December 2012

The Burrard Inlet Area Local Air Quality Study

Monitoring Program Results
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Particulate matter and volatile organic compound chemical analysis was performed by staff at Environment Canada’s Environmental Science and Technology Centre in Ottawa. Analysis of speciated particulate matter data was conducted by Keith Jones and Joanna Zhao from Environment Canada’s Pacific and Yukon Region.

Several government partners contribute to the Lower Fraser Valley Air Quality Monitoring Network including: Fraser Valley Regional District, Environment Canada and BC Ministry of Environment. Other partners (Vancouver Airport Authority, Chevron Canada Ltd., BC Hydro, Kinder Morgan Canada, and Port Metro Vancouver) also provide funding for select network stations.

Representatives from Fraser Health Authority, BC Ministry of Environment, Environment Canada, Port Metro Vancouver, and Chevron Canada Ltd. reviewed this report.

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Executive Summary

In its 2005 Air Quality Management Plan, Metro Vancouver committed to “assessing and monitoring possible local air quality priority areas, and where needed, partnering with the appropriate governments, health agencies, the public and owners/operators of emission sources to develop and implement local air quality action plans.” Metro Vancouver identified the Central Burrard Inlet Area (CBIA) as a possible local air quality priority area since a wide variety of air emission sources are situated within this relatively densely-populated area and emissions are expected to increase due to port expansion.

The objectives of the monitoring portion of the Burrard Inlet Area Local Air Quality Study (BIALAQS) were to: a) determine how air quality in the CBIA differs from other parts of Metro Vancouver and the Fraser Valley Regional District, b) determine the spatial and temporal variability of pollutants, and c) provide information that may be used to determine the major sources contributing to air quality levels. The monitoring portion of the BIALAQS was conducted from July 2008 to June 2010 using twelve fixed monitoring sites and one mobile monitoring trailer which rotated between four locations in the CBIA. Information was collected about air pollutants that have been associated with human health impacts including fine particulate matter, sulphur dioxide and nitrogen dioxide. This report provides a detailed summary of the levels of specific air pollutants observed within the CBIA during this study period. Where possible, recommendations have been provided for further action.

In general, the BIALAQS monitoring program concluded that the CBIA experienced unique air quality compared to other areas in Metro Vancouver and the Fraser Valley Regional District. In particular, this study yielded the following conclusions:

a) **The CBIA experienced elevated sulphur dioxide (SO₂) levels.** Average SO₂ concentrations were generally higher at sites closer to the Burrard Inlet. The largest sources of SO₂ in the CBIA are marine vessels and petroleum refining. Pollution roses and diurnal profiles indicate that marine vessels are the likely source of elevated average SO₂ levels at most sites. However, during a winter inversion episode in January 2009, SO₂ concentrations exceeded Metro Vancouver’s 1 and 24-hour SO₂ objectives at the Burnaby-Capitol Hill site for a short period. Elevated SO₂ concentrations were also recorded at other CBIA sites during this episode, but due to the proximity of the Burnaby-Capitol Hill site to a nearby petroleum refinery and the lack of dispersion during this event, it is suspected that the refinery was...
primarily responsible for the short-term SO$_2$ exceedances at the T23 Burnaby-Capitol Hill station.

b) *Fine particulate matter (PM$_{2.5}$) levels were periodically elevated in the CBIA.* PM$_{2.5}$ concentrations exceeded Metro Vancouver’s 24-hour objective at two CBIA sites with standard network monitors during a winter inversion episode and a regional summertime air quality advisory. Several other CBIA sites also recorded exceedances, but these sites employed non-standard monitoring technology with greater uncertainty than the standard network monitors. There were no PM$_{2.5}$ exceedances at any other Lower Fraser Valley (LFV) network stations outside the CBIA during these episodes.

c) *Black carbon levels were slightly elevated in the CBIA.* A component of PM$_{2.5}$, black carbon is often used as an indicator for diesel fuel combustion and/or wood smoke. Black carbon concentrations were slightly higher at the two CBIA sites compared to the only other station monitoring black carbon at the time in Abbotsford. However, these concentrations were only monitored for a short portion of the study.

d) *The CBIA experienced elevated vanadium and nickel levels.* Nickel and vanadium are found in residual/heavy fuel oil burned in ocean-going vessels and are emitted as particles during combustion. Vanadium and nickel levels were significantly higher in the three sets of PM$_{2.5}$ samples collected from CBIA sites.

e) *Nitrogen dioxide (NO$_2$) levels were similar to the rest of the LFV network, with the exception of the Downtown Vancouver site.* Due to its proximity to a major roadway with high traffic volumes, average NO$_2$ concentrations at the Downtown Vancouver site slightly exceeded Metro Vancouver’s annual NO$_2$ objective.

f) *Unique poor air quality episodes occurred within the CBIA.* With a combination of distinctive meteorology, topography and emissions, the CBIA experienced several unique air quality episodes during the study. PM$_{2.5}$ and SO$_2$ concentrations exceeded Metro Vancouver’s short-term air quality objectives at several CBIA sites during four episodes -- two during summer and two during winter. There were no exceedances of Metro Vancouver’s PM$_{2.5}$ or SO$_2$ objectives at any LFV network stations outside the CBIA during these episodes.

Based on these conclusions and other detailed analyses presented in this report, the following actions are recommended:

a) Metro Vancouver should review its ambient air quality objectives for SO$_2$ using the results of Health Canada’s assessment (when complete), the World Health Organization’s guidelines, and input from public and industry stakeholders.
b) Metro Vancouver should continue to work with Port Metro Vancouver and other stakeholders to investigate and implement measures that will reduce SO$_2$ emissions from marine vessel activities. A number of measures are already underway.

c) Metro Vancouver should continue to work with the Chevron Refinery to ensure reliable ambient air quality data communications and routinely review SO$_2$ excursion mitigation procedures.

d) Additional assessment work which should be considered, in collaboration with partners, includes:

- Additional PM$_{2.5}$, speciation and black carbon monitoring within a few CBIA communities using standard instrumentation.
- Enhanced monitoring of SO$_2$, particularly on Port Metro Vancouver lands and adjacent populated communities on the CBIA’s south shore.
- Collection of representative meteorological measurements (including wind speed and direction, air temperature and humidity) within the community where most of the complaints originate.
- Evaluating the value of the Second Narrows station within the LFV network.
- Analysing the speciated volatile organic compound data collected during the BIALAQS.
- Completing additional dispersion modelling to further assess the contribution of emission sources and test the effectiveness of emission reduction strategies.
# Burrard Inlet Area Local Air Quality Study – Monitoring Program Results

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1. Introduction

Emissions of several air contaminants are forecast to rise over the next 15 to 20 years in Metro Vancouver due to growth in population, trade and transportation. To provide current and future generations with healthy, clean and clear air, Metro Vancouver adopts air quality management plans which aim to protect public health, improve visual air quality, and minimize the region’s contribution to global climate change. These plans recognize that even though regional air quality levels may be acceptable, local emission sources may cause air quality to degrade at the neighbourhood or “local” level. Metro Vancouver has committed to assessing and monitoring possible local air quality priority areas, and where needed, partnering with the appropriate governments, health agencies, the public and owners/operators of emission sources to develop and implement local air quality action plans.

The Burrard Inlet Area Local Air Quality Study (BIALAQS) was the first in a series of local air quality studies initiated by Metro Vancouver. The overall purpose of the BIALAQS was to gain a better understanding of the air quality in the Burrard Inlet Area, and provide information that can be used to determine outdoor exposures and associated human health risks. Although BIALAQS includes three key components - an emission inventory, monitoring and modelling - this report discusses the design, findings and conclusions of the air quality monitoring component.

1.1. Background

The Central Burrard Inlet Area (CBIA) covers a large area bounded by Stanley Park to the west, Marine Drive and 3rd Avenue to the north, Chevron Refinery to the east, and Hastings Street to the south. The CBIA includes several communities and emission sources that surround the waters of the central Burrard Inlet. The CBIA was chosen as the subject of this study for several reasons:

- A wide variety of emission sources are situated within this relatively small geographical area. These sources include ocean-going vessels, cruise ships, harbour vessels, non-road engines (including cargo handling and construction equipment), heavy-duty trucks, locomotives, small aircraft, commuter traffic, and industrial sources such as a refinery and bulk shipping terminals, as well as commercial and residential sources. According to the California Air Resources Board, health risks from diesel PM are highest in areas of concentrated emissions,
such as near ports, rail yards, freeways, or warehouse distribution centers (California Air Resources Board 2008).

- According to 2006 Census of Canada data, there are several densely-populated neighbourhoods within the CBIA (Metro Vancouver 2006).
- Port operations are projected to increase in the near future to accommodate anticipated growth in throughput. By 2025, the total Port throughput is expected to be 163% of the 2010 throughput (SNC Lavalin 2012). As a result, emissions from marine vessels and other port sources in the CBIA are expected to increase, which may degrade local air quality.
- Several existing monitoring stations within the CBIA provide a solid baseline to which additional monitoring sites and equipment can be supplemented.
- According to 2006 Census of Canada data, there are several neighbourhoods with a high percentage of elderly persons (over age 65) within the CBIA (Metro Vancouver 2006). Elderly persons are often more susceptible to the harmful effects of air pollution.

1.2. Description of Potential Health Impacts Associated with Air Contaminants

Descriptions of primary air contaminants within the CBIA, as well as the potential human health impacts associated with exposure to these contaminants, are provided below.

1.2.1. Fine Particulate Matter (PM$_{2.5}$)

The term 'PM$_{2.5}$', or fine particulate matter, refers to airborne particles with an aerodynamic diameter of 2.5 micrometres (μm) or less. PM$_{2.5}$ is emitted by a variety of natural and man-made sources and can also be created when other pollutants react in the atmosphere in the presence of sunlight.

