in the median inhalable PM (PM_{10}) concentration in Revelstoke in the early 1990's, followed by an increase in the mid- to late-1990's with high measurements recorded from 1997 to 1999. (Figure 14.) The years 1997 and 1998 were both severe forest fire years, resulting in extremely high measurements of PM_{10}, of which a large percentage was likely respirable PM ($PM_{2.5}$). The year 1999 also had high readings but in following years, there was a drop to levels similar to those in the early 1990's.

Figure 14. Annual PM_{10} variation at Fire Hall site from 1993 to 2008 using Hi-Vol sampler



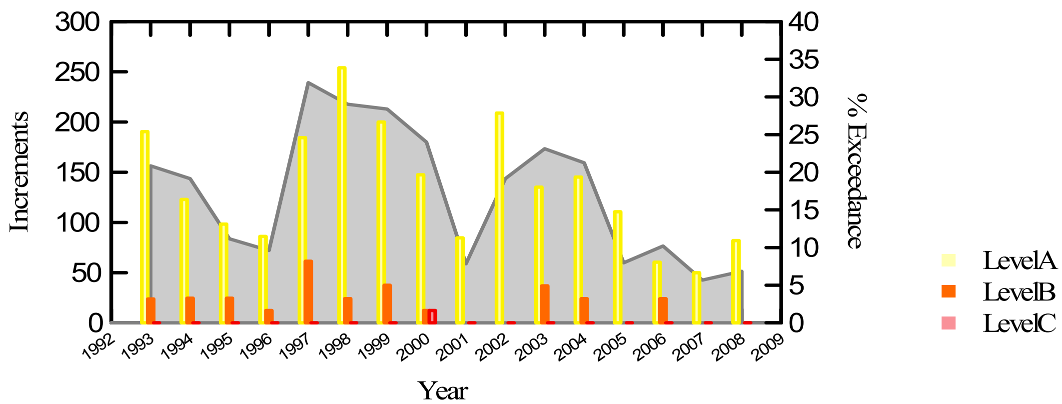
For each year, the rectangle (notched box) and lines extending from the rectangle provide information about the typical and extreme PM_{10} concentrations (Fire Hall site). The median value (the notch in the middle of each box) has been fairly consistent. Exceptions to this include rises in 1993, 1997, 1998, and 1999, which were active years for forest fires, and a marked improvement in 2008. For further explanation about reading this type of graph, see Appendix B. For further information on the statistical significance of the readings for these years see Appendix C. The line at 20 µg/m^3 is the WHO guideline for mean PM_{10} concentration (see section 2.4).

The data set was analysed for the health indicators: exceedance and exposure. Based on the NAAQO standards, there are several days each year that exceed standards for Fair

(Level B) and Poor (Level C) air quality. (Figure 15) The same trend as shown in Figure 14 is visible here - declining in the early 1990's, spiking in 1997 to 1999, then returning to previous levels. The year with the most exceedances was 1998 (the severe fire year), but 2000 was the only year with a Level C (Very Poor) exceedance. The effects of exceedence days on children, the elderly, and those with respriratory problems are a particular concern to health officials. A Level B exceedance will trigger an air quality advisory if near real-time data are available, warning sensitive residents to take precautionary actions. Ideally, there should be no exceedance days, so even 10 to 15% of all sampling days that exeed Level A or 3 to 5% that exceed Level B are cause for concern. In 1998, 39% of days in Revelstoke exceeded health reference levels.

The exposure increments also reflected the elevated PM_{10} concentration in 1997 - 2000, as opposed to the years 1994-1996, 2001, and 2005-2008, which were considerably better.

Figure 15. Annual health exposure increments and NAAQO exceedances in Revelstoke (Fire Hall) from 1993 to 2008



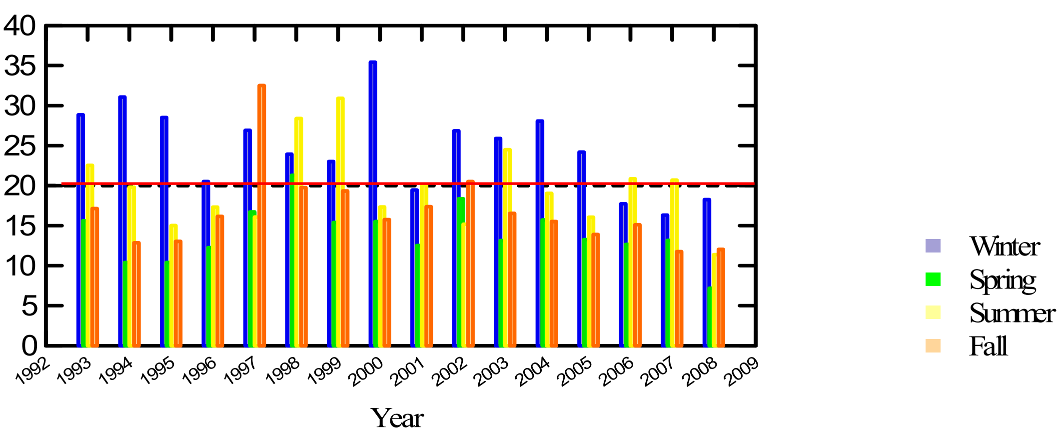
The grey profile describes the annual variation in the Exposure Increment – a measurement of cumulative exposure to PM_{10} (using the scale of the left axis). The bars represent the percentage of days when PM_{10} exceeded Levels A, B, and C NAAQO health levels (right axis). In 1998, severe forest fires caused higher exposure estimates and exceedances, but 2000 was the only year to have a Level C exceedance. Since then, exceedances have returned to earlier levels.

As mentioned above, it is important to note that part of the variation in year-to-year concentrations of PM_{10} is due to between-year climate variability, since meteorological conditions will favour dispersion in some years and not others. The time series data presented here have not been adjusted to account for this climate influence.

5.1.3 Seasonal, Monthly, and Day of Week Patterns

The PM_{10} data for Revelstoke were examined for trends based on seasonal, monthly, and day of week patterns. The analysis by seasons[31] (Figure 16) shows considerable variability among seasons and years. Averaged over the range of years analyzed in Table 4, winter has the highest PM_{10} concentrations, and spring has the lowest. However, there are considerable inter-annual variations. For example, summer has the highest levels in 1998 and 1999, typically caused by forest fires, and in 1997 fall had high levels.

Figure 16. Seasonal variation of PM_{10} in Revelstoke (Fire Hall) from 1993 to 2008



Four coloured bars show the seasonal PM_{10} concentrations for each year. Within a given year, seasons can vary widely, such as in 1994, where winter readings were very high, but spring readings were very low. The line at 20 $\mu g/m^3$ is the WHO guideline for mean PM_{10} concentration (see section 2.4).

Monthly variations in PM_{10} concentrations are shown in Figure 17. The graph shows two peaks in PM_{10} concentration. The February-March peak represents a strong influence from road traction material applied in winter that is ground into finer dust that can become airborne in spring. The slight peak in August reflects the impact of forest fire smoke. In February and March, approximately half of the days have PM_{10} concentrations

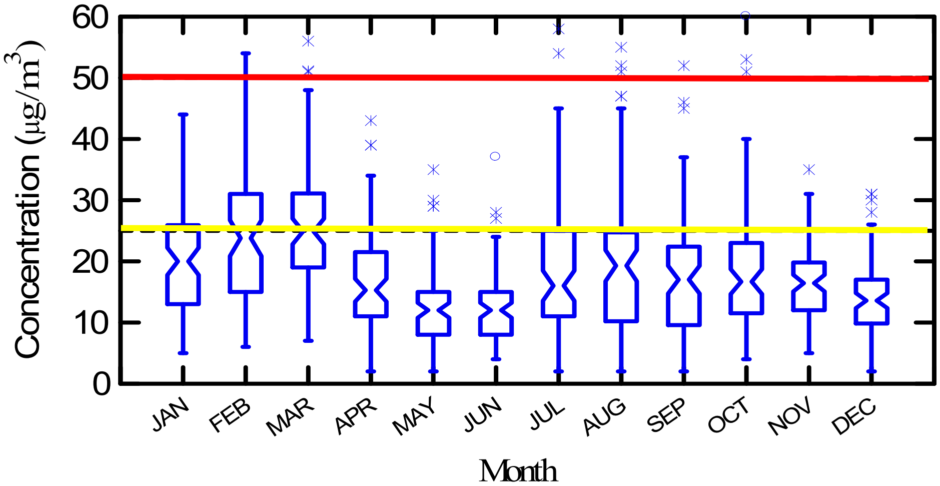
[31] For the purposes of seasonal analysis, Winter is the months of December, January and February; Spring is March, April and May; Summer is June, July, and August; and Fall is September, October, and November.

ENVIRONMENTAL QUALITY

British Columbia Ministry of Environment

above the Level A reference level (indicated by the yellow line at 25 ug/m^3), so sensitive individuals may be advised to avoid strenuous outdoor activities when dust from traction material may be in the air.

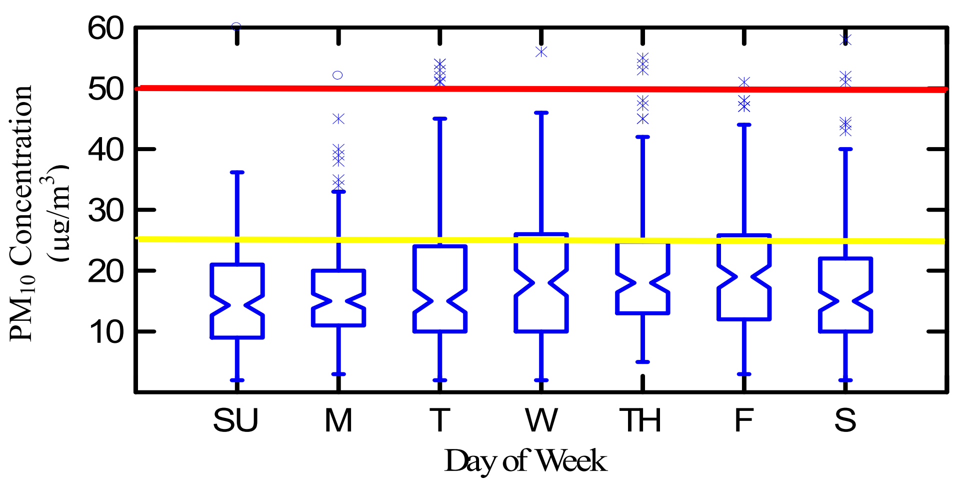
Figure 17. PM_{10} variation by month in Revelstoke (Fire Hall) from 1993 to 2008



Monthly PM (PM_{10}) concentrations for the period 1993 to 2008. The median value is the notch in the middle of each box for each month. See Appendix B for a further explanation of this type of graph.

Figure 18 shows the variation in PM_{10} for the days of the week. Increased commercial and travel activities during weekdays cause higher concentrations, and reduced activities on Sunday result in lower concentrations. On Tuesdays through Fridays, over 25% of the days have PM_{10} above the Level A reference level, so sensitive individuals may be cautioned to avoid outdoor activities on those days.

Figure 18. PM_{10} variation in Revelstoke (Fire Hall) by day of the week from 1993 to 2008



PM (PM_{10}) concentrations for each weekday for the period 1993 to 2008. Weekend (Saturday-Sunday) concentrations are lower than Tuesday-Friday concentrations. See Appendix B for further explanation of this type of graph

Local industrial emissions often represent a large contributor to PM levels in an airshed. Understandably, the public has had concerns about such contributions from the silo burner at Downie Timber to the PM levels in the Revelstoke airshed. The burner ran continually on weekdays, until it was shut down in July, 2007. It was also shut down temporarily in November, 2006. Analyses were done on the limited data collected when the burner was not operating (weekends and November, 2006) but the results were inconclusive. PM_{10} levels were less on weekends, but the same pattern can be found in other airsheds (Golden and Nelson) so the differences in Revelstoke cannot be definitively attributed to the shutdown of the burner.

It should be noted that a similar attempt to establish a correlation between Downie Timber emissions and $PM_{2.5}$ levels did not result in a statistically-supported conclusion because of low data volume.

5.2 Continuous (TEOM) PM_{10} Sampling Results

The installation of a TEOM sampler for PM_{10} in April, 2002, expanded the air quality monitoring capabilities for Revelstoke, although not enough data has been collected to identify long-term trends.

Table 5. Summary of annual inhalable particulate matter (PM_{10}) measured in Revelstoke (Mt. Begbie) from 2002 to 2007

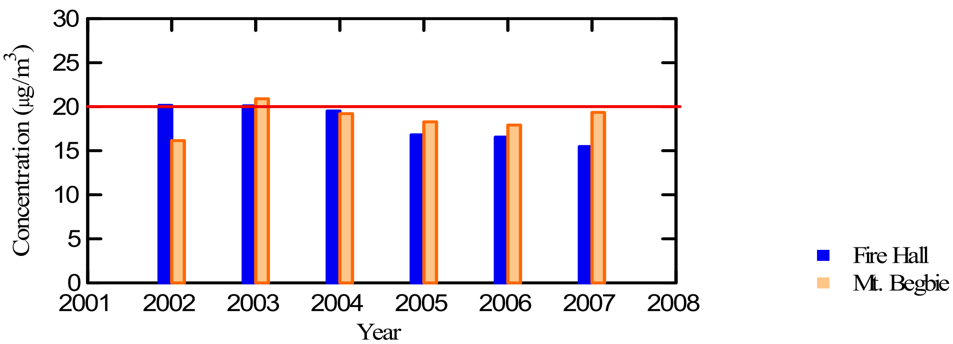
Year	Data Capture (%)	Mean (ug/m^3)	Median (ug/m^3)	98th Percentile (ug/m^3)	Fair Days (%)	Poor Days (%)	Very Poor Days (%)	Exposure Indicator	CWS Indicator (ug/m^3)
2002	79.2	16.2	15.6	33.3	12.5	0	0	50.5	
2003	92.1	20.9	17.7	69.6	24.9	3.5	0	169.1	
2004	98.4	19.2	17.7	45.5	21.4	1.7	0	115.9	49
2005	100	18.3	15.5	52.1	17.0	2.7	0	116	56
2006	100	17.9	17.5	41.6	14.78	0.3	0	68.0	46
2007	100	19.4	17.3	44.5	22.3	2.2	0	118.3	46

See Table 4 for a description of the data presented in this table.

Figure 19 shows the comparison between PM_{10} readings from the Hi-Vol manual sampler and the continuous TEOM sampler operating between 2002 and 2007. In general, the results should be similar, because they measure the same parameter (PM_{10} in Revelstoke). However, differences may occur because the samplers operate on different measurement principles. The TEOM sampler operates daily whereas the Hi-Vol operates one day in six, and the samplers are located some distance apart. Therefore, a localized emission source may operate close to one sampler, but its emissions may not impinge on the other sampler. Another possible difference would be noticeable if the emission source operated on days when the Hi-Vol sampler is not operating, so results would only be captured by the TEOM sampler.