PM$_{2.5}$ are small enough to be breathed deeply into the lungs, resulting in impacts to both human respiratory and cardiovascular systems. Short-term exposure to airborne particles at the levels typically found in urban areas in North America is associated with a variety of adverse effects. Particulates can irritate the eyes, nose and throat and cause coughing, breathing difficulties, reduced lung function and an increased use of asthma medication. Exposure to particulates is also associated with an increase in the number of emergency department visits, an increase in hospitalizations of people with cardiac and respiratory disease and in premature mortality (Health Canada 2006).
In many cities Diesel Particulate Matter (DPM – particulate matter from diesel engines) is a significant contributor to PM$_{2.5}$ levels. In 1998, following a 10-year scientific assessment process, California Air Resources Board identified DPM as a toxic air contaminant based on its potential to cause cancer and other health problems, including respiratory illnesses, and increased risk of heart disease. Subsequent to this action, research has shown that DPM also contributes to premature deaths (CARB 2011). The United States Environmental Protection Agency also concluded that diesel exhaust is “likely to be carcinogenic to humans by inhalation” and may damage the lung in other ways depending on exposure (US EPA 2002). In June 2012, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization, classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer (IARC 2012). In Metro Vancouver, DPM is responsible for 67% of the lifetime cancer risk associated with air pollution (Levelton 2007 and Metro Vancouver 2009).

Formed during incomplete combustion, black carbon is the solid fraction of PM$_{2.5}$ that strongly absorbs light and converts that energy to heat. When emitted into the atmosphere and deposited on ice or snow, black carbon can enhance global temperature change, melting of snow and ice, and changes in precipitation patterns (International Council on Clean Transportation 2009). Black carbon is commonly used as an indicator for diesel fuel combustion and/or wood smoke.

PM$_{2.5}$ can also contain ions (such as sulphate and potassium), metals (such as nickel and vanadium) and sugar compounds (such as levoglucosan). Sulphur dioxide can react with other substances in the atmosphere to form sulphates. Nickel and vanadium are found in residual/heavy fuel oil burned in ocean-going vessels and are emitted as particles during combustion. Levoglucosan has been used as a quantitative tracer for biomass burning emissions for several years. However, recent studies have shown that it may not be as stable in the atmosphere as previously assumed due to degradation in the presence of hydroxyl radicals. Although it is also present to some extent in sea salt and crustal matter, the potassium ion is another commonly used marker for biomass burning.

1.2.2. Sulphur Dioxide (SO$_2$)

Sulphur dioxide (SO$_2$) a colourless gas with a pungent odour. SO$_2$ is formed primarily by the combustion of fossil fuels containing sulphur. Marine vessels and the petroleum products industry are the largest sources of SO$_2$ within the CBIA. SO$_2$ also plays a key role in PM$_{2.5}$ formation when it oxidizes and then reacts with ammonia to form ammonium sulphate.
SO₂ can cause breathing problems in people with asthma, but at relatively high levels of exposure. There is some evidence that exposure to elevated SO₂ levels may increase hospital admissions and premature deaths (Health Canada 2006).

1.2.3. Oxides of Nitrogen (NOx)
Oxides of nitrogen (NOx) include nitric oxide (NO) and nitrogen dioxide (NO₂). Both are produced by the high temperature combustion of fossil fuels or biomass. NO is predominant in combustion emissions, and rapidly undergoes chemical reactions in the atmosphere to produce NO₂. NO₂ is a reddish-brown gas with a pungent, irritating odour. Nitrogen oxides play a key role in the formation of smog (ground-level ozone) and secondary PM₂.₅.

At elevated levels, NO₂ can impair lung function, irritate the respiratory system and, at very high levels, make breathing difficult, especially for people who already suffer from asthma or bronchitis (Health Canada 2006).

1.2.4. Carbon Monoxide (CO)
Carbon monoxide (CO) is an odourless gas. The principal human source of CO is fuel combustion, primarily from vehicles.

When inhaled, CO reduces the body’s ability to use oxygen. Health effects associated with relatively low-level, short-term exposure to CO include decreased athletic performance and aggravated cardiac symptoms. At the levels typically found in large cities, CO may increase hospital admissions for cardiac diseases, and there is also evidence of an association with premature deaths (Health Canada 2006).

1.2.5. Ground-Level Ozone (O₃)
A primary component of smog, ground-level ozone is not directly emitted into the atmosphere, but is created when NOx and volatile organic compounds react in the presence of sunlight. Close to emission sources, ozone is quickly consumed by nitric oxide. As a result, ozone concentrations are expected to be lower in areas like the CBIA which contain significant combustion sources.

Ground-level ozone has been linked with a broad spectrum of human health effects. Because of its reactivity, ozone can injure biological tissues and cells. Exposure to ground-level ozone for even short periods at relatively low concentrations has been found to significantly reduce lung function in healthy people during periods of exercise. This decrease in lung function is generally
accompanied by other symptoms including tightness of the chest, pain and difficulty breathing, coughing and wheezing. The data on health effects of ozone have been examined in human epidemiological studies and exposure to ozone has been associated with mortality, hospital admissions, emergency department visits, and other adverse health effects (Health Canada 2006).

1.3. Monitoring Scope and Study Objectives

The air quality monitoring component of the BIALAQS was designed to achieve the following objectives:
1. Determine how air quality in CBIA differs from that in other parts of the Lower Fraser Valley (Metro Vancouver and the Fraser Valley Regional District);
2. Determine the spatial and temporal variability in air quality patterns within the CBIA;
3. Collect data that can provide validation and/or calibration for the study’s air quality modelling;
4. Provide estimates of air quality that can be used to determine population exposure and health risk, if necessary; and
5. Provide information that may be used to determine the major sources contributing to air quality levels within the CBIA, for the purposes of developing action plans, if necessary.

This report will focus on summarizing the monitoring results as they relate to study objectives 1, 2 and 5. Objectives 3 and 4 have already been achieved through the collection of air quality data at various locations throughout the CBIA.
2. Study Design

The two-year BIALAQS monitoring study was conducted using twelve fixed monitoring sites and one mobile monitoring trailer which rotated between four locations. To capture local pollutant variations, new PM$_{2.5}$ sites were placed between existing network monitoring locations. At several locations, gaseous pollutants (NO, NOx, NO$_2$, SO$_2$, and O$_3$) were monitored, grab samples were collected for volatile organic compound analysis, and filters were collected for analysis of ions, metals and levoglucosan. Meteorological observations included wind speed, wind direction, air temperature and relative humidity.

To meet the monitoring outcomes and the overall objectives of BIALAQS, the monitoring component was designed to:

- Fill some PM$_{2.5}$ gaps between existing Lower Fraser Valley network stations;
- Collect information at various locations within each municipality surrounding the central Burrard Inlet (City of Vancouver, City of Burnaby, City of North Vancouver, and District of North Vancouver);
- Capture activities within a range of land-use types and emission activity levels, including both residential and industrial areas;
- Employ instruments with good comparability to instruments utilized within the existing Lower Fraser Valley network;
- Include a variety of instruments and approaches, that include fixed and mobile sites; standard and portable self-contained instruments;
- Focus on the priority air pollutants, including PM$_{2.5}$, criteria gaseous air contaminants (CO, NO$_2$, SO$_2$ and O$_3$) and priority toxis (diesel particulate matter (DPM), benzene, 1,3-butadiene); and
- Partner with other agencies and researchers where appropriate.

2.1. Siting Considerations

Determining appropriate locations for air quality monitoring requires balancing logistical concerns (e.g., access to land, security, access to power, etc.) with scientific criteria (e.g., instrument exposure, representativeness, topography, etc.) to ensure that appropriate and representative air quality measurements would be captured. Sites were selected to provide a better understanding of the spatial and temporal patterns within the CBIA. Interpretation of air
quality measurements recognizes that air quality concentrations are influenced by emissions originating within the area, as well as by pollutants that are transported from adjacent areas within and outside of Metro Vancouver.

Monitoring locations were selected using the following criteria:

**Security**
Security is an important consideration to reduce the risk of damage or theft. Damage or theft increases costs and jeopardizes data completeness. Portable monitoring units were installed on poles, on top of buildings or in buildings where the public had limited access. Non-portable samplers required a weather-proof climate controlled housing and an enclosed, fully secure location. Mobile trailers housed several pieces of expensive monitoring equipment and therefore required additional security, such as a fenced enclosure or a business with security surveillance.

**Power**
Power was required for all monitors and sites. It was often necessary to establish formal agreements with owners and power providers, and infrastructure modifications were sometimes needed prior to instrument deployment. The establishment of some sites was delayed due to additional power requirements.

**Access**
It was critical that monitoring personnel had good access to all sites for equipment set-up, operation, routine maintenance and regular equipment servicing. Access was secure for staff yet restrictive for the public. Whether equipment was located on the roof of a building, within a structure, or on a pole, access met applicable B.C. safety codes.

**Topography**
The influence of topography was considered in site selection with respect to its potential impact on wind flow patterns and pollutant dispersion within the CBIA.

**Demographics**
As the BIALAQS monitoring program may provide data for future exposure and human health risk studies, demographics played an important role in site selection. CBIA sites were generally situated in areas with high population density. Four existing sites (T4 Kensington Park, T26 Mahon Park, T23 Burnaby-Capitol Hill, T24 North Burnaby) and three new monitoring sites were situated in residential areas (S2 MacLean Park, S3 Pandora Park, and S6 Norgate).
Residents in all of these areas have historically expressed concerns about local air emissions and their impact upon resident health and well-being. One site (S2 MacLean Park) was specifically situated in the neighbourhood of Strathcona which has a high proportion of elderly residents. The T1 Downtown Vancouver station was included in the BIALAQS since the population density in this area is very high (mostly high rise buildings) and rapid population growth is expected in this area over the next decade.

**Proximity to sources**

To gain a better understanding of air quality and associated health risks within a given area, a variety of locations were selected that were relatively close to emission sources and a known population. Care was taken to site fixed monitors in locations that were indicative of human exposure whenever possible.

Mobile trailer locations were situated in areas closer to the Burrard Inlet and emission sources to assist with the identification of local “hot spots”. It should be noted that concentrations observed at trailer locations do not necessarily represent resident exposure levels.

All of the criteria stated above were considered and the final monitoring locations were determined by balancing these factors. Certain sites were ruled out as not suitable from a scientific perspective and others were ruled out based on lack of power or access. The final set of monitoring sites meets all of these siting criteria.

### 2.2. BIALAQS Monitoring Sites

The geographic scope of the BIALAQS is shown on the Figure 1. The study covers a large area roughly bounded by the Lions Gate Bridge to the west, the TransCanada Highway to the north, Chevron Refinery to the east, and Hastings Street to the south. A complete listing of sites, locations, classifications and parameters for each site is presented in Table 1.

The BIALAQS air quality monitoring program utilized twelve fixed sites and one mobile trailer which rotated between four different locations. The twelve fixed sites included six existing network sites and an additional six sites established for this study. As illustrated in Figure 1, the monitoring sites have been grouped by the following categories:
Master Sites

Three sites - S6 Norgate, T6 Second Narrows and T4 Kensington Park - continuously monitored fine particulate matter, gaseous contaminants and meteorological parameters. The T6 Second Narrows and T4 Kensington Park sites are part of the existing Lower Fraser Valley (LFV) network while the S6 Norgate site was added for this study. T6 Second Narrows and S6 Norgate also included instruments that collected particulate matter on 47 mm filters. In the laboratory some of these filters were later analyzed for metals, ions and levoglucosan.

Particulate Matter Sites

Four sites - S1 Vancouver Yacht Club, S2 MacLean Park, S4 Lynn Pump Station and S5 BCIT Marine Campus - were equipped with portable continuous PM$_{2.5}$ monitors (E-samplers) and 47 mm filters. Three sets of the filters were sent to Environment Canada’s Environmental Technology Centre (ESTC) in Ottawa for metals, ions, and levoglucosan detection.

Enhanced Site

One site - S3 Pandora Park, located in east Vancouver - was equipped with a continuous PM$_{2.5}$ monitor (E-Sampler) and gaseous samplers near a public playground.

Mobile Trailer Sites

A mobile monitoring trailer was parked at four different locations during the study. The four locations included S7 Lynn Pump Station MT, S8 Lonsdale Seabus MT, S9 Harbour/Clark Drive MT and S15 Heliport MT. The monitoring trailer rotated between sites every three to four weeks. The trailer was equipped with continuous PM$_{2.5}$ (TEOM), black carbon, gaseous samplers and meteorological instrumentation.

Existing Lower Fraser Valley (LFV) Network Sites

Four existing LFV network monitoring sites are situated within the CBIA including T1 Downtown Vancouver, T26 Mahon Park, T23 Burnaby-Capitol Hill and T24 Burnaby North. These existing sites only monitored gaseous contaminants and some meteorology. T4 Kensington Park and T6 Second Narrows are also existing network stations, but they have been classified as “Master Sites” for the purpose of this study.
* T4 Kensington Park and T6 Second Narrows are also existing LFV network stations.
## Burrard Inlet Area Local Air Quality Study – Monitoring Program Results

### Table 1: Air Quality Monitoring in the CBIA

<table>
<thead>
<tr>
<th>CBIA Sites</th>
<th>Air Quality Monitors</th>
<th>Meteorological Monitors</th>
<th>Duration*</th>
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<td><strong>PM2.5 (TEOM)</strong></td>
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<td>Second Narrows (Riverside Drive, District of North Vancouver)</td>
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<td>Lonsdale Seabus Mobile Trailer (Seabus Terminal, City of North Vancouver)</td>
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<tr>
<td>S9</td>
<td>Harbour/Clark Drive Mobile Trailer (Harbour Pump Station, Vancouver)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>S15</td>
<td>Heliport Mobile Trailer (Helijet Terminal, Vancouver)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Existing LFV network sites</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>Downtown Vancouver (Robson Square, Vancouver)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T23</td>
<td>Burnaby-Capitol Hill (Capitol Hill, North Burnaby)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T24</td>
<td>Burnaby North (Burnaby Heights, North Burnaby)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T26</td>
<td>Mahon Park (Mahon Park, City of North Vancouver)</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

PM<sub>2.5</sub> (E-sampler/TEOM) = fine particulate matter by E-sampler or Tapered Element Oscillating Microbalance method; PM<sub>10</sub> = inhalable particulate matter (TEOM); SO<sub>2</sub> = sulphur dioxide; BC = Black carbon (ethalometer); NO<sub>2</sub> = nitrogen dioxide; TRS = total reduced sulphur; CO = carbon monoxide; O<sub>3</sub> = ozone; THC = Total Hydrocarbons; VOC = volatile organic compounds; Ions/Metals/Levo = ions, metals and levoglucosan in PM<sub>2.5</sub> (3 sets of E-sampler filters); Wind = wind speed and wind direction; T = air temperature; SR = solar radiation; RH = relative humidity

✔ = monitored at this location

* Duration is for the first monitor listed. Other monitors may have been installed after this date.
2.3. Study Period

Air quality monitoring portion of BIALAQS was conducted between July 4, 2008 and June 30, 2010. The majority of the fixed sites were operational in July 2008, with the exception of S3 Pandora Park, S1 Vancouver Yacht Club and S6 Norgate. It took longer than anticipated to secure permission, access and power at these three locations. S3 Pandora Park (Enhanced Site) was fully operational in August 2008 while S6 Norgate (Master Site) and S1 Vancouver Yacht Club (PM Site) were not established until April 2009. The mobile trailer started a rotating schedule between the mobile trailer sites in January 2009. Table 1 summarizes the instrumentation and operational dates for each site.

2.4. Monitoring Equipment

Each air quality monitoring station consisted of air quality monitors, meteorological instrumentation and a data logging system with remote polling capabilities. Three types of monitoring sites were utilized in the study: 1) fixed sites that employed equipment requiring climate controlled housing (e.g., a building or trailer), 2) fixed sites that employed portable equipment that was self-sufficient, lightweight and easily deployable, and 3) a mobile trailer that was moved from location to location.

2.4.1. Master and Network Sites

The Master and Network Sites consisted of an air conditioned trailer or room in a building that provided a secure, climate controlled environment. The air quality monitors were installed inside with sample tubes extending out of the trailer/building roof where air was sampled above roof height.

The continuous air quality monitors at most of these sites consisted of gaseous samplers to measure NO, NOx, NO2, SO2, CO and O3, and a Tapered Element Oscillating Microbalance (TEOM) to measure PM2.5. A TEOM, E-Sampler and aethalometer (to measure black carbon) were co-located at the S6 Norgate and T6 Second Narrows sites.
Meteorological instruments were mounted on a mast at each station\(^1\) with a wind gauge mounted at the top of the mast and an air temperature probe housed in a radiation shield and mounted midway or near the top of the mast. Wind speed, wind direction and air temperature were measured at most of the Master and Network Sites. Some also measured relative humidity.

Continuous air quality and meteorological measurements were logged by computer at each station. A modem was connected to the computer and was polled remotely on a regular basis throughout the day. Data were then stored and archived offsite at Metro Vancouver offices.

Data were subjected to quality assurance and quality control procedures as outlined in Section 2.5.

Non-continuous air quality measurements were also collected at several sites. Volatile organic compounds (VOCs) were sampled by canisters at four sites. The air was collected in a canister for 24 hours every 3 or 6 days. As with all VOC monitoring across Canada, canister preparation, analyses and reporting was conducted by the Environmental Science and Technology Centre (ESTC) using nationally accepted methods and procedures. Canister samples were tested for over 150 VOC compounds.

PM\(_{2.5}\) was also collected on the E-sampler’s 47-mm quartz filters. Each E-sampler was adjusted against the co-located TEOMs at the S6 Norgate and T6 Second Narrows sites and rotated to the Particulate Matter sites. In addition, E-sampler filters were sent to Environment Canada’s ESTC in Ottawa for metals, ions, and levoglucosan detection.

### 2.4.2. Particulate Matter Sites

The four particulate matter (PM) sites (S1 Vancouver Yacht Club, S2 MacLean Park, S4 Lynn Pump Station, and S5 BCIT Marine Campus) each consisted of an E-Sampler PM\(_{2.5}\) monitor, meteorological instruments, and communications modem. The E-Sampler was selected for these sites since it was portable, self-contained, relatively inexpensive, required little infrastructure support, and compared well to the TEOM during a short side-by-side comparison study conducted at Metro Vancouver’s monitoring shop. Though the TEOM has been Metro Vancouver's network standard continuous PM\(_{2.5}\) monitoring instrument since 1995, Metro Vancouver purchased seven of the lower-cost E-Samplers to improve spatial coverage

\(^{1}\) With the exception of T1 Downtown Vancouver as the configuration of this site does not facilitate representative meteorological observations.
throughout the CBIA. However, it should be noted that the E-Sampler and the TEOM measure particulate matter using different methodologies, and as such the readings are not always directly relatable, particularly during humid conditions. Metro Vancouver staff periodically rotated each E-sampler to either T6 Second Narrows or S6 Norgate and adjusted the data against the co-located TEOMs, but care should be taken when comparing the E-Sampler results to the other LFV network stations.

Each E-Sampler collected integrated samples on 47-mm quartz filters for set periods of time (typically 2-3 weeks). The filters were sent to Environment Canada’s ESTC in Ottawa for metals, ions, and levoglucosan detection.

In addition to providing continuous PM$_{2.5}$ measurements, the E-sampler also allowed for the collection of particulates on a filter. Each E-Sampler collected integrated samples on 47-mm quartz filters for set periods of time (typically 4-6 weeks). The filters were sent to Environment Canada’s ESTC in Ottawa for metals, ions, and levoglucosan detection.

Each of the PM sites utilized a wind gauge, air temperature and relative humidity probe housed in a radiation shield. The wind gauge and temperature probe were mounted off a short boom extending from the E-Sampler. Wind and air temperature measurements at these sites are likely influenced to some extent by the structures they are mounted on.

Continuous air quality and meteorological measurements were logged with the E-Sampler’s internal data logger and connected to a modem which was polled remotely on a regular basis throughout the day. Data were then stored and archived offsite at Metro Vancouver offices. Data were subjected to rigorous quality assurance and quality control procedures as outlined in Section 2.5.