The PM_{10} concentrations between the two sites are, on an annual basis, quite close, except for 2002. This discrepancy may be explained by the reasons listed above, or it may provide a hint about the source of the emissions. Because the TEOM sampler was not deployed until several months into 2002, and consequently missed the recording of typically higher values in January, February, and March, the annual average would be expected to be biased low.

Figure 19. Annual PM_{10} variation at Fire Hall (Hi-Vol) site and Mt. Begbie (TEOM) site from 2002 to 2007



The TEOM sampler installed in 2002 allows a comparison to the Hi-Vol sampler operating at the Fire Hall since 1993, using the annual mean of data from each sampler. The line at 20 µg/m^3 is the WHO guideline for mean PM_{10} concentration (see section 2.4).

5.3 Manual (Partisol) $PM_{2.5}$ Results

The installation of a Partisol sampler for $PM_{2.5}$ in February, 2003, further expanded the air quality monitoring capabilities for Revelstoke, although not enough data has been collected yet to identify long-term trends. Table 6 summarizes the data collected for the six years covered by this report, and Figure 20 demonstrates the $PM_{2.5}$ annual variations graphically.

The average (mean and median) $PM_{2.5}$ concentrations were fairly consistent over the first four years with a marked improvement in 2007 and 2008. The 98th percentiles for most years in the period 2003-2006 exceeded the 24-hour Canada-wide Standard of 30 $\mu g/m^3$, indicating that there were days of unsatisfactory air quality each year. In 2003, the 98th percentile was 49.9 $\mu g/m^3$ which was the main driver for the high CWS Indicator calculated in 2005. However, even for the following years, the CWS Indicator hovers near the standard.

A closer inspection of the raw data shows that there were several weeks of very high $PM_{2.5}$ levels in August-September, 2003, with consecutive readings of 51, 75, 26, and 41 $\mu g/m^3$ (samples were taken every sixth day). The PM_{10} levels were closely paralleled, with readings of 63, 76, 29, and 52 $\mu g/m^3$. These high readings were caused by local forest fires, demonstrating the serious effects that these fires have on air quality.

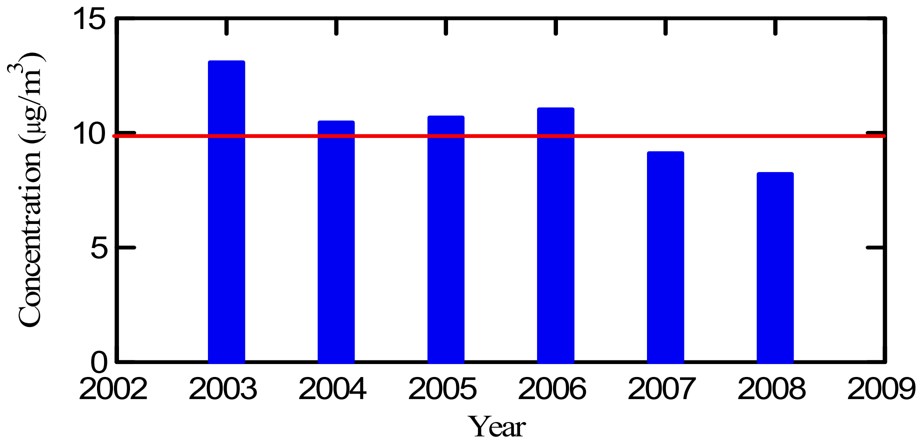
Table 6. Summary of annual respirable particulate matter ($PM_{2.5}$) measured in Revelstoke (Mt. Begbie) from 2003 to 2008

Year	**Data Capture** (%)	**Mean** (ug/m^3)	**Median** (ug/m^3)	**98th Percentile** (ug/m^3)	**CWS Indicator** (ug/m^3)
2003	65.6	13.1	9.3	49.9	
2004	54.1	10.5	8.5	23.1	
2005	88.5	10.7	8.3	35.5	**36.2**
2006	78.7	11.0	9.3	30.0	29.5
2007	100	9.1	6.8	27.0	**30.8**
2008	100	8.2	6.4	21.0	26.0

See Table 4 for a description of the data presented in this table.

E N V I R O N M E N T A L   Q U A L I T Y

Figure 20. Annual $PM_{2.5}$ variation at Mt. Begbie site from 2003 to 2008



The Partisol sampler installed in 2003 allowed the measurement of fine ($PM_{2.5}$) particulates. The line at 10 μg/m^3 is the WHO guideline for mean $PM_{2.5}$ concentration (see section 2.4).

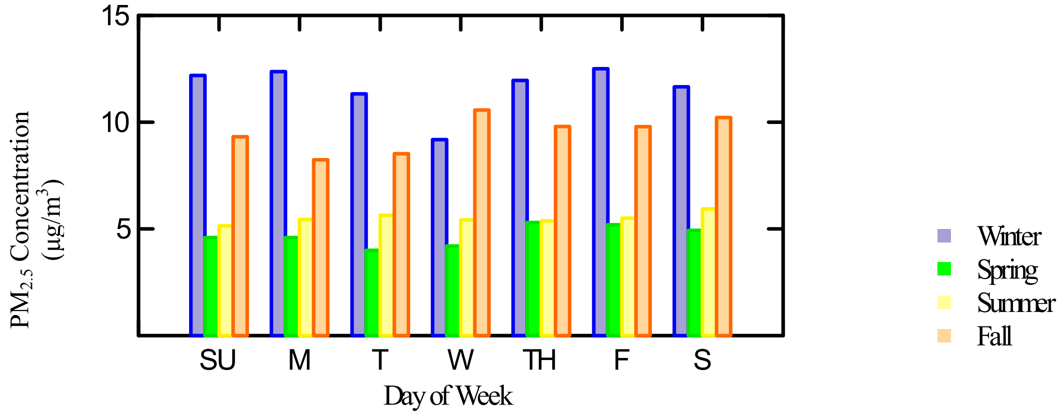
In addition to annual comparisons, differences of $PM_{2.5}$ levels by seasons[32] and the days of the week are displayed in Figure 21. $PM_{2.5}$ concentrations are consistently higher in winter and lower in spring. Because the residential and industrial burning of wood are major sources of $PM_{2.5}$, inversion conditions in winter could trap fine particulates. In spring, reduced residential burning, combined with increased winds (which create better conditions for dispersion) and higher mixing heights would lead to lower levels of PM. In summer and fall, forest fires (especially in 2003, as mentioned above) would increase both $PM_{2.5}$ and PM_{10} levels.

Unlike PM_{10}, the $PM_{2.5}$ levels in winter are higher on weekends, and lower in mid-week. In spring, summer, and fall, no clear trend is evident. A possible explanation is that because Revelstoke is a tourist destination in this season (e.g., skiing, snow-mobiling), traffic volumes on the weekends and/or weekdays as part of 'long' weekends, are elevated with a corresponding rise in fine particulate emissions. This disparity may also well reflect the higher usage of wood stoves on the weekends when residents spend more

[32] For the purposes of seasonal analysis, Winter is the months of December, January and February; Spring is March, April and May; Summer is June, July, and August; and Fall is September, October, and November

time at home. However, it is premature to draw conclusions from this relatively limited data volume.

Figure 21. Seasonal and day of the week $PM_{2.5}$ variation at Mt. Begbie site from 2003 to 2008



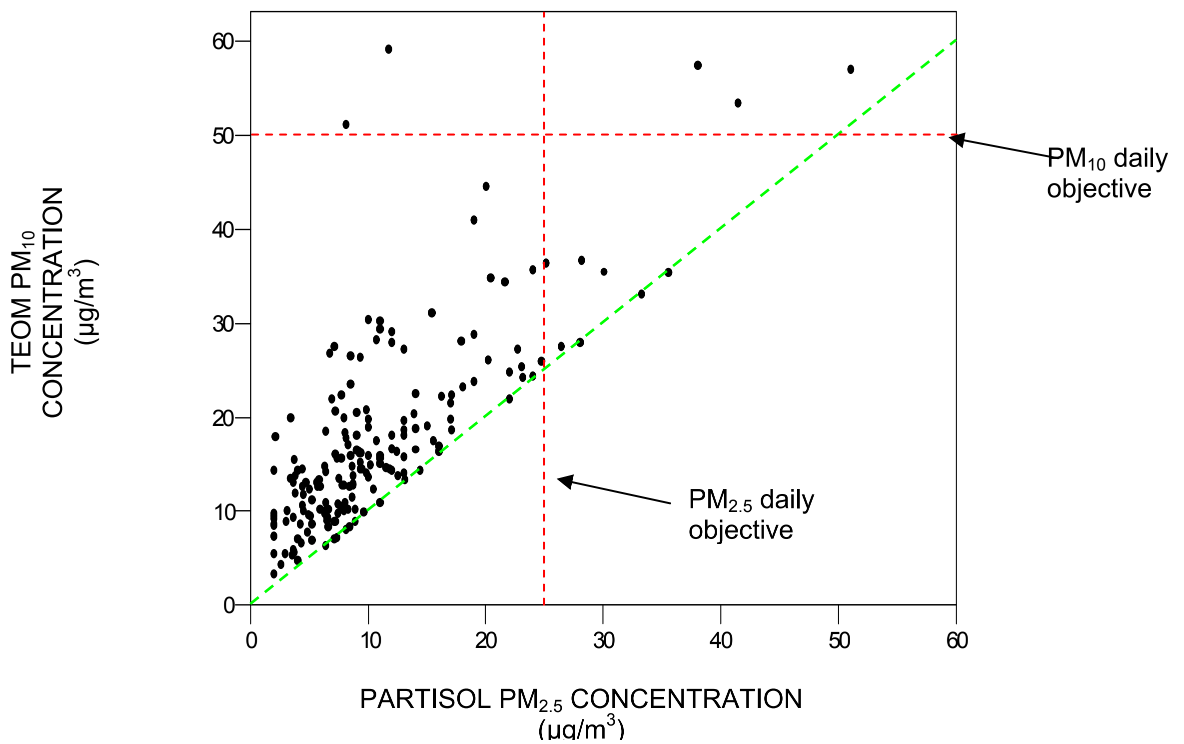
The four coloured bars describe $PM_{2.5}$ levels in the four seasons, and the data are also grouped by day of the week. Winter $PM_{2.5}$ levels are generally highest. Spring $PM_{2.5}$ levels are lowest, and are consistent throughout the week.

5.4 Relationship between $PM_{2.5}$ and PM_{10} Sampling

Because $PM_{2.5}$ is a portion of PM_{10}, it should always be less, as shown in Figure 22. Generally, the concentrations of these two forms of PM are related, although the exact relationship can vary depending on the season, source of emissions, and type of chemicals that make up the emissions. The proportion of $PM_{2.5}$ can be helpful in determining the sources of the emissions, and the proportion is typically calculated as a ratio of $PM_{2.5}$ to PM_{10}. Because $PM_{2.5}$ is part of the total PM_{10}, the ratio should always be between zero and one.

The Mt. Begbie school site has had co-located PM_{10} and $PM_{2.5}$ samplers operating simultaneously since February, 2003. This allows a direct comparison of simultaneous samples, shown graphically in Figure 22.

Figure 22. Relationship between TEOM PM_{10} and Partisol $PM_{2.5}$ at Mt. Begbie site



On this graph, PM_{10} and $PM_{2.5}$ can each be considered separately against their respective guidelines. Each data point gives the concentration of $PM_{2.5}$ (horizontal axis) and PM_{10} (vertical axis) for each day of simultaneous sampling. For $PM_{2.5}$, most values are below 25 µg/m^3 (vertical red line), and for PM_{10} most values are below 50 µg/m^3 (horizontal red line), both of which indicate good air quality. However, several values are higher than the guidelines, on days of reduced air quality.

Values close to the diagonal dotted line indicate days when $PM_{2.5}$ and PM_{10} concentrations were very close. On those days, most of the PM_{10} consisted of the $PM_{2.5}$ fraction. Values far above the diagonal line are days where PM_{10} was considerably greater than $PM_{2.5}$. On those days, only a small part of the PM_{10} was made up of the $PM2_{.5}$ fraction, and much of the PM was in the size range of 2.5 to 10 µg/m^3. Values below the diagonal dotted line are not possible, because $PM_{2.5}$ would have to be greater than PM_{10}.

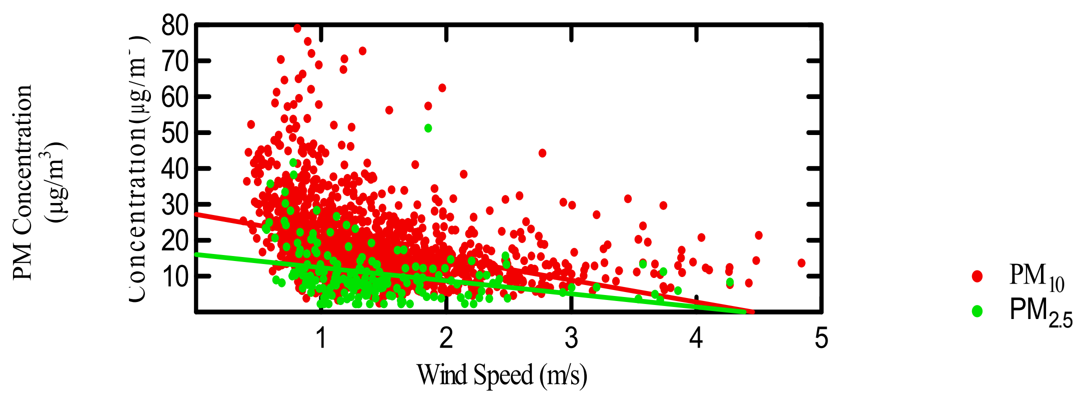
Because the data points are scattered, it is not possible to identify a clear relationship. For some data points where the $PM_{2.5}$ and PM_{10} are very close, $PM_{2.5}$ is the predominant fraction of particulates, perhaps indicating a limited number and types of sources that emit only fine particulates. When the $PM_{2.5}$ was noticeably different than the PM_{10}, there were different sources emitting different fractions of particulates, or sources that emitted a range of sizes of particulates. Appendix E has more information on the relationship between PM_{10} and $PM_{2.5}$.

Ongoing monitoring with the new manual and continuous samplers will increase the knowledge about air quality in Revelstoke, allowing us to understand the variations in concentrations of PM, its sources, and its effects. Further, officials can react better to episodes of diminished air quality by determining the causes, and by issuing timely air quality warnings.