The siting characteristics of each E-Sampler were slightly different at the four locations. At the S1 Vancouver Yacht Club, the E-Sampler was mounted on a vertical post extending several meters above a wharf over the water of Coal Harbour. The S2 MacLean Park E-Sampler was mounted on a vertical fixture on the roof of the caretaker’s house in the park near a playground. The S4 Lynn Pump Station E-Sampler was mounted on a tripod on the roof of a one-story pump station. At S5 BCIT Marine Campus, the E-Sampler was mounted on a vertical post on the roof of a three-story building.
2.4.3. Enhanced Site

The Enhanced Site (S3 Pandora Park) was equipped with the same equipment as the PM sites with the addition of an Airpointer gaseous analyzer. An E-Sampler and Airpointer were mounted on a vertical post attached to the roof of the caretaker’s house within Pandora Park in East Vancouver. The Airpointer is a self-contained, portable system requiring little infrastructure support. Continuous NO, NO\textsubscript{x}, NO\textsubscript{2}, SO\textsubscript{2}, CO and O\textsubscript{3} were measured by the Airpointer while PM\textsubscript{2.5} was measured by an E-Sampler. The Airpointer’s gaseous samplers employed standard network detection methods. Meteorological measurements observed at this site include wind speed and direction, air temperature and relative humidity. The wind gauge and temperature probe housed in a radiation shield were mounted on a short boom extending from the E-Sampler.

As with the PM sites, integrated samples of particulate were collected on 47-mm quartz filters at this site using the E-Sampler. Filters were sent to Environment Canada’s ESTC in Ottawa for metals, ions, and levoglucosan detection.

Continuous air quality and meteorological measurements were logged with the Airpointer’s internal data logger and connected to a modem which was polled remotely on a regular basis throughout the day. Data were then stored and archived offsite at Metro Vancouver offices. Data were subjected to rigorous quality assurance and quality control procedures as outlined in Section 2.5.

2.4.4. Mobile Trailer Sites

A mobile trailer was located at four different sites during the study (S7 Lynn Pump Station, S8 Lonsdale Seabus, S9 Harbour/Clark Drive and the S15 Heliport). The mobile trailer provided a portable, climate-controlled environment which was towed by a truck to four different locations. The trailer was outfitted with air quality sampling equipment and meteorological instruments. Sample tubes were extended out of the roof and air was sampled above roof height.

The continuous air quality monitors housed in the trailer consisted of gaseous samplers to measure NO, NO\textsubscript{x}, NO\textsubscript{2}, and SO\textsubscript{2}, a TEOM to measure PM\textsubscript{2.5} and an aethalometer to measure black carbon. Wind speed and direction was observed by a wind gauge and outdoor air temperature was observed by a temperature probe housed in a radiation shield. The wind gauge was mounted at the top of a telescoping mast with the radiation shield mounted midway on the mast.
Continuous air quality and meteorological measurements were logged by computer situated inside the trailer. A modem was connected to the computer and was polled remotely on a regular basis throughout the day. Data were then stored and archived offsite at Metro Vancouver offices. Data were subjected to rigorous quality assurance and quality control procedures as outlined in Section 2.5.

2.5. Quality Assurance and Quality Control

Air quality and meteorological data were collected in accordance with approved Methods and Standard Operating Procedures (Metro Vancouver’s Air Quality Monitoring Program and Environment Canada’s National Air Pollution Surveillance Program) for most instruments. Exceptions included the aethalometer and E-Sampler, which were relatively new instruments that had not been used previously by Metro Vancouver or within other Canadian air quality monitoring networks. These instruments were operated according to the manufacturer’s instructions and by the best judgement of Metro Vancouver’s experienced air quality and instrument technicians.

Air quality technicians visited the sites on a regular schedule to perform checks on all air quality and meteorological instruments and associated equipment. Visual instrument/equipment checks, verification of operating parameters, zero and spanning of gaseous monitors, routine maintenance and data review were undertaken during these visits. Any issues or problems were corrected and documented on check/log sheets and on the electronic logbook, and in some cases brought to the attention of instrument technicians to perform repairs. Through Metro Vancouver’s data acquisition system, technicians also checked remotely on instruments prior to site visits. This system also allowed calibration of the instruments either automatically or upon demand. Automatic zero and span checks were conducted by the computer on every fourth day. In addition the instruments were subject to performance audits on a quarterly schedule during the study period, after instruments were deployed, and finally at the end of the study.

Air quality monitoring data were subject to validation procedures to ensure that the recorded data were valid and accurate and not a result of any problems in any part of the measurement system. For hourly data and associated status flags assigned by the data acquisition system, reviews were conducted every weekday, monthly and annually. Thus three reviews, typically by three separate technicians, were undertaken for most data collected as part of this study.
2.6. Study Limitations

Air quality monitoring studies are typically limited by a finite number of monitoring locations which represent a variety of spatial scales. A monitoring site may represent a spatial scale ranging from neighbourhood or local to regional, depending on its proximity to an emission source. An examination of nearby emission sources and interpretation of air quality measurements are needed to gain an understanding of the spatial scale of a particular monitoring site. Although Metro Vancouver staff made a conscious effort to choose monitoring locations that represented similar spatial scales, some sites were closer to emission sources than others. For example, at the S6 Norgate site, an unforeseen emission source influenced air quality measurements. After the site was established, it was discovered that fire trucks were idling close to the air intake during routine morning safety checks. Although pollutant levels were elevated during a one to two hour period every day, these elevated readings do not represent residential exposure levels. Therefore, care must be taken to consider unusual readings like these when comparing air quality at this site to other locations.

Two different particulate matter monitors, TEOM and E-Sampler, were used in the BIALAQS. Data from these monitors are not always relatable. The E-Sampler was selected to be deployed at several sites since it is portable, self-contained, relatively inexpensive, and requires little infrastructure support. Though the TEOM has been Metro Vancouver’s standard network continuous PM$_{2.5}$ monitoring instrument since 1995, Metro Vancouver purchased seven of the lower-cost E-Samplers to provide better spatial coverage throughout the CBIA. However, it should be noted that the E-Sampler and the TEOM measure PM$_{2.5}$ using different methodologies, and as such the readings are not always relatable, particularly during humid conditions.

2.7. CBIA Emissions

A wide variety of emission sources operate within the CBIA including ocean-going vessels, cruise ships, harbour vessels, non-road engines (e.g., cargo handling and construction equipment), heavy-duty trucks, locomotives, small aircraft, commuter traffic, commercial and residential buildings, and industrial sources such as a refinery and bulk shipping terminals. Table 2 provides a summary of the largest emission sources in the CBIA.
Table 2: Largest Emission Sources in the CBIA

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emission sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{PM}_{2.5} )</td>
<td>Marine vessels, non-road engines, building heating, bulk shipping terminals</td>
</tr>
<tr>
<td>Diesel PM</td>
<td>Marine vessels, non-road engines, locomotives, heavy-duty vehicles</td>
</tr>
<tr>
<td>Black carbon</td>
<td>Diesel fuel combustion, wood smoke</td>
</tr>
<tr>
<td>( \text{SO}_2 )</td>
<td>Marine vessels, petroleum refinery, biogenic oxidation of marine dimethyl sulphide</td>
</tr>
<tr>
<td>( \text{NO}_x )</td>
<td>Marine vessels, non-road engines, light-duty vehicles, industrial facilities</td>
</tr>
<tr>
<td>CO</td>
<td>Light-duty vehicles, non-road engines</td>
</tr>
</tbody>
</table>

Some of these sources, like on-road vehicles and non-road engines, are also present outside the CBIA, while others, such as a petroleum refinery, are unique to this area. Although the closest emission sources are not always the main contributors to air pollutant levels at a given location, they provide a starting point for further investigation. Table 3 provides information about the emission sources that are adjacent to the BIALAQs monitoring sites.

Table 3: Significant Emission Sources within One Kilometre of the CBIA Sites*

<table>
<thead>
<tr>
<th>Monitoring Location</th>
<th>Significant Emission Sources</th>
<th>Distance from Site (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring Location</td>
<td></td>
<td>&lt; 50</td>
</tr>
<tr>
<td>ID</td>
<td>Station Name</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>Vancouver Yacht Club</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marina (pleasure crafts, passenger ships)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Floatplane terminal (Seaplanes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Major roadway (Highway 99)</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>MacLean Park</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple rail yards (trains)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port terminal (Containers, wood pulp)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ocean-going vessels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cruise ship terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Major roadway (Prior and Hastings Streets)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Residential heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>S3</td>
<td>Pandora Park</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Major roadway (Nanaimo and Hastings Streets)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rail yard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concrete batch plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marco Marine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agricore United (bulk products)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ocean-going vessels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>West Coast Reduction (rendering plant)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Port terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Residential and commercial heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>S4</td>
<td>Lynn Pump Station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neptune Terminals (Coal, Potash, Agri-bulk, vegetable oils)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Port terminal (Wood Products, Smelter Products)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Saskatchewan Wheat Pool (Grain)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rail yard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck route (East 3rd Street and Low Level Road)</td>
<td>x</td>
</tr>
<tr>
<td>Monitoring Location</td>
<td>Significant Emission Sources</td>
<td>Distance from Site (m)</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>ID</td>
<td></td>
<td>$&lt; 50$</td>
</tr>
<tr>
<td>S5</td>
<td>Ocean-going vessels</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Residential heating (natural gas and possibly wood)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BCIT Marine Campus</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Marina (pleasure crafts)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Seabus terminal (passenger ships)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ocean-going vessels</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>Vancouver Drydock</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Railway</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Residential and commercial heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>S6</td>
<td>Norgate</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Firehall (idling fire trucks)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>West Vancouver bus depot (idling buses and bus movements)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Seaspan</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Fibreco (wood chips)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rail yard</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Residential /commercial heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>T1</td>
<td>Downtown Vancouver</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Major roadway (Robson and Hornby Streets)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Cruise ship terminal (Canada Place)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Marina (pleasure craft)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Floatplane terminal (Seaplanes)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rail yard</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Seabus terminal (passenger ships)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Building heating (natural gas)</td>
<td>x</td>
</tr>
<tr>
<td>T4</td>
<td>Kensington Park</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Major roadway (Hastings Street)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Shell Canada</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Residential heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>T6</td>
<td>Second Narrows</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Northshore Recycling Depot/Transfer Station</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Traffic line-up for Northshore Recycling Depot/Transfer Station</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Nexen Manufacturing Plant (Salt, Caustic Soda, Chlorine)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>BA Blacktop Limited (Asphalt Plant)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ocean Construction (Concrete Batch Plant)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rempel Bros. Concrete (Concrete Batch Plant)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Rail yard</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Ocean-going vessels (dockside, manoeuvring and underway)</td>
<td>x x x x</td>
</tr>
<tr>
<td></td>
<td>Marina (pleasure crafts and passenger ships)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Dow Chemicals (Caustic soda, ethylene glycol, ethylene dichloride)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Port terminal (Wood Products, Smelter Products)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Major roadway (Second Narrows Bridge/Hwy 1 and Dollarton)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Chevron Refinery</td>
<td>x x x x</td>
</tr>
<tr>
<td>T23</td>
<td>Burnaby Capitol Hill</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Chevron Refinery</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>Residential heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
</tbody>
</table>
2.8. Complaints