5.5 *Winds and PM Levels*

In general, the recorded wind speeds at the Mt. Begbie School site show an inverse relationship with both PM_{10} and $PM_{2.5}$ concentrations. In other words, light winds or calm conditions are conducive to poor atmospheric dispersion conditions, and hence higher PM concentrations. Figure 23 graphically demonstrates the predominance of high levels of PM with low wind speeds. At low wind speeds (less than 1.5 metres/second[33] (m/s), PM concentrations can reach high levels because the winds are not strong enough to disperse the emissions. As wind speed increases, emissions are carried away, preventing high concentrations. However, note that there were some days where strong and/or gusty winds enabled crustal material to become airborne, resulting in high PM_{10} readings.

Figure 23. Effects of wind speed on PM_{10} and $PM_{2.5}$ at Mt Begbie site



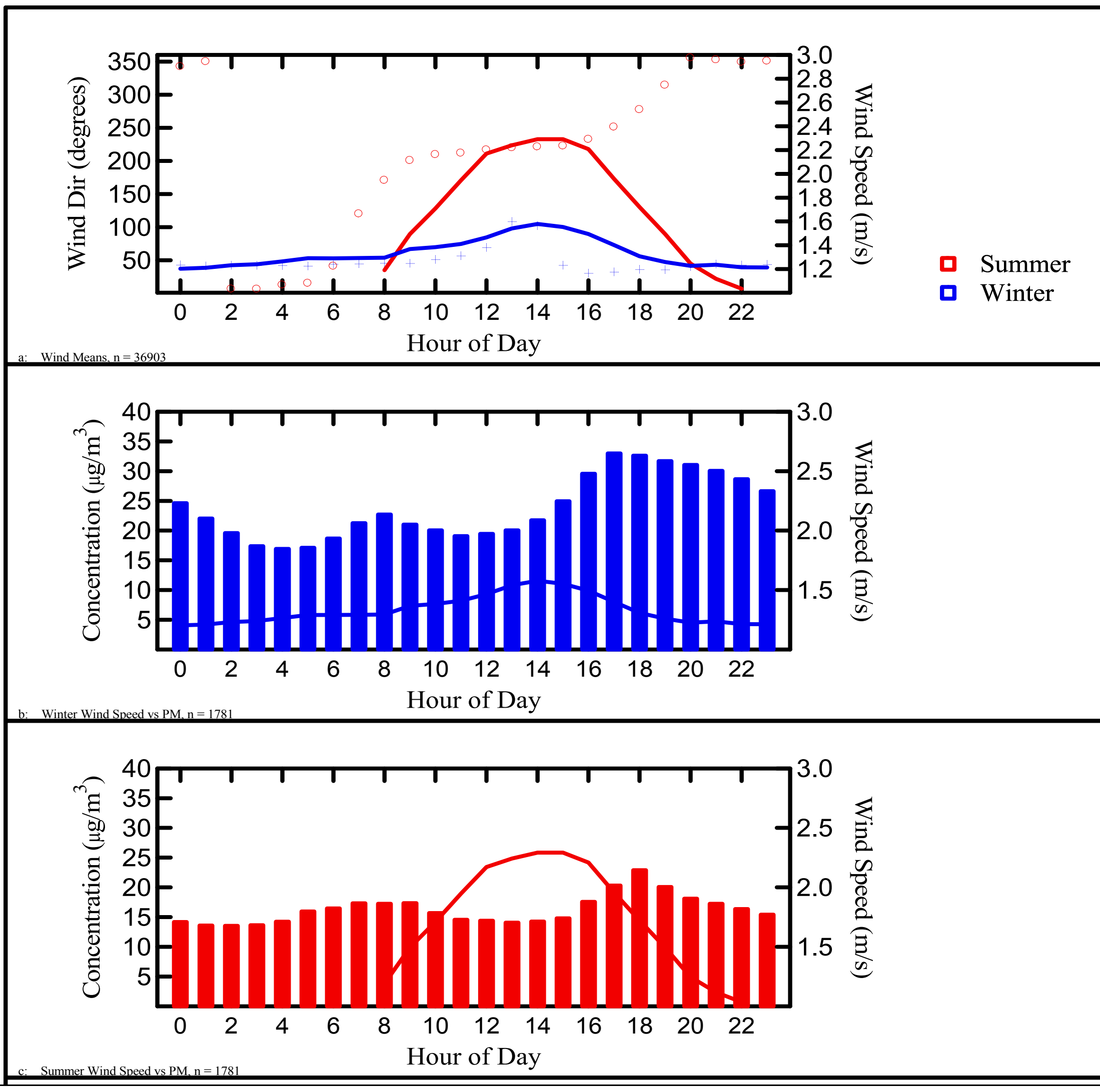
Incidents of high PM almost always occur at low wind speeds (below 1.5 m/s). At higher wind speeds (above 2 m/s) $PM_{2.5}$ levels are consistently below 20 ug/m^3.

[33] One metre/second is equivalent to 3.6 km/hr or 2.2 miles/hr.

Figure 24 shows how PM_{10} concentrations at Mt. Begbie vary through the day, during summer and winter. Winds in winter are predominantly from the northeast, and of relatively low speed, which allows stagnant conditions allowing PM_{10} levels to increase, as shown in the second graph.

Summer winds are stronger in mid afternoon, dispersing PM_{10} emissions and preventing high levels. The third graph shows the reduction in PM_{10} in early afternoon when winds are strongest. In both winter and summer, PM_{10} concentrations rise as the wind speed drops in late afternoon.

Figure 24. Diurnal variation of Mt Begbie PM_{10} and winds in summer and winter



Top – This graph shows the wind speed and direction throughout the 24-hour day, in summer and in winter. The left axis is the wind direction, from 0 to 360 degrees (0 and 360 are due north), and the right axis is wind speed, in metres/second. The red dotted line is the summer wind direction, which is predominantly from the north in early morning and late evening, and from the south (about 200 degrees) in midday – from 9 AM until 5 PM.. The blue dotted line is the winter wind direction, which is all from the northeast or east (40 to 100 degrees). The red curve is summer wind speed (right axis) which is calm all night, and maximum at 2 PM. The blue dotted curve is winter wind speed (right axis), which is low and steady throughout the 24-hour day..

Middle - Blue dotted curve is winter wind speed (right axis). Blue bars are PM_{10} levels, which rise in the evening while wind speed drops. (PM is generated during the day and evening (road dust and wood smoke)

Lower – The red curve shows the summer wind speed (right axis). Red bars are PM_{10} levels, which dip slightly in midday when wind speeds increase, then increase in late afternoon as wind speed drops.

Figure 24 and Appendix F provide additional perspectives on the relationship of winds and the ambient PM levels. Conclusions resulting from analysis of these plots include:

- The wind patterns, in general, follow known relationships of terrain and meteorology (e.g., seasonal and diurnal patterns associated with mountain/valley flow). Hence, although this analysis uses only one sampling station, it is presumed that wind direction and speed will vary considerably between different areas of the airshed: a reflection on the varying valley orientations.
- The prevailing winds in Revelstoke vary dependent on season.
- There is a strong bias towards easterly winds (i.e., winds *from* the east) in winter. However, surrounding terrain help steer the winds to give a northerly component as the air travels across the Mt. Begbie School monitoring location. Winter winds are light when compared to summer (although the differences are minor when compared with other provincial airsheds). Calm conditions (and light winds) have less air dispersion capabilities than stronger winds.
- Summer winds tend to be more variable in both direction and speed. The frequency of calm conditions in summer is less than half that of the winter season.
- Overnight winds in both summer and winter tend to be dominated by drainage from Rogers Pass to the east. In the summer, valley winds reverse direction during the day due to daytime solar heating.

6.0 Conclusions / Recommendations

In summary:

- With the exception of active wildfire years (e.g., 1997,1998, 1999, 2003), the air quality in Revelstoke has remained fairly stable. Another encouraging exception is the trend downward for both $PM_{2.5}$ and PM_{10} in the last three years of the data examined for this report (2006, 2007, 2008).

- Every year there are days that exceed national guidelines for acceptable air quality which are a concern to public health officials. Sensitive individuals should be aware that elevated PM concentrations can occur at any time, but are more frequent in February and March, and during forest fire events.

- Exceedances of these standards are concentrated in specific late winter and summer months. These peaks have been linked to both natural and human causes. Winter exceedances are a combination of the effects from poorer atmospheric dispersion and increased emissions from wood stoves, combined with normal emissions from local industry (primarily Downie Timber Ltd. and Joe Kozak Sawmill Ltd.). Late winter exceedances are generally attributed to these plus the contributions of road traction material being released into the air as above-freezing temperatures begin to allow for thawing of road surfaces. Summer exceedances are most often associated with forest fire activity. Continued monitoring, when possible, will aid in identifying the causes of individual periods of elevated PM.

- The steep valley walls surrounding Revelstoke makes it more susceptible during the winter to temperature inversions that trap PM. These periods of inversions during times of higher emissions from road dust and wood burning appliances can result in adverse health effects, making Revelstoke an airshed of concern for the MoE.

- With only discrete (non-continuous) PM_{10} measurements, it is difficult to differentiate between sources and types of PM in Revelstoke. A more comprehensive monitoring program began in 2002 involving continuous PM_{10} measurements until mid-2007 when it was converted to $PM_{2.5}$, and was further enhanced with the addition of manual $PM_{2.5}$ monitoring in 2003.

- Data collected to date suggest a relatively high $PM_{2.5}$ to PM_{10} ratio. The recent introduction of a continuous $PM_{2.5}$ sampler will aid in the assessment of the types of emissions that drive the PM levels in this airshed.

- Analysis to demonstrate a correlation between industrial emissions and PM_{10} resulted in a positive but weak correlation. That is, the data suggests that when Downie Timber was operating, the ambient PM_{10} levels were higher than during non-operating periods. However, any contribution was small and inconsistent.

- Analysis to demonstrate a correlation between industrial emissions and $PM_{2.5}$ was inconclusive; primarily because of low data volume.

Because of the high potential for inversions in the Revelstoke airshed, PM levels are an area of concern. Even low or moderate amounts of PM emissions can be magnified by the effects of an inversion, resulting in negative health effects. In addition, the community should be attempting to reduce levels of PM, as there is no minimum health impact level or 'safe' level for PM_{10} or $PM_{2.5}$[34]. This means that even at low levels of PM there is an impact on community health.

Those involved with developing airshed management planning (typically municipal levels of government, industrial stakeholders, MoE, and advocacy groups) should examine more closely those years when PM levels were outside the expected range (as determined by statistical analysis) for possible reasons for the elevated/depressed level. In particular, some departures from the norm may be a result of favourable or unfavourable weather conditions, and others may be a result of changes in airshed emission levels and/or sources. Such knowledge will help guide the identification of strategies to improve air quality.

The following are some recommendations (many of which are currently being initiated by the local government), to improve air quality in Revelstoke:

- Local residents and municipal governments are encouraged to engage in air quality management planning. Presently, there is a very proactive stakeholder partnership led by the City. A tool to assess the need for planning and the options to consider has been developed, and can be accessed at:
  http://www.cleanairbc.com/
  Additional information on air quality management planning can be found at:
  airshedplan_provframework.pdf

- Local government should continue to collaborate with similar communities and provincial and federal governments to explore other options for air quality management.

- Residents should be encouraged to buy more efficient wood-burning appliances (woodstoves) and local retailers should promote the benefits of improved appliances.

ENVIRONMENTAL QUALITY

[34] http://www.env.gov.bc.ca/epd/bcairquality/reports/phoannual2003.html

- Residents should be educated in techniques of efficient woodstove operation, selection of fuel, and proper storage and curing of wood.

- Local municipalities should continue to identify different/additional techniques that could result in more efficient winter road maintenance and reduction of road dust. Examples of such measures are more frequent street cleaning, coarser sand for roadways, and possibly the use of magnesium chloride to keep roadways clear of ice. A recent collaboration between the MoE and the Ministry of Transportation and Infrastructure has resulted in the development of a 'Best Management Practices' document. This can be found at:
  http://www.env.gov.bc.ca/epd/bcairquality/reports/topic_Dust.html

- Bylaw enactment and enforcement is another tool often used to improve local air quality. The following sites offer examples to help guide local levels of government in bylaw development:
  Backyard burning bylaw template:
  model-bylaw-backyard-burning.html
  Wood stove bylaw template:
  http://www.ec.gc.ca/cleanair-airpur/default.asp?lang=En&n=975A1778-1

- All levels of government should be cognizant of the poor dispersion capability in the winter season (see Fig. 24). Planned burning activity by industry or residents should always require an enquiry if there exist alternatives to the planned burning before authorization is given. If no alternative is feasible then a request should be made that burning be conducted in the spring if possible.

For More Information

The Environmental Quality Branch of the Ministry of Environment has several reports on air quality at http://www.bcairquality.ca/reports/topic_Monitoring.html

A report on Air Quality in the Kootenays 1993-1999 is available at http://www.env.gov.bc.ca/epd/regions/kootenay/aq_reports/pdf/kootenay_air_quality_report.pdf

The Environmental Protection Division of the Ministry of Environment in the Kootenay Region has information at http://www.env.gov.bc.ca/kootenay/index.html

B.C. provincial legislation related to air quality is described at http://www.env.gov.bc.ca/epd/bcairquality/regulatory/air-regulations.html

The 2003 Provincial Health Officer annual report about air quality in British Columbia can be found at http://www.env.gov.bc.ca/epd/bcairquality/reports/phoannual2003.html

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Appendices

Appendix ***A - Glossary and Abbreviations***

98th percentile In a sequential list of data values, the 98th percentile is the data value that is 98 percent of the way through the list from the smallest reading (or 2 percent below the highest reading). The absolute maximum reading is not used for analysis because an unusually high reading may be the result of outlier (or suspect) data and can distort the analysis unduly.

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

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, PM, 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://a100.gov.bc.ca/pub/aqiis/air.info.

Anthropogenic Produced by human activities.

ARB Air Resources Branch, Ministry of Environment

Area source An emission source of pollutants that covers a large, and sometimes poorly defined, area – sometimes call non-point source (e.g., prescribed burning and residential fuel wood combustion). Note: A single residential wood burning appliance is considered a small source of emissions, but many appliances together can emit a significant amount of emissions, and are collectively thought of as an area source, instead of many small point sources.

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.

Central tendency In statistics, a measure of the middle or center of a set of data. The arithmetic mean is the most commonly used, but median, mode, and geometric mean are also used. See Appendix C for a detailed description.

CEPA/FPAC The Canadian Environmental Protection Act Federal-Provincial Advisory Committee directs the development and assessment of National Ambient Air Quality Objectives (NAAQOs) for airborne pollutants.

Coarse fraction PM with diameter between 2.5 and 10 microns ($PM_{10-2.5}$).

CWS Indicator A measure of the severity of maximum levels of $PM_{2.5}$ concentration. The 98th percentile of the daily averages is determined for each year, then averaged for the last three calendar years (which reduced the influence of a particularly bad year). This value can then be compared to a given standard and to other communities. Though the CWS standard for PM is limited to $PM_{2.5}$ concentrations, this report adopts this algorithm for PM_{10} analysis and comparison purposes.

Emissions 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.

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

Exposure Indicator A measure of the accumulated exposure to PM_{10} over a specified time (typically one year), taking into account both the concentration of PM_{10} and the length of time of exposure. Larger exposures indicate an increased risk to human health.

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

Fugitive dust PM_{10} from finely ground rock and clay, origination from human sources such as sand and gravel traction material applied to roads in winter, or from natural sources such as exposed lake beds and river banks.

Haze 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.

Hi-Vol High volume sampler – an instrument that draws large volumes of air through a filter that traps pollutants.

Inversion An increase in temperature with height, which is the reverse of the normal cooling with height in the atmosphere. Warm air at ground level tends to rise, but because warmer air is already above it, vertical air movement is minimized, trapping atmospheric pollutants in the lower troposphere, and resulting in higher concentrations of pollutants at ground levels than would usually be experienced.

Mean In statistics, an "average" (arithmetic mean) calculated by dividing the total of all values of a set of data by the number of values. (In special circumstances, the geometric mean is used instead – see Appendix C.)

Median In statistics, the value closest to the middle in a ordered list of data values.

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

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

$\mu g/m^3$ Micrograms per cubic metre (concentration)

µm Micrometres (10^{-6} m) (diameter). Also called "microns".

Mixing height The mixing height is the height to which the air near the earth's surface is well mixed due to turbulence caused by the interaction between the surface and the atmosphere. The mixing height is usually located at the base of a temperature inversion**.**

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.

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

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 objectives and standards in B.C.

National Ambient Air Quality Standards (NAAQS) Health-based pollutant concentration limits established by the United States Environmental Protection Agency 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_x species (given conventional analyzers).

Ozone (O_3) 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.

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

$PM_{2.5}$ PM less than 2.5 microns in diameter: the fine fraction of PM, also called respirable 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} PM less than 10 microns in diameter, including both coarse and fine fractions, also called inhalable PM. 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.

$PM_{10-2.5}$/PM_{coarse} PM 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.

Point source An emission source of pollutants that remains in a small identifiable area (e.g., an industrial plant)

Primary particle The fraction of $PM_{2.5}$ or PM_{10} 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.

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

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

TEOM Tapered element oscillating microbalance. An instrument for the continuous measurement of PM.

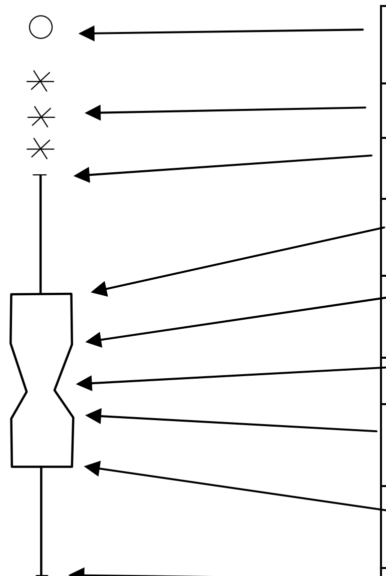
Ultrafine fraction PM with diameter less than 0.1 microns.

Appendix B - Reading a Boxplot Graph

A boxplot describes the distribution of a set of data. When data are listed in numerical order, a boxplot indicates how many of the data values are contained within a certain range, and how widely the data are spread out.

The median value (the notch in the middle of each box) represents the middle value of a sequential list of data. It is the midpoint, where 50% of the data readings are lower and 50% are higher. The 95% confidence interval is the range in which the median falls, with a 95% probability. The ends of the box show the range of the middle 50% of the data – from 25% to 75% through the range of data. The lines extending from the ends of the boxes (called whiskers) show most of the extreme range of readings for each year. The whiskers extend to existing data points, but only to a maximum of 1.5 times longer than the length of the box. If the data are fairly evenly distributed, most of it should fall within the whiskers. Points beyond the whiskers are extreme values, and indicate further investigation is suggested to confirm data quality.

Figure B1. A Typical boxplot with the names and descriptions of key features



Outlier	Extreme values. (Confidence in the data is low.)
Outside values	Extreme values
Upper inner fence	Most data is below this
Upper hinge (75th percentile)	
Upper 95% confidence interval	
Median	Midpoint of the data
Lower 95% confidence interval	
Lower hinge (25th percentile)	
Lower inner fence	Typically the lowest value

Appendix C – Central Tendency and Statistical Significance[35]

In statistics, central tendency is a measure of the location of the middle or the centre of a distribution of data. The definition of "middle" or "centre" is purposely left somewhat vague so that the term "central tendency" can refer to a wide variety of measures.

The arithmetic mean (also known as the arithmetic average) is the most commonly used measure of central tendency (see Table 2 and Figures 12 and 14 for the calculated means of Hi-Vol PM_{10} data). It takes every score into account, is the most efficient measure of central tendency for normal distributions[36] and is mathematically tractable making it possible for statisticians to develop statistical procedures for drawing inferences about means.

On the other hand, the mean is not appropriate for highly skewed distributions[37] and is less efficient than other measures of central tendency when extreme scores are possible. Environmental data can often be highly skewed and means tend to be unduly influenced by extreme events, rendering it less appropriate to indicate "typical" or "average" or "central" tendencies. The geometric mean is a viable alternative if all the scores are positive and the distribution has a positive skew.

Fire Hall PM_{10} Data

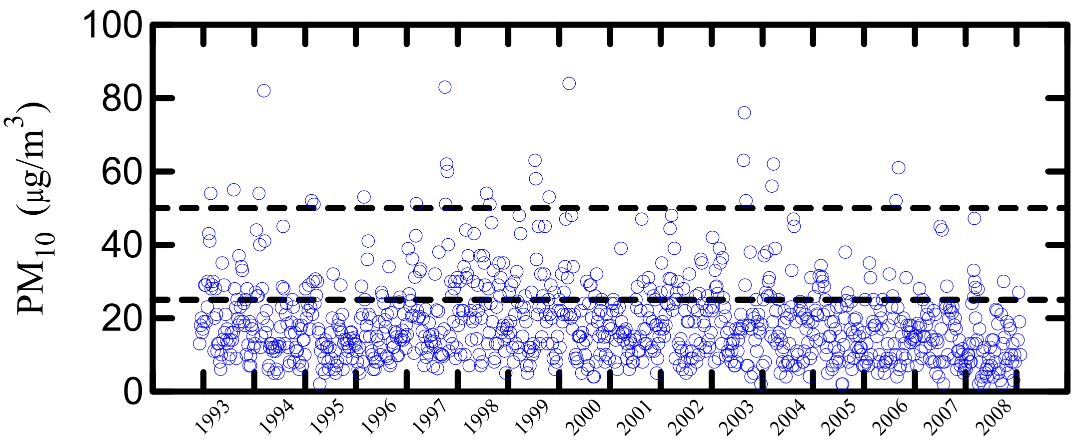
The Revelstoke PM_{10} and $PM_{2.5}$ data appear to be typical examples of environmental time series data, as shown by the 14 years of data shown in Figure C1a. Plotting a histogram of the data for Figure C1b shows that this data distribution is skewed to the right bringing into question whether the mean will be the best descriptor of this data.

A common statistical approach to find the best central tendency measure is to transform the data in some manner so they approximate a normal distribution. In the case of the Revelstoke data, the natural logarithm of the original data results in a more normally distributed curve, as shown in Figure C1c. It is from this form of the data that we then compute the measures of central tendency. The mean for each year is calculated and is

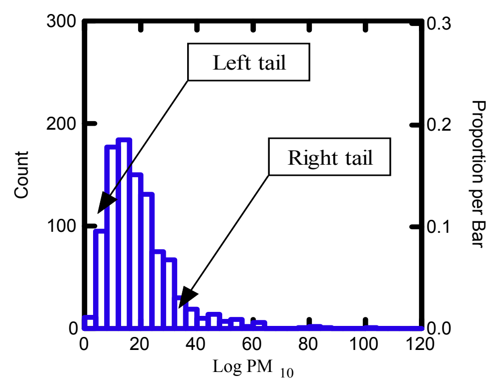
[35] Although this report explains the concepts of statistics needed to understand Revelstoke's air quality, other reference material should be consulted to understand all the details of the report. Some statistical results have been included for those conversant with advanced statistical concepts.
[36] The normal distribution (the "bell-shaped curve" which is symmetrical about the mean) is a theoretical function commonly used in inferential statistics as an approximation to sampling distributions. Normal distributions are symmetric with scores more concentrated in the middle than in the tails.
[37] A distribution is skewed if one of the tails of the distribution curve is longer than the other. A positive skew (sometimes called "skewed to the right") means that it has a long tail in the positive direction (to the right), and a negative skew ("skewed to the left") has a long tail in the negative direction.

referred to as the geometric mean. Confidence intervals at the 95% level[38] are calculated as well.[39]

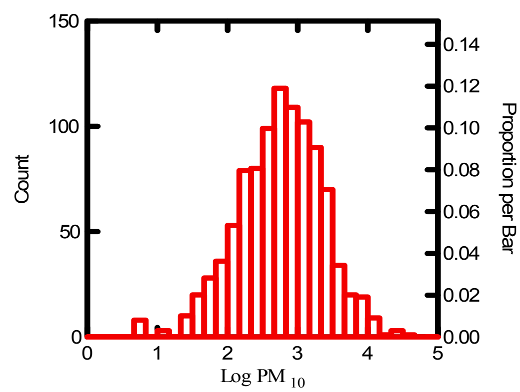
Figure C1. Distribution of data from Fire Hall Hi-Vol sampler from 1993 to 2008 (n = 983)



C1a – A scatterplot of all raw data from a 16 year period. Readings near 100 ug/m3 occur occasionally.



C1b – The histogram of the data shows a right-skewed distribution, with a long right tail..



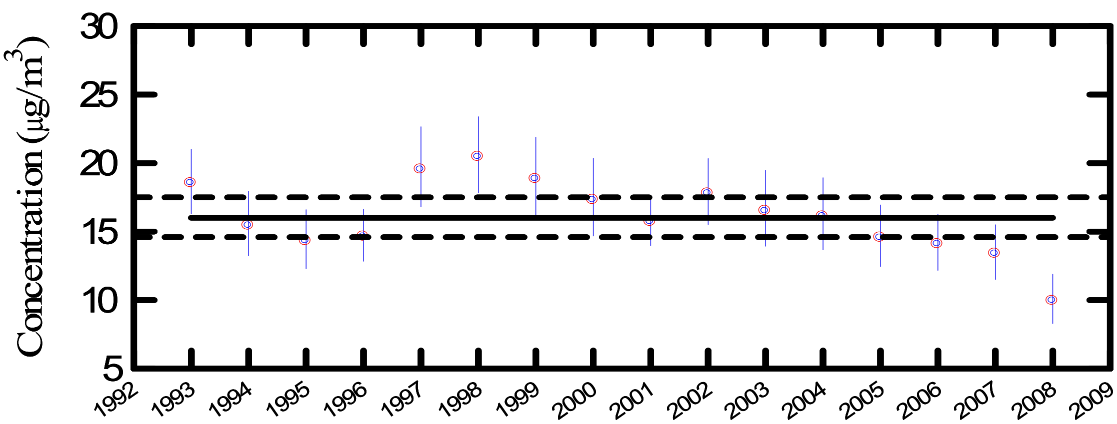
C1c – After a log transformation of the data, the distribution is close to a normal distribution, and regular statistical procedures can be used.

[38] In other words, the mean is considered statistically significant within these upper and lower limits with 95% confidence, or nineteen times out of twenty. Means outside of this range cannot be considered similar and represent statistical departures from typical values.

[39] A test for autocorrelation (estimated to be less than .2) suggests that there is little autocorrelation; hence, the ambient levels between years can be considered independent of each other.

Figure C2 shows these geometric means (red circles) and the confidence intervals (range in blue vertical lines) for each year. Once these means have been determined, a mean (arithmetic) of the all yearly means (geometric) with its corresponding confidence intervals is calculated. These are overlaid in Figure C2 as a black horizontal line and dashed horizontal lines, respectively. Note that while the general trends of this data, as represented in Figure C2, compare well with Figure 12 and Figure 14, the values of the geometric means (Figure C2) are consistently less than the arithmetic means (Figures 12 and 14). This is a feature of the geometric mean calculation and caution is required when comparing graphs derived from different distributions of the same data.

Figure C2. Annual variation of the mean and range of PM_{10} at Fire Hall from 1993 to 2008



The red circles represent the geometric means of each individual year's data, and those with corresponding blue vertical yearly confidence intervals that are outside of the total range confidence intervals (dotted lines that associated with all years) are significantly different from the mean (represented by the horizontal black line associated with all years).

The strength of the transformed plots of yearly geometric means lies in their ability to statistically demonstrate which years of the data range represent 'significant' departures from average. Such departures are those where yearly means lie outside of the confidence intervals of the entire data set. Figure C2 demonstrates that only the years 1998 and 2008 were unusual in terms of statistical significance.

E N V I R O N M E N T A L   Q U A L I T Y

For the purposes of airshed management planning it is prudent to better understand the causes for these departures from the norm. One wants to know if any changes from year to year in the ambient levels are a result of changes to anthropogenic emissions (e.g., better emission control in industry, wood stove exchange programs, etc.) or because of natural causes beyond the control of local initiatives (e.g., wild fires or meteorology). Investigation into the possible reasons for these departures is beyond the scope of this report but it could provide useful information for those involved with airshed management planning.