Metro Vancouver receives public air quality complaints through the Air Quality Hotline and website. Information about each complaint is logged and an enforcement officer is assigned to follow up with the complainant for further investigation, if necessary. Officers use a combination of site visits, wind direction analysis, their knowledge about facility operations, presence of other possible sources, and complainant experience to assess the probable source. However, it is not always possible to confirm the source with absolute certainty.

During the study period (July 4, 2008 to June 30, 2010) Metro Vancouver received roughly 1,500 complaints within the CBIA. This unusually high volume of complaints reflects the fact that:

- There are many densely-populated neighbourhoods within the CBIA,
- Several industrial operators are acknowledging their potential to cause impacts and actively engaging adjacent communities, and
- Several resident associations are concerned about air quality in these communities.

Figure 2 shows the locations of the top six sources of complaints to Metro Vancouver within the CBIA. As illustrated in Table 4, the majority of these complaints (86%) were associated with odours and 48% of all odour complaints were attributed to a rendering plant (West Coast Reduction) located at the north end of Commercial Drive in east Vancouver.
Burrard Inlet Area Local Air Quality Study – Monitoring Program Results

Figure 2: Locations of the Top Six Probable Sources* of Complaints in the CBIA.

Table 4: Complaints in the CBIA from July 4, 2008 to June 30, 2010.

<table>
<thead>
<tr>
<th>Probable source*</th>
<th>Number of complaints</th>
<th>Odours</th>
<th>Visible (smoke, fume, dust) or particulate</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Coast Reduction Ltd.</td>
<td>672</td>
<td>100%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unknown</td>
<td>447</td>
<td>86%</td>
<td>13%</td>
<td>1%</td>
</tr>
<tr>
<td>Polonia Sausage House/Bakery</td>
<td>114</td>
<td>42%</td>
<td>58%</td>
<td>-</td>
</tr>
<tr>
<td>Chevron Canada Limited</td>
<td>79</td>
<td>95%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>Hallmark Poultry Processors Ltd.</td>
<td>57</td>
<td>100%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fibreco Export Inc.</td>
<td>31</td>
<td>6%</td>
<td>94%</td>
<td>-</td>
</tr>
<tr>
<td>Newalta Corporation</td>
<td>26</td>
<td>100%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Households</td>
<td>14</td>
<td>20%</td>
<td>80%</td>
<td>-</td>
</tr>
<tr>
<td>Other sources (fewer than 4 complaints each)</td>
<td>76</td>
<td>42%</td>
<td>53%</td>
<td>4%</td>
</tr>
<tr>
<td>Total</td>
<td>1,516</td>
<td>86%</td>
<td>13%</td>
<td>1%</td>
</tr>
</tbody>
</table>

* A “Probable source” is attributed following complaint investigation by Metro Vancouver’s Permitting and Enforcement Officers.

In response to ongoing concerns regarding odour from the West Coast Reduction Ltd. rendering plant, Metro Vancouver’s Regulation and Enforcement division continues to work with West Coast Reduction to mitigate odorous emissions from this facility. As part of its commitment to work with Metro Vancouver to reduce odour impacts on surrounding communities, West Coast Reduction Ltd. requested an amendment to its GVRD Air Quality Management Permit in June 2011. In response, the GVRD District Director amended the permit in November 2011 to authorize upgraded control works on one of the major emission sources. The amendment also
included requirements to measure, assess, and formulate a systematic approach for the remainder of the facility to further reduce the company’s odour impact on surrounding communities.

Unfortunately, odour detection is subjective and odours are not easily monitored. Although some odourous compounds are monitored at T23 and T24 there are no health-based objectives or guidelines for these compounds. For these reasons, the BIALAQS focussed on monitoring PM$_{2.5}$, SO$_2$, and NOx which can result in greater human health impacts.
3. Results

This section summarizes the levels of outdoor pollutants observed at the BIALAQS monitoring sites from July 2008 to June 2010, focussing on pollutants that are typically of concern from a health perspective – PM$_{2.5}$, SO$_2$, NOx, CO and O$_3$. Black carbon is also discussed as an indicator for diesel fuel and/or biomass combustion. A summary of Environment Canada’s PM$_{2.5}$ speciation analysis is also provided in Section 3.3.1 (the full report appears in Appendix B) and a summary of the mobile trailer data follows in Section 3.3.2 (details in Appendix C).

This section is divided into four parts: 1) a comparison of measurements taken within the CBIA to those in the rest of the Lower Fraser Valley network, 2) a discussion of diurnal trends in CBIA, 3) a discussion of four episodes where pollutant levels likely exceeded Metro Vancouver’s air quality objectives within the CBIA, and 4) a summary of additional analyses – PM$_{2.5}$ speciation and mobile trailer data.

3.1. Comparison of CBIA Sites to Other Lower Fraser Valley Network Stations

The first objective of the BIALAQS monitoring program was to determine how air quality within the CBIA differs from that in other parts of the Lower Fraser Valley. In the following subsections, pollutant concentrations measured at CBIA sites are presented alongside data from other LFV network stations. Table A1 in Appendix A provides additional information about levels at each location over the entire monitoring period.

3.1.1. PM$_{2.5}$ Comparison

As illustrated in Figure 3a, none of the CBIA sites were above (i.e., exceeded) Metro Vancouver’s annual PM$_{2.5}$ objective of 8 μg/m$^3$. However, it appears that PM$_{2.5}$ levels may be slightly elevated within the CBIA compared to other LFV network stations. Annually-averaged PM$_{2.5}$ concentrations at CBIA sites ranged from 4.8 to 5.6 μg/m$^3$, while other LFV network stations experienced annually-averaged PM$_{2.5}$ levels from 3.6 to 5.1 μg/m$^3$. 

December 2012
As illustrated in Figure 3b, Metro Vancouver’s 24-hour PM$_{2.5}$ objective$^2$ (25 μg/m$^3$) was exceeded at most sites within the CBIA. Exceedances at T6 Second Narrows and T4 Kensington Park were measured with the standard network monitor (TEOM), but the other PM$_{2.5}$ exceedances at CBIA sites were measured using the non-standard E-Sampler.

Several PM$_{2.5}$ exceedances occurred during an episode in January 2009, before the S1 Vancouver Yacht Club and S6 Norgate sites were established, so it is possible that exceedances could also have occurred at these sites during that episode. Most CBIA sites experienced the highest PM$_{2.5}$ levels during four distinct episodes in 2009. These episodes are described in Section 3.4.

Figure 4 displays seasonal trends with monthly PM$_{2.5}$ averages plotted as symbols and lines for CBIA sites. For comparison, a blue band illustrates the range of concentrations at other LFV network stations that measured PM$_{2.5}$.

As illustrated in Figure 4, PM$_{2.5}$ levels within CBIA were similar to those measured at other LFV network stations with several exceptions in the winter and summer. During the months of January and December in 2009, all CBIA sites (with the exception of T4 Kensington Park) experienced higher averages than sites outside the CBIA. These higher monthly averages likely resulted from stagnant meteorological winter-time conditions that persisted in the CBIA. Two wintertime events are described in more detail in Section 3.4.

In the summer of 2008, T6 Second Narrows measured higher PM$_{2.5}$ concentrations than other LFV network stations. Many of the other CBIA sites were not established yet. During the summer of 2009, S5 BCIT Marine Campus, S4 Lynn Pump Station, T6 Second Narrows, and S3 Pandora Park measured higher concentrations than other LFV network stations.

PM$_{2.5}$ levels at the S1 Vancouver Yacht Club site were lower than sites outside the CBIA in early spring and summer of 2009. Overall, PM$_{2.5}$ levels were consistently higher at S2 MacLean Park and S3 Pandora Park (while they were operational), especially in the first half of 2010. PM$_{2.5}$ levels at T6 Second Narrows were also higher most of the time as this site was located in an industrial setting. T6 Second Narrows is situated near several particulate matter emission sources including an asphalt plant (within 250 m), two concrete batch plants (within 750 m), a

$^2$ Compliance with Metro Vancouver’s 24-hour PM$_{2.5}$ objective is determined using 24-hour rolling averages. Rolling averages are calculated for every 24-hour interval (not just midnight to midnight). Therefore, there are twenty four 24-hour rolling averages for each day. Exceedances of the 24-hour objective are reported as having occurred over the duration of “X” hours.
Burrard Inlet Area Local Air Quality Study – Monitoring Program Results

major port and ocean-going vessels (within 1 km), and multiple unpaved surfaces that are active with vehicles and non-road equipment.
Figure 3a: Annual average PM$_{2.5}$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010. Annual bars are shown for each site only if hourly data were available for over 75% of the year.

Figure 3b: 24-hour rolling average PM$_{2.5}$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010. *PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Figure 4: Monthly average PM$_{2.5}$ concentrations at CBIA sites (symbols and lines) and other LFV network stations (blue band).

* PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).

**Other LFV network stations that monitor PM$_{2.5}$ (TEOM): T2, T9, T12, T18, T20, T27, T29, T31, T34 and T35
3.1.2. SO₂ Comparison

As illustrated in Figure 5a, none of the CBIA sites exceeded Metro Vancouver’s annual SO₂ objective of 12 ppb. However, several CBIA sites experienced elevated SO₂ concentrations compared to other LFV network stations. Annually-averaged SO₂ concentrations at CBIA sites ranged from 1.4 to 5.8 ppb, while other LFV network stations experienced annually-averaged SO₂ levels from 0.4 to 1.9 ppb. S3 Pandora Park experienced the highest annually-averaged SO₂ concentrations, followed by T1 Downtown Vancouver and T23 Burnaby-Capitol Hill.

As illustrated in Figure 5b, SO₂ levels exceeded Metro Vancouver’s 1-hour objective at one location (T23 Burnaby-Capitol Hill) for one hour on January 17th, 2009. The 24-hour SO₂ objective was also exceeded at this station on January 17-18th, 2009 for a total of five hours. The sources of the elevated SO₂ concentrations at T23 Burnaby-Capitol Hill and S3 Pandora Park are investigated in Section 3.4.1. CBIA sites experienced higher hourly average SO₂ concentrations than other LFV network stations, with the exception of T9 Port Moody, which is located on the far east side of the Burrard Inlet area, but outside the CBIA.

In 2011, the City of Vancouver set a goal in their Greenest Action City Plan to always meet or beat the most stringent air quality guidelines from Metro Vancouver, British Columbia, Canada, and the World Health Organization. The WHO recommends a daily SO₂ guideline of 7.7 ppb (20 μg/m³) which is more stringent than BC, Metro Vancouver or Canadian SO₂ objectives. As shown in Table 5, SO₂ levels exceeded the WHO’s daily SO₂ guideline at all sites within the CBIA except T26 Mahon Park. SO₂ levels also exceeded this guideline at T2 Kitsilano which is located close to several marine vessel anchorage points in English Bay, as well as T9 Port Moody which is close to Pacific Coast Terminals. The main sources of SO₂ emissions in the LFV are marine vessels and a petroleum refinery, so it is not surprising that elevated SO₂ concentrations were measured at most CBIA sites.

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3 Compliance with Metro Vancouver’s 24-hour SO₂ objective is determined using 24-hour rolling averages. Rolling averages are calculated for every 24-hour interval (not just midnight to midnight). Therefore, there are twenty four 24-hour rolling averages for each day. Exceedances of the 24-hour objective are reported as having occurred over the duration of “X” hours.
Figure 5a: Annual average SO$_2$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010. Annual bars are shown for each site only if hourly data were available for over 75% of the year.

Figure 5b: Hourly average SO$_2$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010.
Table 5:  Exceedances of daily average WHO SO₂ guideline⁴ at CBIA sites and other LFV network stations – July 2008 to June 2010

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>July 2008 to June 2009</th>
<th>July 2009 to June 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exceedances of the WHO daily SO₂ guideline (number of days)</td>
<td>Data completeness</td>
</tr>
<tr>
<td>S3 Pandora Park</td>
<td>89</td>
<td>90%</td>
</tr>
<tr>
<td>T1 Downtown Vancouver</td>
<td>22</td>
<td>100%</td>
</tr>
<tr>
<td>T23 Burnaby - Capitol Hill</td>
<td>15</td>
<td>100%</td>
</tr>
<tr>
<td>T24 North Burnaby</td>
<td>19</td>
<td>100%</td>
</tr>
<tr>
<td>T6 Second Narrows</td>
<td>8</td>
<td>100%</td>
</tr>
<tr>
<td>T4 Kensington Park</td>
<td>5</td>
<td>100%</td>
</tr>
<tr>
<td>S6 Norgate</td>
<td>0</td>
<td>24%</td>
</tr>
<tr>
<td>T26 Mahon Park</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>T2 Kitsilano</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>T9 Port Moody</td>
<td>7</td>
<td>98%</td>
</tr>
<tr>
<td>T12 Chilliwack</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>T17 Richmond</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>T18 South Burnaby</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>T20 Pitt Meadows</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>T27 Langley Township</td>
<td>0</td>
<td>99%</td>
</tr>
<tr>
<td>T31 YVR</td>
<td>0</td>
<td>99%</td>
</tr>
<tr>
<td>T33 Abbotsford</td>
<td>0</td>
<td>99%</td>
</tr>
<tr>
<td>T34 Abbotsford Airport</td>
<td>0</td>
<td>96%</td>
</tr>
</tbody>
</table>

Sites in italics are located outside the CBIA.

Monthly SO₂ averages are plotted in Figure 6. It is evident that CBIA sites generally experience higher SO₂ concentrations than other LFV network stations. Specifically, five sites - S3 Pandora Park, T1 Downtown Vancouver, T23 Burnaby-Capitol Hill, T24 Burnaby North and T6 Second Narrows - experienced higher SO₂ levels than other LFV network stations. These five CBIA sites are located within one kilometre of a marine/port area or a refinery. Overall, the S3 Pandora Park site experienced the highest monthly averages with the highest levels measured in July 2009. Monthly SO₂ averages at the S3 Pandora Park were nearly double those measured at

⁴ The World Health Organization’s (WHO) air quality guidelines are not legally-binding standards. They are intended to support air quality improvement and the protection of public health, but the WHO also recognizes that governments should consider their own local circumstances carefully before adopting these guidelines as air quality objectives. Metro Vancouver’s SO₂ objectives, which are currently less stringent than those of the WHO, were only exceeded at one CBIA site during one fog episode in January 2009 (see Section 3.4.1).
other LFV network stations. Monthly SO$_2$ averages at the T24 Burnaby North and T1 Downtown Vancouver sites were also consistently higher than other LFV network stations. The T23 Burnaby-Capitol Hill site experienced the highest 1-hour peak concentration (Figure 5b), and some of the highest monthly SO$_2$ averages, while monthly SO$_2$ levels were similar to those other LFV network stations at other times. Monthly SO$_2$ averages were elevated at the T6 Second Narrows site, except during the colder months (November-February in both 2009 and 2010). As illustrated in Figure 6, there was no discernable seasonal trend in SO$_2$ concentrations.

The T26 Mahon Park site is located at the highest elevation and furthest distance from any major SO$_2$ emission source than any other CBIA site. Understandably this station experienced the lowest monthly SO$_2$ averages in the CBIA.
Figure 6: Monthly average $\text{SO}_2$ concentrations at CBIA sites (symbols and lines) and other LFV network stations (blue band).

**Other LFV network stations that monitor $\text{SO}_2$: T2, T9, T12, T17, T18, T20, T27, T31, T33 and T34
3.1.3. **NO$_2$ Comparison**

As illustrated in Figure 7a, the T1 Downtown Vancouver site just exceeded Metro Vancouver’s annual NO$_2$ objective of 22 ppb by 0.1 ppb. Located in the center of the downtown core and near a major roadway, this site is heavily influenced by vehicular traffic, a large source of NOx emissions. Annually-averaged NO$_2$ concentrations at other CBIA sites ranged from 12.9 to 17.9 ppb, while other LFV network stations experienced annually-averaged NO$_2$ levels from 8.2 to 18.7 ppb.

As illustrated in Figure 7b, NO$_2$ levels did not exceed Metro Vancouver’s 1-hour average objective during the study at any site. The highest 1-hour peak levels were observed at the S6 Norgate site. This site was located in the driveway of the Norgate Fire Hall. At this site fire hall staff performed regular safety checks on fire engines every morning. These safety checks involved the idling the fire trucks for several minutes which caused the short-term NO and NO$_2$ concentrations to spike everyday between 8:00 and 10:00 am.

Figure 8 displays the seasonal trend of NO$_2$ with monthly averages plotted for CBIA sites (shown as symbols and lines) and other LFV stations (shown as the blue band). Overall NO$_2$ concentrations were higher in the winter and lower in the summer. This seasonal trend is typical of the region due to lower atmospheric mixing heights and increased residential heating during the winter. In addition, NO$_2$ conversion to other nitrogen species is more prevalent during the warmer, sunnier summer months.

As illustrated in Figure 8, most of the CBIA sites show a similar seasonal pattern to other LFV network stations. Monthly NO$_2$ averages at the majority of CBIA sites fell mid-range in winter and near the top of the range in summer. Three CBIA sites experienced notably higher NO$_2$ levels than other LFV stations. Monthly NO$_2$ averages were elevated year round at the T1 Downtown Vancouver site, during late spring and summer at the S3 Pandora Park site (August and September 2008, May to September 2009, March to June 2010), and during some summer months at the T6 Second Narrows (July 2008, June to August 2009 and June 2010). These sites likely experience higher NO$_2$ concentrations as a result of their close proximity to NOx emission sources. The T1 Downtown Vancouver site is dominated by traffic in the downtown core. The S3 Pandora Park site is less than 150 metres from a commercial district and major intersection (Nanaimo and East Hastings Streets), but it is unclear why NO$_2$ levels at this site were notably higher than other sites during the summer. The T6 Second Narrows site is situated on an active industrial property less than 50 metres from the intermittent traffic line-up into the Northshore.
Recycling Depot/Transfer Station, 250 m from the 4th largest emitter of NOx in the region (Nexen Chemicals) and 450 m from the elevated bridge deck of Highway 1 to the west and Dollarton Highway to the north.
Figure 7a: Annual average NO$_2$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010. Annual bars are shown for each site only if hourly data were available for over 75% of the year.

Figure 7b: Hourly average NO$_2$ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010.
Figure 8: Monthly average NO\textsubscript{2} concentrations at CBIA sites (symbol and line) and other LFV network stations (blue band).

**Other LFV network stations that monitor NO\textsubscript{2}: T2, T9, T12, T13, T14, T15, T17, T18, T20, T27, T29, T30, T31, T32, T33 and T34**
3.1.4. **CO Comparison**

As illustrated in Figure 9, CO levels were well below Metro Vancouver’s 1-hour average objective both within and outside the CBIA.