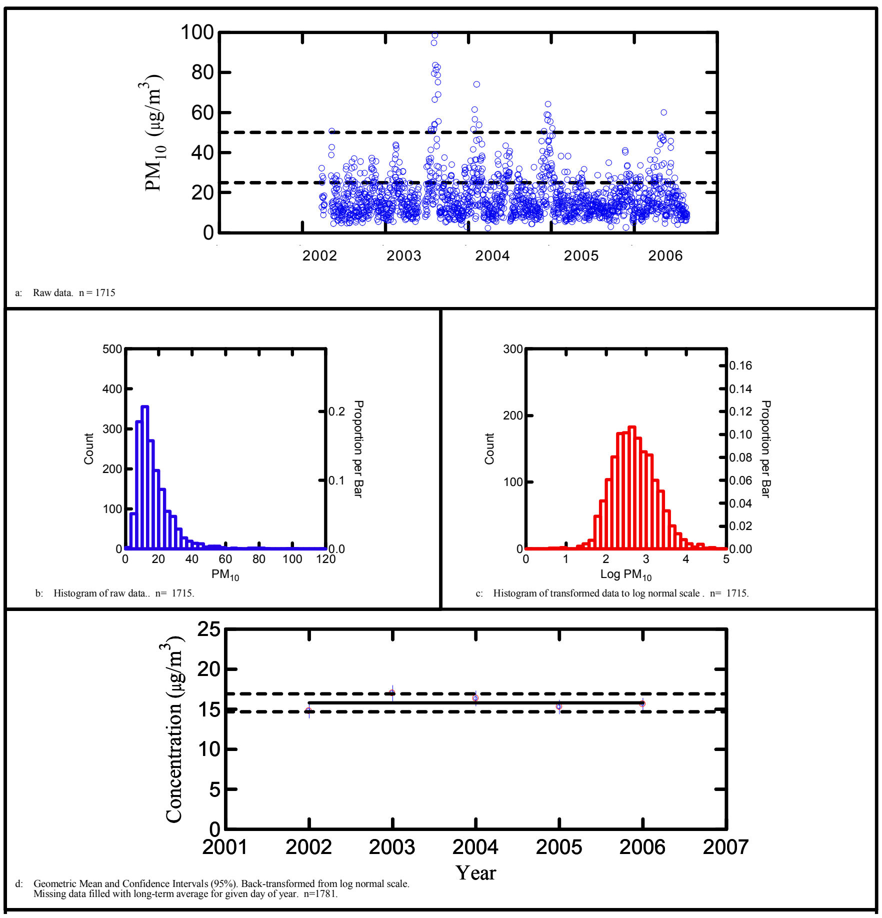
However, it is known that the years 1997 and 1998 experienced particularly active wild fire activity. Dry conditions are usually associated with dominant high pressure systems. Such weather patterns are conducive to more stagnant conditions and when Figure C2 is reproduced with ambient data collected during regional wild fire activity is removed, the resultant plot (not shown) is essentially the same, differing only by lower means (but still outside the 95% confidence intervals) for those years.

It is also known that the years of 2005-2008 showed an improving trend in most regional reporting communities. Does this mean that all communities were successful in mitigating emissions during these years or is the trend a reflection of some common factor such as meteorology? Though not conclusive, it is very likely the latter because both years experienced more frequent moisten-laden storm systems than in previous years (though in some areas, still below climatic norms in terms of precipitation). Active storm systems tend to help air quality by scavenging PM from the air during precipitation periods or flushing the airshed of contaminants with stronger winds.

Mt. Begbie PM_{10} Data

Figure C3, PM_{10} data from Mt. Begbie Elementary School, generally follows both the trends and the yearly mean values of the Fire Hall Hi-Vol sampler results (Figures C1 and C2) though there is significantly less variation from year to year. Possible explanations include the fact that there is much less historical data at the Mt. Begbie site to compare with, and less opportunity to experience atypical years. As well, the higher data volume (in a given year) afforded by the TEOM technology tends to hinder any bias to the calculated mean value caused by extreme data points.

Figure C3. Distribution of PM_{10} data from Mt. Begbie TEOM sampler from 2002 to 2006 (n = 1715)



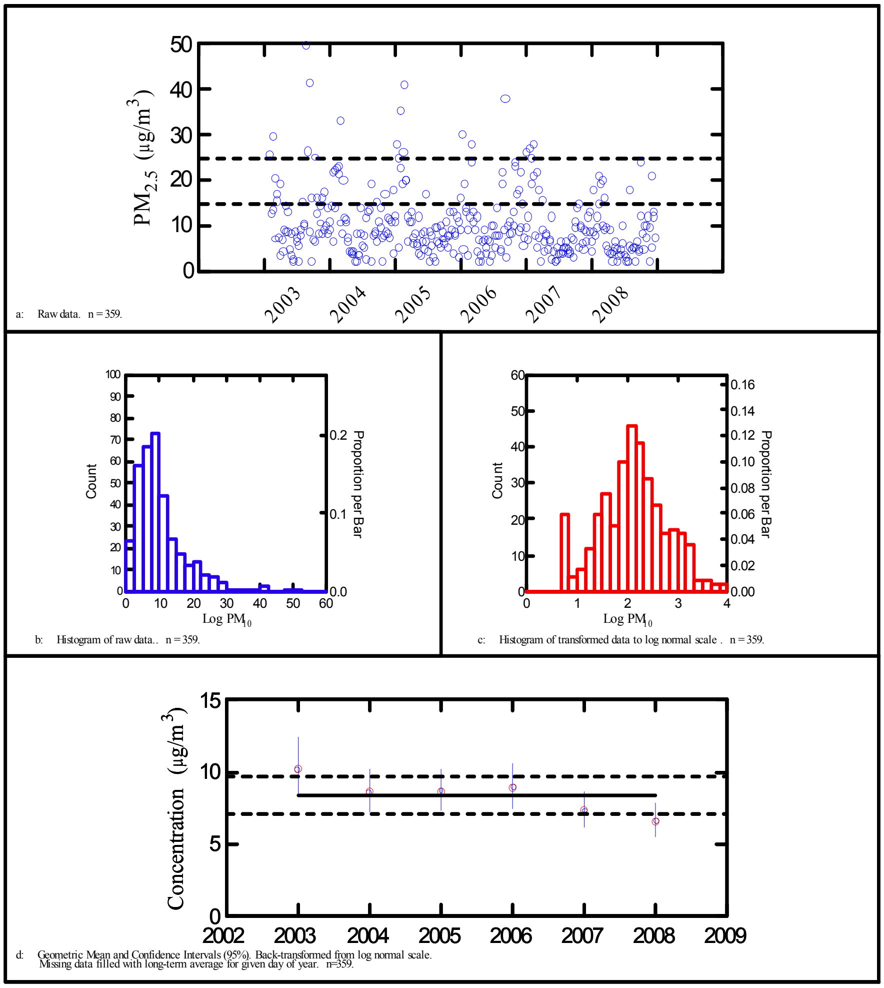
This data has undergone the same transformations as shown in Figures C1 and C2.

British Columbia Ministry of Environment

Mt. Begbie $PM_{2.5}$ Data

Like the results of the TEOM PM_{10}, there is only slight variation in the $PM_{2.5}$ levels for the four years of recording. Establishing trends are not possible with such a limited data set.

Figure C4. Distribution of $PM_{2.5}$ data from Mt. Begbie Partisol sampler from 2003 to 2008. (n = 359)



This data has undergone the same transformations as shown in Figures C1 and C2.

Appendix D – Data Quality and Completeness

Because of the variety of data collecting, handling and archiving methods over the period of sampling, and because of the characteristics of different types of samplers, the collection of data sometimes has gaps and inconsistencies. For the purposes of the analyses for this report, some of the data has undergone some quality checks and minor adjustments.

Manual samplers are typically scheduled to operate one day in six, to coincide with the National Air Pollution Surveillance network (NAPS) protocol. This ensures that samples are taken on all days of the week and all seasons throughout the year, and comparisons between sites will compare data for the same calendar days. However, occasionally samplers have operated one or two days off schedule, in which case the data for this report have been shifted to NAPS days.

Occasionally data archived in separate databases result in duplicate results for the same day, in which case the conservative approach of selecting the larger value is used.

In cold weather the tapered element oscillating microbalance (TEOM) continuous sampler requires a heating element, which can drive off (volatilize) some types of particulates. For this report, TEOM data was subjected to regression analyses with co-located manual instruments, and adjustment factors were applied to the data before being used for analysis. These adjustments were applied separately for each season, and were usually most significant in winter (January to March). See Appendix E for more details on these adjustments.

Finally, breakdowns of samplers resulted in gaps in the data, often covering several sampling days, so insufficient data were available to perform proper analyses. In these situations, the missing data was filled, using an algorithm that selected and averaged typical data from the same time periods from other years.

The data in Appendices I2 to I15 for Fire Hall Hi-Vol PM_{10} and Mt Begbie Partisol $PM_{2.5}$ have been corrected for NAPS days and duplicate values, but have not been otherwise modified.

Appendix E - Relationships of Data from Different Samplers

Emission sources can produce PM of one size, or different sizes ($PM_{2.5}$, the fine fraction, and $PM_{10-2.5}$ the coarse fraction). An analysis of the relationship between the fractions can help to understand the sources of PM.

The relationship, or lack of relationship, can be used to identify emission sources and patterns in fluctuations in air quality. For example, high concentrations of $PM_{2.5}$ in winter might be attributed to smoke from wood burning appliances, and high concentrations of PM_{10} in spring may come from dust created by traction materials (sand) applied to roads.

Appendix E1 - TEOM PM_{10} and Partisol $PM_{2.5}$ Data from Mt. Begbie

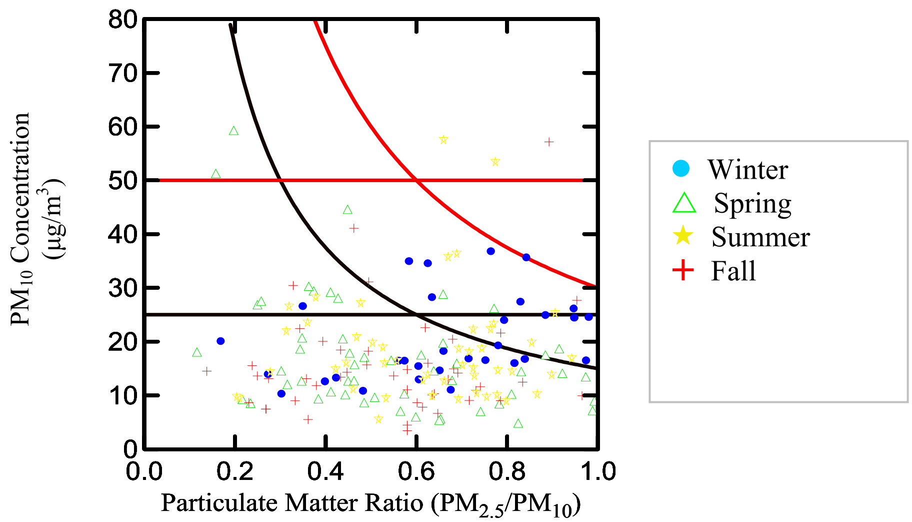
The TEOM started operation in 2002, and the Partisol started in 2003, so coincident data are available for every sixth day from April, 2003 to December, 2008. The relationships between different fractions of particulates and different samplers were explored using linear regression, a statistical technique that develops a slope-intercept form of an equation. The slope of the equation indicates the amount the dependent variable changes for each unit change of the independent variable, and the constant indicates how much the whole line shifts vertically.

dependent variable = slope x (independent variable) + constant

To get an overview of the data, Figure E1 shows the comparison of the two fractions in graphic form.

In the data collected so far, the relationship between the two PM fractions seemed inconsistent, with a wide range of the $PM_{2.5}/PM_{10}$ ratio. Concentration of PM_{10} has generally been below 25 $\mu g/m^3$, but a few readings have been noticeably higher. Two readings in spring (green triangles near the upper left) were close to 50 $\mu g/m^3$ PM_{10}, when the $PM_{2.5}$ was about 10 $\mu g/m^3$, showing that most of the PM was in the coarse fraction. Summer/fall show a different relationship. Two readings (red plus sign and yellow star near the upper right) were also near 50 $\mu g/m^3$ PM_{10}, but the $PM_{2.5}$ were about 40 $\mu g/m^3$, showing that most of the PM was in the fine fraction. Although these few readings are not sufficient to draw definite conclusions, they do demonstrate that different times of year can have different sources and types of PM.

Figure E1. Comparison of PM_{10} and $PM_{2.5}$ at Mt. Begbie site



This graph shows the levels of PM_{10}, $PM_{2.5}$, and the ratio between PM_{10} and $PM_{2.5}$. Each symbol represents one day's reading of PM_{10} and $PM_{2.5}$. However, instead of plotting $PM_{2.5}$ directly, the ratio of $PM_{2.5}$/ PM_{10} is calculated, and the ratio is plotted against PM_{10}.

The left axis is the concentration of PM_{10}, and the bottom axis is the $PM_{2.5}/PM_{10}$ ratio. The horizontal lines at 25 µg/m^3 and 50 µg/m^3 represent Level A and Level B provincial reference levels for PM_{10}. The curved lines represent the NAAQO reference level for $PM_{2.5}$ of 15 µg/m^3 for the lower curve, and the CWS reference level 30 µg/m^3 for the upper curve (i.e., any point on the lower curve represents a $PM_{2.5}$ reading of 15 µg/m^3). Any data point above the upper horizontal line indicates poor air quality from PM_{10}. Any point above or right of the upper curved line indicates poor air quality from $PM_{2.5}$.

Regression Analysis of TEOM PM_{10} and Partisol $PM_{2.5}$ Data

Linear regression analyses were run on the data to determine the strength of the relationship between PM_{10} and $PM_{2.5}$, using SPSS statistical software.

The general form of the equation comparing PM_{10} to $PM_{2.5}$ is:
concentration of PM_{10} = coefficient x (concentration of $PM_{2.5}$) + constant

The regression equation for all data (n=185) is:

(concentration of PM_{10}) = 0.999 (concentration of $PM_{2.5}$) + 7.025

The value of the correlation coefficient (R^2 =.582) indicates that the regression equation is a fair match for actual conditions. (An R^2 of 1.0 indicates a perfect relationship.) An inspection of Figure E1 shows few surprises; the majority of 'episode' conditions occur during the poor dispersion conditions in winter and from forest fires in the summer, and better air quality occurs in the spring.

However, to investigate the relationship between PM_{10} and $PM_{2.5}$ further, analyses were done for each season.

Regression Analyses by Season

Winter is December, January, February
Spring is March, April, May,
Summer is June, July, August,
Fall is September, October, November

Regression equations for these seasons are:

Winter: **(concentration of PM_{10}) = 0.804 (concentration of $PM_{2.5}$) + 8.856**
Spring: **(concentration of PM_{10}) = 1.111 (concentration of $PM_{2.5}$) + 7.381**
Summer: **(concentration of PM_{10}) = 1.020 (concentration of $PM_{2.5}$) + 6.446**
Fall: **(concentration of PM_{10}) = 1.195 (concentration of $PM_{2.5}$) + 4.422**

In these analyses, R^2 varies considerably.