3.1.5. **O₃ Comparison**

As illustrated in Figure 10, ground-level O₃ levels did not exceed Metro Vancouver’s 1-hour average objective at any CBIA sites. In fact, O₃ levels in downtown Vancouver were the lowest in the region. NO tends to consume O₃ in high traffic, NOx-rich environments like downtown Vancouver. Exceedances were observed outside the CBIA in Port Moody, Chilliwack, Abbotsford and Hope during summer regional air quality advisories. Ongoing research indicates that the highest ozone levels occur in the eastern parts of the LFV during hot, sunny weather.
Figure 9: Hourly average CO concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010.

Figure 10: Hourly average ground-level O₃ concentrations at CBIA sites and other LFV network stations from July 4, 2008 to June 30, 2010.
3.1.6. Black Carbon Comparison

Black carbon is often used as an indicator for diesel fuel combustion and/or wood smoke. Metro Vancouver does not have any air quality objectives for black carbon.

Aethalometers collected continuous black carbon data at two fixed CBIA sites - S6 Norgate (starting in April 2009) and T6 Second Narrows (starting in October 2009). During the study period, the T34 Abbotsford Airport station was the only LFV network station collecting black carbon measurements outside the CBIA. Table 6 summarizes the black carbon data from each location from October 2009 to April 2010.

Table 6: Hourly Average Black Carbon Concentration Statistics at S6 Norgate, T6 Second Narrows and T34 Abbotsford Airport (October 2009 to March 2010)

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean (µg/m³)</th>
<th>Maximum (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6 Norgate</td>
<td>1.0</td>
<td>9.4</td>
</tr>
<tr>
<td>T6 Second Narrows</td>
<td>0.9</td>
<td>7.9</td>
</tr>
<tr>
<td>T34 Abbotsford Airport</td>
<td>0.6</td>
<td>7.9</td>
</tr>
</tbody>
</table>

The S6 Norgate site experienced the highest average and maximum black carbon levels of these three sites. This site was situated in a mixed commercial/residential neighbourhood adjacent to the Norgate fire hall. During daily safety checks, the fire truck was idling adjacent to the site. Knowledge of this activity allowed for an attribution of air pollutant measurements to a known emission source (e.g., a heavy-duty diesel truck) during these periods. However, it is suspected that idling fire trucks may not be the only source of black carbon at this site.

Figure 11 illustrates the monthly average black carbon concentrations for the three locations. As noted above, black carbon levels at both the T6 Second Narrows and S6 Norgate sites were slightly elevated compared to T34 Abbotsford Airport. Black carbon concentrations at S6 Norgate were highest during the winter months. It is suspected that smoke from residential wood burning may have contributed to black carbon concentrations at S6 Norgate in December 2009. An episode-specific interpretation of black carbon data is provided in Section 3.3.
3.1.7. Summary of Comparisons to Other LFV Network Stations

Compared to other areas in the LFV, the CBIA experiences unique air quality due to its complex topography, meteorology and emissions.

Annual PM$_{2.5}$ levels were slightly elevated in the CBIA, ranging from 4.8 to 5.6 $\mu$g/m$^3$, while other LFV network stations experienced annual averages of 3.6 to 5.1 g/m$^3$. The 24-hour PM$_{2.5}$ objective was exceeded at several CBIA sites. Exceedances at T6 Second Narrows and T4 Kensington Park were measured with standard network monitor (TEOM), but other PM$_{2.5}$ exceedances were measured using the non-standard E-Sampler. PM$_{2.5}$ is emitted by many sources in the CBIA including fossil fuel combustion, residential wood burning, coal dust and industrial processing.
Not surprisingly, SO$_2$ levels were elevated within the CBIA compared to other LFV network stations. Annual SO$_2$ levels at CBIA sites ranged from 1.4 to 5.8 ppb, while other LFV network stations experienced annual SO$_2$ levels from 0.4 to 1.9 ppb. The S3 Pandora Park site experienced the highest annual average SO$_2$ concentrations, followed by T1 Downtown Vancouver and T23 Burnaby-Capitol Hill. The sites with the highest averages were located in close proximity to marine areas and/or a refinery. Hourly SO$_2$ exceeded Metro Vancouver’s hourly objective at one location (T23 Burnaby-Capitol Hill) for one hour, and Metro Vancouver’s 24-hour objective on January 17-18th, 2009 for a total of five hours.

NO$_2$ levels did not exceed Metro Vancouver’s 1-hour average objective during the study period at any CBIA sites, however the T1 Downtown Vancouver site slightly exceeded the annual NO$_2$ objective. The downtown site experienced the highest NO$_2$ concentrations on average, which was anticipated since the site is located adjacent to a roadway with high volumes of traffic. Concentrations of NO$_2$ at other CBIA sites were similar to other LFV network stations, with the exception of T6 Second Narrows and Pandora Park which experienced elevated NO$_2$ levels during the summer and spring/summer respectively. In general, higher average NO$_2$ levels were measured during the winter and lower NO$_2$ levels during the summer. This seasonal trend is typical throughout the region due to lower atmospheric mixing heights, less photochemistry and increased residential heating during the wintertime.

A limited amount of black carbon data was collected during the BIALAQS. However, between October 2009 and April 2010, sites within the CBIA experienced slightly elevated black carbon levels compared to those at T34 Abbotsford Airport.

3.2. Variability Between CBIA Sites

The second objective of the BIALAQS monitoring program was to determine the spatial and temporal variability in air quality patterns within the CBIA. A detailed discussion of the variation in PM$_{2.5}$, SO$_2$, NO$_2$, NO and black carbon concentrations is provided in this section. Diurnal plots are provided in Figures 12 to 16 where weekday (Monday to Friday) and weekend (Saturday to Sunday) trends are given for both summer and winter. Summer is defined as June, July and August and winter defined as December, January and February. In the figures weekday (Monday through Friday) averages are shown as a solid circle, weekend (Saturday and Sunday) averages are shown as an open circle, winter is shown in blue and summer is shown in red.
3.2.1. PM$_{2.5}$ Variability

The diurnal trend of PM$_{2.5}$ is illustrated in Figure 12 for each site in CBIA where fine particulate was measured. At most sites PM$_{2.5}$ levels were elevated on summer mornings and then gradually decreased through the rest of the day. Winter PM$_{2.5}$ levels followed a typical pattern of low PM$_{2.5}$ concentrations in the early morning just before sunrise, an increase after sunrise, a decrease in the afternoon, and then an increase in the evening. Elevated PM$_{2.5}$ concentrations occurred during winter evenings at S4 Lynn Pump Station, S5 BCIT Marine Campus and S6 Norgate. Higher PM$_{2.5}$ levels were observed at these sites during weekend evenings. It is suspected that residential wood smoke may be responsible for this trend.

Local PM$_{2.5}$ emission sources clearly influenced measurements at several sites. For example, after the S6 Norgate site was established, Metro Vancouver air quality technicians noted that fire hall staff performed daily safety checks every morning which required the fire trucks to idle for several minutes. Given the close proximity of the S6 Norgate site to the fire truck exhaust, it is not surprising that the exhaust influenced the measurements between 8:00 and 10:00 am daily. Outside these hours, it is expected that the air quality measurements from the S6 Norgate site were representative of those in the surrounding neighbourhood. The truck idling is very local-scale phenomenon that is only likely detectable close to the tailpipe of the vehicles.

There was little difference between weekday and weekend PM$_{2.5}$ levels at all sites, with the exception of T6 Second Narrows. At T6 Second Narrows during the weekdays, PM$_{2.5}$ levels quickly rose in the early morning to a plateau and dropped off in the late afternoon. This pattern mimics a typical workday schedule with local anthropogenic sources that begin in the morning and end in the late afternoon/early evening. The T6 Second Narrows site is located near several particulate matter emission sources including an asphalt plant (within 250 m), two concrete batch plants (within 750 m), a major port terminal and ocean-going vessels (within 1 km), and multiple unpaved surfaces frequented by moving vehicles and non-road equipment. The influence of these sources was not as evident during weekends.

The winter weekend morning peak observed at S4 Lynn Pump Station is not a typical trend, but rather the result of high PM$_{2.5}$ levels observed during a calm stable wintertime inversion in January 2009 (discussed in Section 3.4.1).
Figure 12: Diurnal profiles of all fixed PM$_{2.5}$ monitoring sites within CBIA.
*PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
3.2.2. **SO₂ Variability**

Sulphur dioxide concentrations were higher at sites closer to the large sources of SO₂ emissions in the region – marine vessels/port areas and a petroleum refinery. The diurnal profile of SO₂ for eight sites is shown in Figure 13. The T23 Burnaby Capitol Hill site was first established in 1995 for the purposes of tracking refinery emissions. Hourly SO₂ levels varied little during the summer months, but it appears that levels varied substantially on winter weekends. However, these variable winter weekend levels were heavily influenced by one high SO₂ episode which occurred during a calm stable inversion event in January 2009 (discussed in Section 3.4.1).

At T4 Kensington Park and T24 Burnaby North SO₂ concentrations were relatively low and fairly constant throughout the day and night. Although these sites are located within the CBIA, they are further removed from Burrard Inlet and marine vessel activity. The T6 Second Narrows, T26 Mahon Park and S6 Norgate sites observed a winter peak around noon, but in summer changed to a bi-modal trend with a peak in the morning and a peak in the afternoon. The summertime distribution was likely due to photochemical conversion of SO₂ to sulphates and mixed layer growth with a collapse prior to sunset. It is interesting to note that the summer evening peak was higher on weekends than weekdays, but it is unclear why this occurred.

The overall trend at S3 Pandora Park differs from the other sites in the CBIA. This site experienced the highest average SO₂ concentrations, especially during the summer. On summer weekends the trend was similar to that at T26 Mahon Park, S6 Norgate and T6 Second Narrows, but higher. SO₂ levels were also elevated on summer weekdays at S3 Pandora Park, but a midday dip was not observed. S3 Pandora Park is located 750 metres from a major port terminal. Examination of pollutant concentrations and meteorology shows that the highest concentrations occurred when the winds were blowing from west northwest or the location of the port.