Winter shows a good relationship (R^2 = .729) (n=33)
Spring shows a poor relationship (R^2 = .260) (n=56)
Summer shows a good relationship (R^2 = .746) (n=43)
Fall shows a good relationship (R^2 = .796) (n=49)

This indicates that in winter, summer, and fall, the two fractions (PM_{10} and $PM_{2.5}$) may be related, but in spring, they are likely not related. It is possible that emission sources in winter, summer, and fall emit both fractions, but emission sources in spring emit the different fractions independently. As an example, it is common in interior BC communities to see very high PM_{10} levels that are largely driven from fugitive road dust (and hence a relatively small fine/coarse PM ratio and $PM_{2.5}$) in March during spring break-up.

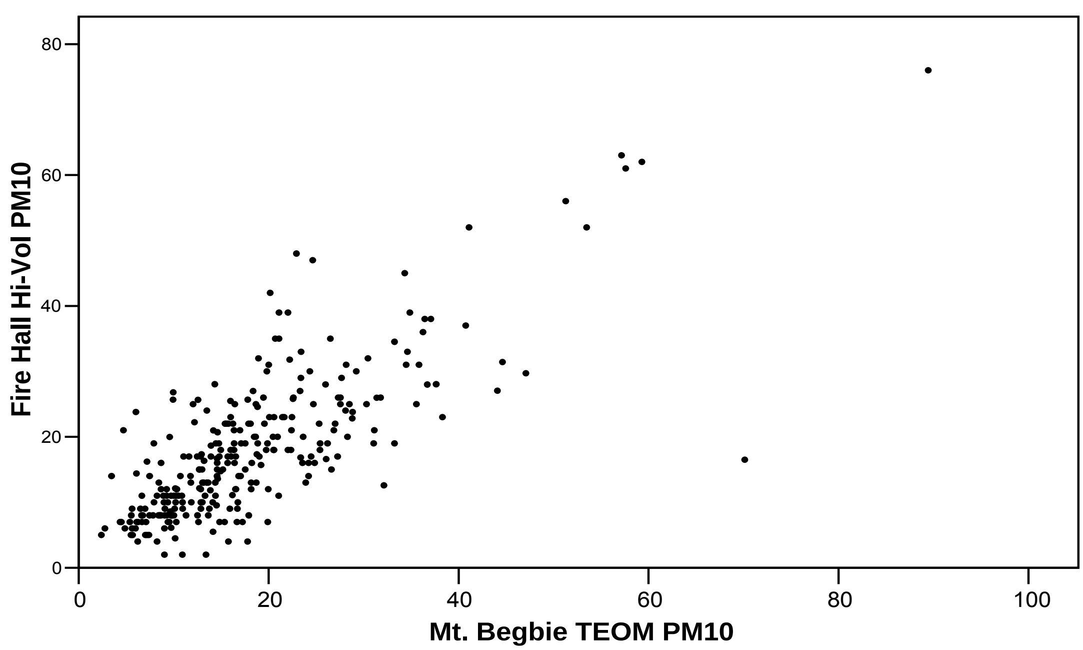
Further data collection and analysis, and an understanding of the sources of PM emissions, would be required to determine if a useful relationship exists.

Appendix E2 - Comparison of PM_{10} Data from Fire Hall Hi-Vol Manual Sampler and Mt. Begbie TEOM Continuous Sampler

The operation of the TEOM continuous sampler starting in 2002 also allowed the comparison of one air quality parameter (PM_{10}) as measured by two types of instruments: Hi-Vol manual sampler and TEOM continuous sampler. During the period from 2002 to 2006, the TEOM sampled every day and the Hi-Vol sampled every 6th day, so comparisons can be done for the 288 days of coincident sampling. Although it is easy to assume that these reading should be very similar, the two samplers are located approximately 2 km apart, and the PM_{10} concentration can differ noticeably. Different sources can emit PM near one source, but far from the other, and localized weather conditions can influence dispersion of the emissions.

The scatter diagram below (Figure E2) shows that there seems to be a good relationship between these two sets of data, with most data points demonstrating approximately equal concentrations of PM_{10}.

Figure E2. Scatter diagram of PM_{10} data from the Fire Hall Hi-Vol and the Mt. Begbie TEOM samplers from 2002 to 2006



PM_{10} data from two sampling instruments on days when both were in operation.

The regression equation for all data (n=288) is:

Hi-Vol reading = 0.772 (TEOM reading) + 4.123

This shows a fair relationship (R^2 = .600), indicating that Hi-Vol data are reasonable, but not precise, predictors of TEOM data.

Regression Analyses by Season

Winter is December, January, and February
Spring is March, April, and May
Summer is June, July, and August
Fall is September, October, and November

Regression equations for these seasons are:

Winter: **Hi-Vol reading = 0.550 (TEOM reading) + 9.261**
Spring: **Hi-Vol reading = 1.123 (TEOM reading) + 1.118**
Summer: **Hi-Vol reading = 0.948 (TEOM reading) + 2.234**
Fall: **Hi-Vol reading = 0.687 (TEOM reading) + 3.942**

In these analyses, R^2 varies considerably.

Winter shows a poor relationship	(R^2 = .303)	(n=60)
Spring shows a fair relationship	(R^2 = .591)	(n=75)
Summer was a good relationship	(R^2 = .793)	(n=78)
Fall was a fair relationship	(R^2 = .443)	(n=75)

In the warmer months (spring and summer) the TEOM and Hi-Vol results match closely, as indicated by the regression constants being close to 1.000 (1.123 for spring and 0.948 for summer). Further, because the R^2 values are moderately strong (.591 and .793) the relationships show good consistency.

In contrast, the fall and winter months show larger differences between the TEOM and Hi-Vol, because the regression constants differ from 1.000 (0.550 for winter and 0.687 for fall). The relationships for these seasons are not as good either, as the R^2 values are lower (.303 and .443). Hence, a noticeable difference can be seen between the two instruments in certain seasons of the year.

Appendix F – Relation between Wind and Particulate Matter Concentration

As mentioned in the main text, meteorology plays an important role in the determination of air quality. Wind information can be critical when trying to establish possible sources of air contaminants. The Mt. Begbie site has a continuous PM_{10} sampler (TEOM) and a meteorological station, so it is suitable for a relational analysis of PM and wind.

The wind rose (Figures F2a, F3a, c, e and F4a, c, e in blue tones) and its cousin, the pollution rose (Figures F2b, F3d, f, and F4d, f in rainbow tones), depict the relative frequency of wind direction on a 16-point compass, with north, east, south, and west directions going clockwise. Calms (winds less than 0.5 m/sec) are included as a separate category, giving a total of 17. Each ring on the wind rose represents a proportion of the total[40].

In the case of the wind rose, the radial spikes or rose 'petals' indicate not only the frequency of wind from that particular direction but also categories of wind speeds recorded for that wind direction (in effect, the frequency of each wind speed for each direction). In the case of the pollution rose, categories of ambient pollutant levels are plotted.

Using Figure F4f as an example, note the predominance of winds blowing from the northeast. Winds from this direction account for roughly 45 percent of all wind speeds and directions recorded. Additionally, one can discern that about 22 percent of all records (blue and dark green segments) were associated with winds from this direction that had relatively pristine air quality conditions (PM_{10} less than 15 $\mu g/m^3$). A further 20 percent of all records (light green, yellow, and orange segments) were associated with winds from this direction that had moderate air quality conditions (PM_{10} less than 50 $\mu g/m^3$, greater than 15 $\mu g/m^3$), and a final 1-2 percent for poor air quality conditions (PM_{10} levels greater than 50 $\mu g/m^3$).

As described in Section 4.2, topographic features can have a strong influence on weather (including winds). This is especially true for so-called "complex-terrain" as is found in the Revelstoke airshed. Figure F1 is presented here to help guide the reader in understanding air quality in relation to terrain and winds.

[40] Note these increments of frequency vary dependent on the length of the rose 'petals'. Hence, the reader is cautioned when comparing roses with different frequency rings: e.g., Figure F3f (5% frequency rings) is an 'expanded' view when compared to Figure F4f (10% frequency rings).

Figure F1: Revelstoke terrain with the Fire Hall and Mt. Begbie sampling locations

This view is looking NE towards Rogers Pass at top of frame. The two ministry sampling locations are indicated by the red circles with the Mt. Begbie sampling site to the right and the Fire Hall to the left.

Image obtained from Google Earth 2005, v3.0 2006 MDA EarthSat & 2006 DigitalGlobe. Retrieved: August 8, 2007, from http://google.earth.com.

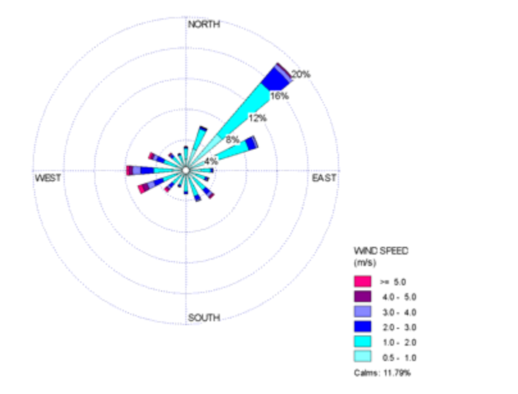
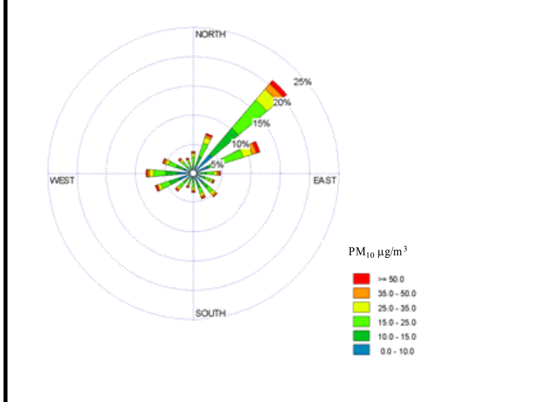
Season / Time	Wind Rose	Pollution Rose
All Data (available during study period)	 **a:** n =36903	 **b:** n =35536

Figure F2: Wind direction/speed and air quality for all data

ENVIRONMENTAL QUALITY

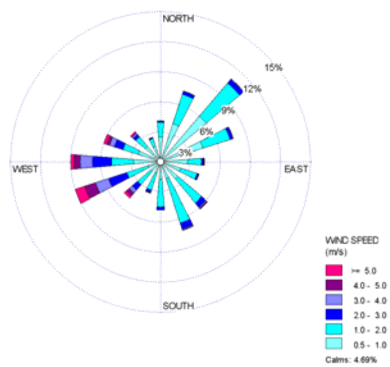
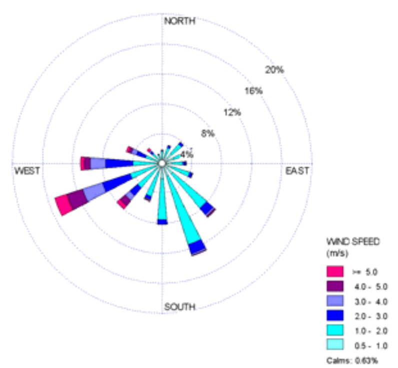
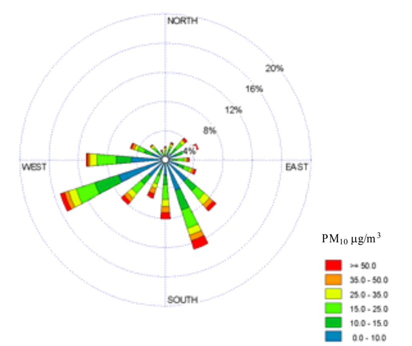
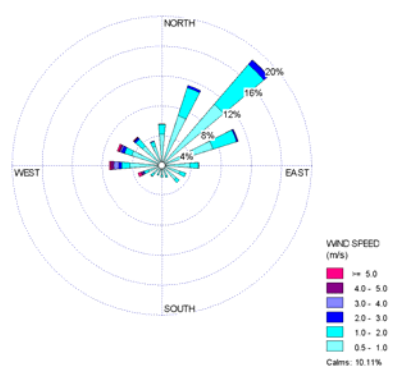
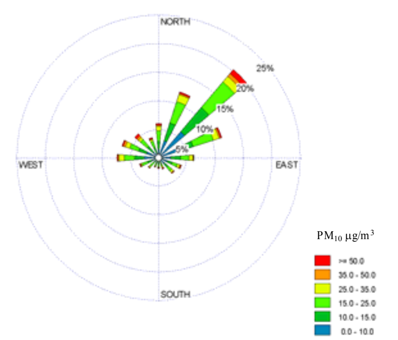
Season / Time	Wind Rose	Pollution Rose
Summer (all hours)	 **a:** n =8596	**b:** not available
Summer (day)	 **c:** n =4112	 **d:** n =3775
Summer (night)	 **e:** n =3352	 **f:** n =3227

Figure F3: Wind direction/speed and air quality in summer

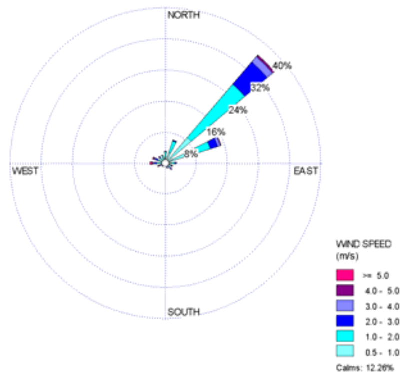
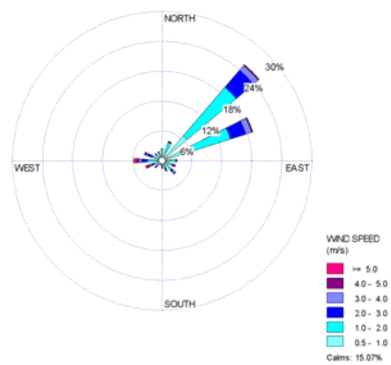
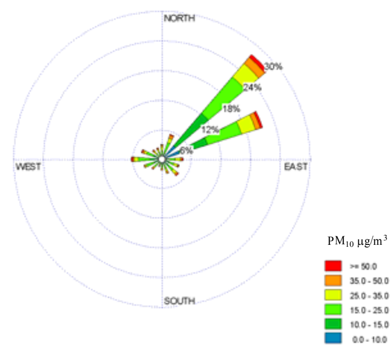
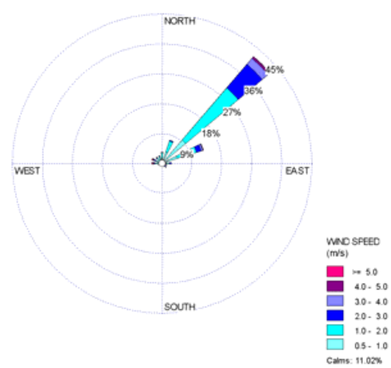
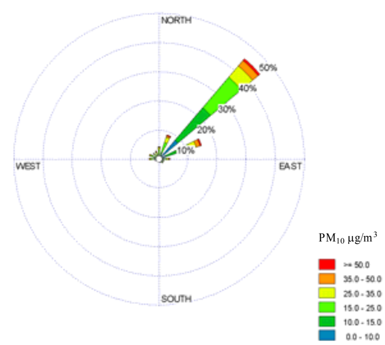
Season / Time	Wind Rose	Pollution Rose
Winter (all hours)	 **a:** n =10296	**b:** not available
Winter (day)	 **c:** n =3432	 **d:** n =3379
Winter (night)	 **e:** n =6006	 **f:** n =5839

Figure F4: Wind direction/speed and air quality in winter

Analyses from Figures F3 and F4 reveal the following observations on wind patterns:

- The wind patterns, in general, follow known relationships of terrain and meteorology (e.g., seasonal and diurnal patterns associated with mountain/valley flow). Hence, although this analysis uses only one sampling station, it is presumed that wind direction and speed will vary considerably between different areas of the airshed: a reflection on the varying valley orientations.

- The prevailing winds in Revelstoke vary dependent on season.

- There is a strong bias towards easterly winds in winter. However, surrounding terrain help steer the winds to give a northerly component as the air travels across the Mt. Begbie School monitoring location. Winter winds are light when compared to summer (although the differences are minor when compared with other provincial airshed). Calm conditions (and light winds) have less air dispersion capabilities than stronger winds.

- Summer winds tend to be more variable in both direction and speed. The frequency of calm conditions in summer is less than half that of the winter season.

- Overnight winds in both summer and winter tend to be dominated by drainage from Rogers Pass to the east. In the summer, valley winds reverse direction during the day due to daytime solar heating.

Wind Sector Analysis

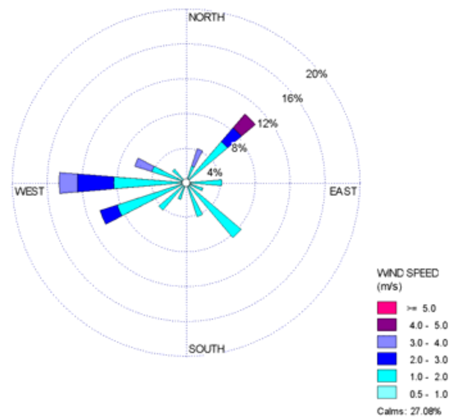
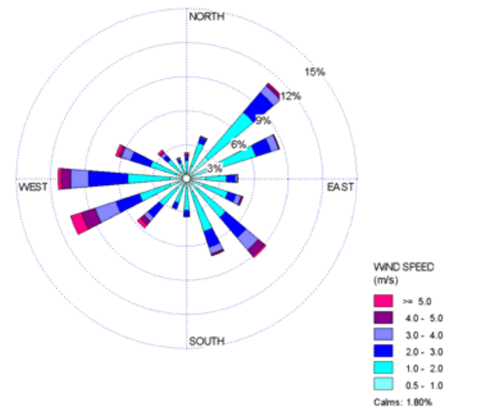
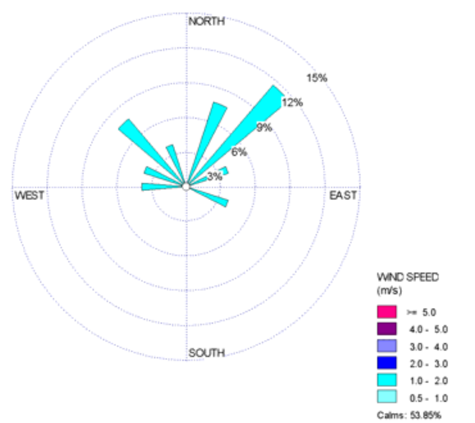
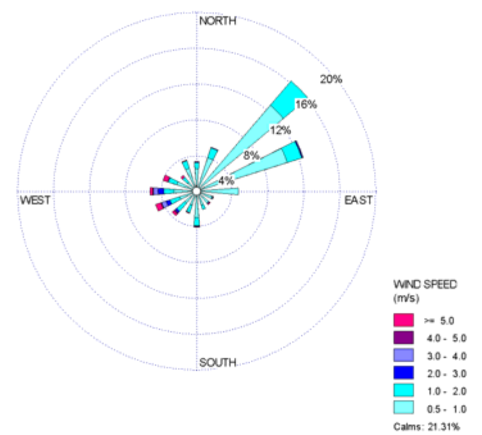
Air Quality Condition	$PM_{2.5}$	PM_{10}
Pristine	 a: **Wind Rose for $PM_{2.5}$ < 6 µg/m^3** (over 50% occurred in April, May, June). n = 48	 b: **Wind Rose for PM_{10} < 8 µg/m^3.** n = 6153
Episode	 c: **Wind Rose for $PM_{2.5}$ > 15 µg/m^3.** (all occurred during October through March. Five records culled during periods of forest fires in August and September). n = 28	 d: **Wind Rose for PM_{10} > 50 µg/m^3.** (excludes periods of forest fires). n = 1131.

Figure F5: Wind direction by air quality condition

Analysis of wind patterns with ambient air quality levels, often called "wind sector analysis", is used to identify possible sources of air pollution at the receiving environment. That is, it can often help answer the question, "what are emission sources that are upwind when the sampling equipment is recording elevated levels of contaminants?" Analyses from the eight pollution roses of Figures F3 and F4 and the wind roses reveal the following information on relationships of wind with air quality:

- Figure F5a, b show that better air quality ('pristine') tends to be associated winds that have higher speeds. Note the dominance of 'calm' winds associated with poor air quality ('episode').

- Unfortunately, for the case of Revelstoke's airshed, there is no strong evidence from the Figure F5 pollution roses that point to any particular emission source. That is, high levels of PM are found from most directions. Note the similar percentages of high PM levels in all of the wind direction barbs in the pollution roses regardless of diurnal or seasonal variation. However, Figures F5c, d suggest that episode conditions are less likely to occur when winds are from the south.

- The pollution roses of Figures F4d, f and Figure F5d seem to suggest that air quality problems are linked to emission sources from the northeast. Yet, there are no known industrial sites or municipalities in that direction. A few explanations are possible: 1) there could have been heavy industrial slash burning activity in that valley that have biased the readings due to the prevailing winds from the northeast, 2) air contaminants recorded may have actually been emitted elsewhere in the airshed but were pushed up the valley before the dominating valley flow reversed and brought the polluted air back across the sampling equipment, and 3) emissions from the Trans Canada corridor (including rail diesel emission) were brought into the airshed from the northeast likely combining with other existing air contaminants to raise the ambient levels.

There are a few reasons why, in airsheds like that of Revelstoke, it is often difficult to use wind sector analysis for identifying the causes of the recorded air contaminants. Because of effects of surrounding complex terrain, air movement is often governed by the mountain/valley wind phenomenon; drainage of colder air during nocturnal hours and reversal during daytime heating hours. Hence, a parcel of polluted air may in fact travel across the sampling site multiple times, perhaps each time with a different corresponding wind direction, before the PM finally succumbs to deposition on the surface (perhaps the sampler filter), precipitation scavenging, or being flushed from the airshed by stronger winds. The latter solution to poor air quality is made more difficult by the confined nature of the airshed which is bound by steep valley walls and experiences extended periods of stagnant air, especially in the winter season.

Appendix G - Calculation of Exposure

An exposure calculation is a technique to combine the AMOUNT of a pollutant to which we are exposed, and the TIME that we are exposed to the pollutant. At the two extremes, a low concentration of a pollutant could be in the air for several months, yielding an exposure, but the same exposure would result if there was a high concentration of the pollutant for a few days and clean air for the rest of the time. (One of the assumptions is that these two types of exposures will have similar effects on human health.)

Exposure calculations are based on the assumption that there is a concentration (25 $\mu g/m^3$) below which there is minimal risk to health, and above which there exists a statistically significant greater health response. This reference level can be exceeded either by a short period of exposure to high concentrations, or a longer period of exposure to lower concentrations.

Although there are many different ways to calculate exposure, the values cited in this report were calculated based on the NAAQO definition. This method assumes that PM_{10} has negligible health effects until the daily average exceeds a reference health level of 25 $\mu g/m^3$. For days in which this threshold is exceeded, the difference between the daily mean and the reference level is computed, divided by 10, and rounded up to the nearest whole number. After this is done for each day in a particular year, the numbers are summed to provide an overall measure of exposure. Such exposure measures can be used in both inter-annual and inter-site comparisons.

Because the monitoring in Revelstoke is done on a non-continuous basis, many days, for many years, did not have a daily average for PM_{10}. Thus, exposure values were extrapolated from the days for which daily averages were available.

For example, suppose that for a given year, 58 daily averages were available and the NAAQO exposure calculation is applied to this 58 day dataset, with a resultant value of 85. An estimate for the year can then be achieved by assuming that the days sampled are representative of PM levels over the entire year and scaling the level of exposure accordingly. Thus, for our example, since the year had 365 days, we can multiply 85*(365/58) = 534.9 to get an estimate of the NAAQO exposure for this year.

Appendix H1 – Air Quality Sampling Parameters and Sites in Revelstoke

Legend

Met – Meteorological (weather) data
PM_{10} – Particulate matter (up to 10 µm diameter)
$PM_{2.5}$ - Particulate matter (up to 2.5 µm diameter)
TSP - Total Suspended Particulate

Table A1. Dates and types of the monitoring programs in Revelstoke.

Start – End Date	Parameter	Sampling Type and Frequency	MoE Site Identification
May 1989 – Jun 2004	TSP	Discrete Manual, 1-in-6 days	Downie Timber E211940
Jan 1993 – Jul 2007	PM_{10}	Discrete Manual, 1-in-6 days (HiVol sampler)	Fire Hall E217680
Apr 2002 – Jul 2007	PM_{10}	Continuous TEOM	Mt. Begbie School E248021
July 2007 - current	$PM_{2.5}$	Continuous TEOM	Mt. Begbie School E248021
Feb 2003 - current	$PM_{2.5}$	Discrete Manual, 1-in-6 days	Mt. Begbie School E251469
Jul 2007 - current	PM_{10}	Discrete Manual, 1-in-6 days (Partisol Low-vol sampler)	Fire Hall E217680
Sep 2002 - current	Met	Continuous	Mt. Begbie School E248021

ENVIRONMENTAL QUALITY

Appendix H2 – Air Quality Sampling Sites and Parameters in Kootenay Region Communities

Some communities have had samplers located in several sites within their boundaries. If there was more than one site, the quantity is listed in parentheses after the community name. The Dates of Operation list the first and last dates of any sampling for each airshed, but are not specific for each parameter. The Parameters Measured lists all parameters that have been measured at each site. Not all parameters have been measured at all times. Golden underwent a Source Apportionment Study, hence had some specialized sampling equipment.

Legend

TSP	Total suspended particulates	NO_2	Nitrogen dioxide
PM_{10}	Particulate matter (up to 10 μm diameter)	NO	Nitric oxide
$PM_{2.5}$	Particulate matter (up to 2.5 μm diameter)	SO_2	Sulphur dioxide
PM Coarse	$PM_{10-2.5}$	CO	Carbon monoxide
Dustfall	Dustfall	Aethalometer	An instrument for measuring elemental (black) carbon
Metals	Heavy metals: arsenic, cadmium, zinc	PM speciation	Instruments that measure specific chemicals found in emissions
TRS	Total reduced sulphur	VOC	Volatile organic compounds
O_3	Ozone	Met	Meteorological (weather) data

Table A2. Dates and parameters measured at Kootenay Region air quality monitoring sites.

Airshed	Dates of Operation	Parameters Measured
Canal Flats	February 1974 – January 1985	Dustfall
Castlegar (9 sites)	March 1985 - present	TSP PM_{10} Dustfall Metals TRS NO_2 SO_2 CO Met

ENVIRONMENTAL QUALITY

British Columbia Ministry of Environment

Airshed	Dates of Operation	Parameters Measured
Cranbrook	Apr 1985 – Mar 1991 May 1990 – Sep 1993 Apr 1994 – Nov 1998 Mar 2001 – Sep 2006	TSP PM_{10} Met
Creston	September 1990 – present	PM_{10} $PM_{2.5}$ CO NO_2 O_3 SO_2 Met
Elk Valley (4 sites)	April 1978 – present	TSP PM_{10} $PM_{2.5}$ Dustfall
Elkford	October 1982 – March 1993	TSP PM_{10} Dustfall
Golden (4 sites)	January 1992 – present	PM_{10} $PM_{2.5}$ PM coarse Aethalometer PM speciation VOC NO_2 NO CO O_3 SO_2 Met
Grand Forks	August 1973 – present	TSP PM_{10} $PM_{2.5}$ Dustfall Met
Invermere	July 1993 – January 2009	PM_{10}
Kimberley	May 1988 – January 2009	TSP PM_{10} SO_2
Kokanee Park	July 2001 – August 2002	PM_{10}

ENVIRONMENTAL QUALITY

Airshed	Dates of Operation	Parameters Measured
Nelson	March 1985 – present	TSP PM_{10} $PM_{2.5}$ O_3 Met
Radium	July 1998 – December 2007	PM_{10}
Revelstoke	May 1989 – present	PM_{10} $PM_{2.5}$ Dustfall Met
Skookumchuck	August 1987 – July 2005	TRS Met
Slocan	April 1985 – May 1986 November 1991 - present	TSP PM_{10} Dustfall
Sparwood	January 1982 – present	TSP PM_{10} $PM_{2.5}$ Dustfall
Trail (15 sites)	February 1970 - present	TSP PM_{10} $PM_{2.5}$ Dustfall Metals CO NO NO_2 O_3 SO_2 Met
Ymir	May, 1984 – February 1988	TSP Dustfall

Appendix I1 - Revelstoke Hi-Vol PM_{10} Data for 1993

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	1	19
	7	29
	13	29
	19	19
	25	23
	31	30
February	6	43
	12	41
	18	54
	24	28
March	2	29
	8	30
	14	11
	20	20
	26	28
April	1	21
	7	11
	13	13
	19	13
	25	8
May	1	6
	7	10
	13	35
	25	29
	31	16
June	6	21
	12	14
	18	17
	24	13
	30	9
July	6	14
	12	10
	18	16
	24	14
	30	16
August	5	55
	11	28
	23	9
	29	25
September	4	18
	10	37
	16	19
	22	23
	28	34

Month	Day	PM_{10}
October	4	33
	10	19
	16	24
	22	18
	28	25
November	3	10
	9	28
	21	7
	27	19
December	3	7
	9	18
	15	17
	21	15
	27	12

Appendix I2 - Revelstoke Hi-Vol PM_{10} Data for 1994

(PM_{10} in µg/m^3.)

Month	Day	PM10
January	2	13
	8	27
	14	44
	20	26
	26	26
February	1	54
	7	40
	13	12
	19	15
	25	28
March	3	20
	9	82
	15	41
	21	16
	27	22
April	2	18
	8	6
	14	7
	20	12
	26	13
May	2	13
	14	11
	20	5
	26	12
June	1	11
	7	6
	19	5
	25	13
July	25	45
	31	28
August	6	13
	12	21
	30	12
September	5	7
	11	8
	17	16
	29	25
October	5	23
	11	8
	17	16
	23	12

Month	Day	PM10
	29	11
November	4	11
	10	18
	16	6
	22	8
	28	17
December	4	18
	10	7
	16	14
	22	14
	28	10

Appendix I3 - Revelstoke Hi-Vol PM_{10} Data for 1995

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	3	28
	9	20
	15	24
	21	22
	27	29
February	2	17
	8	23
	14	52
	20	21
	26	30
March	4	51
	10	24
	28	30
April	3	17
	9	16
	15	2
	21	11
	27	13
May	3	6
	9	13
	15	9
	21	5
	27	14
June	14	8
	20	6
	26	12
July	2	16
	8	9
	14	20
	20	32
	26	6
August	1	11
	7	5
	13	7
	19	8
	25	18
September	12	29
	18	16
	24	21

Month	Day	PM_{10}
	30	6
October	6	13
	18	9
	24	14
	30	13
November	5	11
	11	12
	23	16
December	5	9
	23	13

ENVIRONMENTAL QUALITY

Appendix I4 - Revelstoke Hi-Vol PM_{10} Data for 1996

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	4	11
	10	8
	16	6
	22	12
	28	5
February	3	20
	15	21
	21	8
	27	53
March	4	25
	10	15
	16	18
	22	36
	28	41
April	3	21
	9	15
	15	20
	21	11
	27	10
May	3	6
	9	9
	15	6
	21	8
	27	15
June	2	8
	8	14
	14	19
	20	12
	26	10
July	2	27
	8	26
August	19	9
	25	34
	31	7
September	6	8
	12	21
	18	13
	24	12
	30	12
October	6	16
	12	16
	18	15
	24	10
	30	10
November	5	24
	11	26
	17	14
	23	15
	29	17
December	5	14
	11	21
	17	15

Appendix I5 - Revelstoke Hi-Vol PM_{10} Data for 1997

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	10	39
	16	27
	22	23
	28	25
February	3	20
	9	36
	15	21
	21	10
	27	31
March	5	43
	11	51
	17	22
	23	20
	29	20
April	4	33
	10	33
	16	12
May	4	7
	10	15
	16	22
	22	9
	28	12
June	15	15
	21	14
	27	13
July	3	16
	9	7
	15	14
	21	32
	22	12
	27	22
August	2	6
	8	22
	14	15
	26	10
September	1	16
	7	10
	13	10
	25	17
October	1	83
	7	51
	13	62
	19	60
	25	40

Month	Day	PM_{10}
	31	11
November	6	15
	12	30
	18	26
	24	13
	30	19
December	6	28
	12	30
	18	9
	24	12
	30	31

ENVIRONMENTAL QUALITY

Appendix I6 - Revelstoke Hi-Vol PM_{10} Data for 1998

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	5	18
	11	22
	17	30
	23	10
	29	20
February	4	22
	10	22
	16	34
	22	10
	28	44
March	6	31
	12	32
	18	37
	24	7
	30	20
April	5	22
	11	14
	17	19
	23	30
	29	43
May	5	24
	11	20
	23	29
	29	22
June	4	10
	10	37
	16	7
	22	20
	28	8
July	4	37
	10	35
	16	29
	28	54
August	3	13
	9	28
	15	16
	21	51
	27	24
September	2	46
	8	19
	14	33
	20	8
	26	9
October	2	13
	8	23
	14	13
	20	29
	26	35
November	1	26
	7	31
	8	23
	13	16
	19	17
	25	35
December	1	14
	7	11
	13	5
	19	17
	25	18
	31	15

Appendix I7 - Revelstoke Hi-Vol PM_{10} Data for 1999

(PM_{10} in μg/m^3.)

Month	Day	PM_{10}
January	6	27
	12	16
	18	19
	24	29
	30	12
February	5	8
	11	30
	17	21
March	13	12
	19	48
	25	10
	31	43
April	6	23
	12	15
	18	21
	24	23
	30	26
May	6	19
	12	7
	18	5
	24	11
	30	12
June	5	7
	11	12
	17	27
	23	10
	29	13
July	5	11
	11	63
	17	58
	23	36
	29	21
August	4	45
	10	23
	16	13
	22	32
	28	0
September	3	26
	9	23
	15	32
	21	45

Month	Day	PM_{10}
	27	21
October	3	19
	9	13
	15	25
	21	53
	27	21
November	2	29
	8	20
	14	13
	20	9
	26	27
December	2	6
	8	10
	14	8
	20	15
	26	22

Appendix I8 - Revelstoke Hi-Vol PM_{10} Data for 2000

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	1	25
	7	12
	13	22
	19	32
	25	19
	31	21
February	6	27
	12	34
	18	47
	24	21
March	1	31
	7	103
	13	84
	19	21
	25	20
	31	47
April	6	18
	12	34
	18	21
	24	9
	30	10
May	6	9
	12	8
	18	15
	24	15
	30	15
June	5	22
	11	5
	17	16
	23	13
	29	24
July	5	10
	11	14
	17	30
	23	6
	29	7
August	4	24
	10	29
	16	29
	22	20

Month	Day	PM_{10}
	28	17
September	3	4
	9	4
	15	26
	21	8
	27	32
October	3	19
	9	21
	15	15
	21	10
	27	22
November	2	25
	8	16
	26	8
December	2	10
	8	21
	14	15
	20	18
	26	9

Appendix I9 - Revelstoke Hi-Vol PM_{10} Data for 2001

(PM_{10} in µg/m^3.)

Month	Day	PM_{10}
January	1	18
	7	17
	13	24
	19	22
	25	25
	31	24
February	6	8
	12	14
	18	22
	24	6
March	2	16
	8	23
	14	15
	20	39
	26	19
April	1	16
	7	14
	25	17
May	1	9
	7	13
	13	11
	19	6
	25	14
June	12	8
	18	8
	24	15
	30	14
July	6	25
	24	11
	30	11
August	5	15
	11	22
	17	47
	23	8
	29	30
September	4	17
	10	13
	16	17
	22	13
	28	22
October	4	31
	10	20
	16	28
	22	11

Month	Day	PM_{10}
	28	12
November	3	19
	9	26
	15	11
	21	25
	28	18
December	3	5
	9	9
	15	13
	21	15
	27	17

Appendix I10 - Revelstoke Hi-Vol PM_{10} Data for 2002

(PM_{10} in µg/m^3. Continuous (hourly) data are available upon request.)

Month	Day	PM_{10}
January	2	27
	8	35
	14	19
	20	17
	26	15
February	1	21
	7	18
	13	24
March	21	48
April	8	39
	14	9
	20	25
	26	27
May	2	30
	8	13
	14	7
	20	12
June	1	11
	7	6
	13	28
	19	8
	25	22
July	1	5
	7	11
	13	19
	19	19
	25	32
	31	6
August	6	9
	12	11
	18	9
	24	23
	30	19
September	5	14
	11	26
	17	8
	23	22
	29	10
October	11	13
	17	36
	23	35
	29	24

Month	Day	PM_{10}
November	4	19
	10	18
	16	12
	22	11
	28	22
December	4	26
	10	14
	16	12
	22	23
	28	16

Appendix I11 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2003

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	3		22
	9		42
	15		23
	21		8
	27		33
February	2		26
	8		13
	14		30
	20		14
	26	20	39
March	4	7	35
	10	16	19
	16	17	13
	22	2	
	28	19	
April	3	4	
	9	9	
	15	5	5
	21	9	16
	27	14	11
May	3	9	10
	9	9	17
	15	13	13
	21	5	
	27	8	11
June	2	4	13
	8	2	14
	14	3	7
	20	9	7
	26	6	17
July	2	8	8
	8	6	11
	14	2	14
	20	8	17
	26	9	16
August	1	15	21
	7	10	17
	13	10	18
	19	51	63
	25	75	76

Month	Day	$PM_{2.5}$	PM_{10}
	31	26	29
September	6	41	52
	12	9	7
	18	2	7
	24	16	18
	30	7	18
October	6	25	38
	12	6	4
	18	13	17
	24	16	21
	30	8	5
November	5	11	20
	11	12	14
	17	15	25
	23	2	11
	29	17	19
December	5	9	21
	11	7	17
	17	15	16
	23	3	2
	29	9	

Appendix I12 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2004

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	4	5	7
	10	16	25
	16	30	37
	22	0	8
	28	14	27
February	3	31	38
	9	23	26
	15	23	30
	21	22	31
	27	33	26
March	4	11	15
	10	8	56
	16	20	19
	22	12	62
	28	6	14
April	3	19	39
	9	7	22
	15	7	13
	21	4	15
	27	4	25
May	3	4	16
	9	4	5
	15	4	14
	21	2	11
	27	8	8
June	2	2	12
	9	4	22
	14	1	7
	20	10	4
	26	14	20
July	2	6	8
	8	6	8
	14	10	13
	20	1	21
	26	16	23
August	1	18	33
	7		7
	13	19	47
	19	27	45
	25	1	7
	31	10	6
September	6	8	11

Month	Day	$PM_{2.5}$	PM_{10}
	12	7	10
	18	4	6
	24	19	22
	30	14	
October	6	14	
	12	10	20
	18	2	8
	24	7	8
	30	8	11
November	5	17	21
	11	9	17
	17	12	
	23	8	
	29	12	19
December	5	1	4
	11	8	9
	17	18	31
	23	4	
	30	12	

ENVIRONMENTAL QUALITY

Appendix I13 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2005

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	4	10	
	10	28	
	16	5	14
	22	25	12
	28	36	
February	3	38	
	9	30	49
	15	46	42
	21	78	56
	27	32	38
March	5	20	
	11	12	30
	17	7	21
	23	11	
	29	11	
April	4	13	10
	10	6	12
	16	7	5
	22	8	22
	28	6	15
May	4	6	15
	10	12	19
	16	4	6
	22	4	7
	28	8	19
June	3	7	12
	9	9	17
	15	5	8
	21	17	23
	27	6	9
July	3	4	11
	9	2	8
	15	9	15
	21	8	23
	27	6	2
August	2	3	2
	8	2	
	14	10	
	20	10	

Month	Day	$PM_{2.5}$	PM_{10}
	26	6	
September	1	6	
	7	10	
	13	5	8
	19	7	
	25	9	
October	1	6	
	7	7	6
	13	11	16
	19	8	9
	25	5	
	31	8	
November	6	13	
	12	9	12
	18	13	17
	24	4	11
	30	9	15
December	6	8	12
	12	12	12
	18	3	10
	24	11	7
	30	16	16

Appendix I14 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2006

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	5	9	7
	11	30	25
	17	5	8
	23	19	13
	29	13	9
February	4	14	7
	10	9	35
	16	3	31
	22	12	10
	28	24	17
March	6	28	19
	12	11	25
	18	13	18
	24	9	18
	30	12	24
April	5	4	15
	11	7	5
	17	2	8
	23	4	10
	29	2	22
May	5	6	20
	11	9	17
	17	7	25
	23	4	7
	29	5	5
June	4	7	8
	10	2	8
	16	7	9
	22	3	13
	28	10	18
July	4	10	32
	10	8	9
	16	5	8
	22	8	23
	28	14	26
August	3	8	20
	9	5	13
	15	5	10
	21	19	52
	27	22	4
September	2	10	
	8	38	61
	14	3	6
	20	7	7
	26	10	19
October	2	11	15
	8	7	10
	14	9	20
	20	13	13
	26	10	9
November	1	20	31
	7	13	18
	13	9	7
	19	3	
	25	13	
December	1	19	
	7	10	
	13	13	
	19	6	
	25	4	
	31	8	

ENVIRONMENTAL QUALITY

Appendix I15 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2007

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	6	26	15
	12	12	15
	18	6.9	7
	24	27	
	30	19	
February	5	25	28
	11	28	18
	17	21	11
	23		9
March	1	5.1	25
	7	22	15
	13	7.4	15
	19	18	12
	25	2	18
April	6	9.2	23
	12	6.7	20
	18	4.5	9
	24	8.2	13
	30		15
May	6	4.9	8
	12	7	14
	18	6.7	22
	24	2.8	8
	30	12	21
June	5	4.3	5
	11	2.2	
	17	2.1	
	23	2.4	4
	29	5.4	8
July	5	4	45
	11	6.4	17
	17	3.8	44
	23	4	8
	29	4.6	2
August	4		8
	10		
	16	6.7	
	22	4.1	
	28	4.8	10
September	3	4.5	
	9	3.8	
	15	7.5	
	21	3	
	27	6.8	
October	3	9.5	23
	9	11	9
	15	14	18
	21	5.4	20
	27	15	17
November	2	9.5	6
	8	10	11
	14	6.2	11
	20	4.7	14
	26	9	7
December	2	8.8	8
	8	6.4	10
	14	12	
	20		5
	26	13	6

ENVIRONMENTAL QUALITY

Appendix I16 - Revelstoke Mt. Begbie Partisol $PM_{2.5}$ and Fire Hall Hi-Vol PM_{10} Data for 2008

($PM_{2.5}$ and PM_{10} in µg/m^3. Continuous (hourly) PM_{10} data are available upon request.)

Month	Day	$PM_{2.5}$	PM_{10}
January	6	26	15
	12	12	15
	18	6.9	7
	24	27	
	30	19	
February	5	25	28
	11	28	18
	17	21	11
	23		9
March	1	5.1	25
	7	22	15
	13	7.4	15
	19	18	12
	25	2	18
April	6	9.2	23
	12	6.7	20
	18	4.5	9
	24	8.2	13
	30		15
May	6	4.9	8
	12	7	14
	18	6.7	22
	24	2.8	8
	30	12	21
June	5	4.3	5
	11	2.2	
	17	2.1	
	23	2.4	4
	29	5.4	8
July	5	4	45
	11	6.4	17
	17	3.8	44
	23	4	8
	29	4.6	2
August	4		8
	10		
	16	6.7	
	22	4.1	
	28	4.8	10
September	3	4.5	
	9	3.8	
	15	7.5	
	21	3	
	27	6.8	
October	3	9.5	23
	9	11	9
	15	14	18
	21	5.4	20
	27	15	17
November	2	9.5	6
	8	10	11
	14	6.2	11
	20	4.7	14
	26	9	7
December	2	8.8	8
	8	6.4	10
	14	12	
	20		5
	26	13	6

ENVIRONMENTAL QUALITY