T1 Downtown Vancouver experienced consistently elevated SO₂ concentrations, with higher levels during summer mornings than the afternoons. In fact this site experienced the highest SO₂ concentrations in the morning compared with the other sites. Without wind data from this site, it is difficult to deduce the direction from which the SO₂ emissions were originating. However, the summer morning peak was likely associated with the cruise ships as they arrived and operated fully on engines (personal communication with Gary Olszewski – Port Metro Vancouver, 2012). Starting in August 2009, properly-outfitted cruise ships could shut down their diesel engines and plug in to the electrical grid shortly after docking. The afternoon dip in SO₂ concentrations is likely associated with the decrease in emissions as some cruise ships switched to shore-power.
Figure 13: Diurnal profiles of all fixed SO\textsubscript{2} monitoring sites within the CBIA.
Figure 14 shows SO$_2$ pollution roses for several SO$_2$ monitoring sites within the CBIA. In the figure, the pollution rose illustrates the distribution of SO$_2$ concentrations and the associated direction from which the wind was blowing. With knowledge of the upwind emissions, pollution roses can provide an indication of the possible sources of elevated pollutant levels. As indicated in Figure 14, the highest SO$_2$ concentrations at each site were measured when the wind was blowing from marine areas and/or the petroleum refinery. For example, the highest SO$_2$ concentrations at T26 Mahon Park in North Vancouver were measured when the wind is blowing from the southwest and south-southwest (i.e., from the Burrard Inlet). Similarly, T23 Burnaby-Capitol Hill experienced the highest SO$_2$ concentrations when the wind was blowing from the northwest, north and northeast (the direction of the Burrard Inlet and the petroleum refinery).

3.2.3. NO$_2$ and NO Variability

In general NO$_2$ exhibited a bi-modal diurnal trend with a peak in the morning and afternoon, as shown in Figure 15. NO$_2$ concentrations were higher on weekdays than weekends and winter concentrations were higher than those in summer. At the traffic-dominated T1 Downtown Vancouver site, NO$_2$ peaked in the early morning and afternoon, correlating with the highest traffic volumes. Concentrations were over 10 ppb higher in the winter than in summer. Higher winter NO$_2$ concentrations likely resulted from a combination of greater emissions of nitrogen oxides from residential and commercial heating, less photochemical nitrate transformation, lower atmospheric mixing heights and less dispersion during the winter. The S3 Pandora Park, S6 Norgate, T4 Kensington Park and T26 Mahon Park sites also displayed a traffic-dominated source pattern, although with lower concentrations than T1 Downtown Vancouver.

A spike in NO$_2$ levels was observed at S6 Norgate site every day of the week between the hours of 8:00-10:00 am. As mentioned previously, S6 Norgate was located in the driveway of the fire station and fire trucks idled adjacent to the station every morning during safety checks.

The diurnal profile of NO$_2$ at T6 Second Narrows differed from other sites. NO$_2$ levels quickly rose in the early morning hours of winter weekdays, while on winter weekends they slowly ramped up with a plateau around noon. The weekday morning gradient at T6 Second Narrows was similar to that observed at T1 Downtown Vancouver, except steeper. The T6 Second Narrows station is situated on an active industrial property within half a kilometre from the 4$^{th}$ largest emitter of NOx in the region (Nexen Chemicals), local truck traffic and the elevated bridge deck of Highway 1 to the west and Dollarton Highway to the north.
Figure 14: Pollution rose showing hourly average SO$_2$ concentrations plotted on wind direction at fixed CBIA sites.  

The length of the rose indicates the frequency of occurrence.
The diurnal trend of NO is shown in Figure 16 for each station in CBIA where NO was measured. All sites with the exception of T4 Kensington Park experienced a steep weekday morning NO increase starting around 6:00 am. This steep increase in NO concentrations began at the start of the work day, undoubtedly linked to rush hour traffic and/or local industrial activity. On the weekends this increase was delayed and much less pronounced. A dramatic NO gradient was observed at S6 Norgate everyday of the year in the mornings, resulting from fire truck idling. Conversely, the T4 Kensington Park site experienced a smooth gradual morning NO increase and much smaller peak than the other CBIA sites, even though T4 Kensington Park is within 100 m of a major roadway (East Hastings Street to the North).

Figure 15: Diurnal profiles of all fixed NO$_2$ monitoring sites within the CBIA.
3.2.4. Black Carbon Variability

Aethalometers collected black carbon data at two fixed CBIA sites - S6 Norgate (starting in April 2009) and T6 Second Narrows (starting in October 2009). T34 Abbotsford Airport, located in a rural area relatively distant from diesel fuel combustion sources, was the only station collecting black carbon measurements outside the CBIA. Figure 17 illustrates the diurnal profiles of black carbon data from each location.

As observed with PM$_{2.5}$, NO$_2$ and NO concentrations, morning spikes in black carbon at S6 Norgate reflect the influence of idling diesel fire engines while firehall staff performs safety checks.

Black carbon at T6 follows a similar diurnal pattern to that of PM$_{2.5}$, NO$_2$ and NO, with a steep increase in concentration on weekday mornings, tapering off through the afternoon/evening and then low concentrations overnight. This common pollutant trend suggests a common source -
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likely emissions from local industry, local industrial traffic and quite possibly traffic from Highway 1 to the west.

Black carbon concentrations were generally higher in winter than summer at both S6 Norgate and T34 Abbotsford Airport. Summer black carbon was not available for T6 Second Narrows.

Overall, black carbon measurements at T6 Second Narrows and S6 Norgate were elevated compared to those at T34 Abbotsford Airport.

Figure 17: Diurnal profiles of fixed black carbon monitoring sites within the CBIA compared to T34 Abbotsford Airport.

3.3. Additional Analyses

To assist with source attribution, Metro Vancouver included PM$_{2.5}$ speciation and near-source mobile monitoring as part of the BIALAQS monitoring program. A summary of the results of these analyses is presented here, while detailed information is provided in Appendices B and C.

3.3.1. PM$_{2.5}$ Speciation Summary

Using the E-Sampler’s 47 mm filter catch, integrated PM$_{2.5}$ samples were collected from seven CBIA PM speciation sites (S1 Vancouver Yacht Club, S2 MacLean Park, S3 Pandora Park, S4 Lynn Pump Station, S5 BCIT Marine Campus, S6 Norgate and T6 Second Narrows). Three sets of these filters - collected in fall 2009, early spring 2010 and late spring 2010 - were sent to Environment Canada’s Environmental Science and Technology Centre in Ottawa and analyzed.
for select water extractable ions, metals and sugar compounds. Environment Canada used this speciation data to perform a partial PM$_{2.5}$ mass reconstruction for the CBIA sites and compared the reconstruction with data from other LFV network PM$_{2.5}$ speciation stations (T18 South Burnaby and T34 Abbotsford Airport). The main conclusions of this mass reconstruction are summarized below. Environment Canada’s full report is provided in Appendix B.

**Ammonium sulphate**
Ammonium sulphate particulate matter can form when oxidized sulphur dioxide reacts with gaseous ammonia. Environment Canada concluded that the amount of ammonium sulphate (ASO$_4$) in the PM$_{2.5}$ mass at the CBIA sites was higher than T18 South Burnaby and T34 Abbotsford Airport during all three sampling periods. On a percentage basis, ASO$_4$ averaged 29% of the PM$_{2.5}$ mass collected at the CBIA sites, compared to 17% and 12% at T18 South Burnaby and T34 Abbotsford Airport, respectively. Higher overall ASO$_4$ levels at the CBIA sites illustrate the greater influence of anthropogenic sulphur dioxide emissions on the formation of secondary PM$_{2.5}$ in the CBIA. The highest concentrations of ASO$_4$ were observed at the three sites on the south shore of the CBIA (S1 Vancouver Yacht Club, S2 MacLean Park and S3 Pandora Park), which were impacted by winds predominantly from or along Burrard Inlet or from the east during the sampling periods. ASO$_4$ was highest in late spring at all but one site. It is expected that ASO$_4$ levels would be even higher during the summertime when biogenic emissions and ocean-going vessel activity at the port tend to peak.

**Black carbon**
On a percentage basis, the black carbon contribution to PM$_{2.5}$ mass averaged 17% at the CBIA PM speciation sites compared to an average elemental carbon contribution of 12% at both T18 South Burnaby and T34 Abbotsford Airport. This difference appears to be indicative of the higher relative contribution of black carbon sources - namely ocean-going vessels and diesel combustion (heavy-duty trucks and rail) - to PM$_{2.5}$ in the CBIA.

**Nickel and vanadium**
Nickel and vanadium are found in residual/heavy fuel oil burned in ocean-going vessels and are emitted as particles during combustion. Concentrations of nickel and vanadium were higher at all seven CBIA PM speciation sites than T18 South Burnaby and T34 Abbotsford Airport. Although there are no Canadian or Metro Vancouver air quality objectives for nickel and vanadium, the average nickel and vanadium concentrations at the S1 Vancouver Yacht Club (which showed the highest levels) were much lower than the U.S. Agency for Toxic Substances and Disease Registry’s minimal risk levels for chronic inhalation exposure.
Assuming the vanadium content in heavy fuel oil burned in ships in the CBIA ranges from 65 to 150 ppm, the average contribution of ocean-going vessels to primary PM$_{2.5}$ at the CBIA sites ranged from 6 to 37%. This range is significantly higher than those at T18 South Burnaby (2 to 6%) and T34 Abbotsford Airport (0.3 to 0.8%). Overall, the contribution of ocean-going vessels was highest in the late spring sampling period at S1 Vancouver Yacht Club followed by S3 Pandora Park and S2 MacLean Park. This finding follows the spatial and temporal pattern of ASO$_4$ concentrations and confirms the importance of the ocean-going vessel contribution to sulphate concentrations in the CBIA. However, it is expected that vanadium levels would be even higher during the summertime when ocean-going vessel activity at the port tends to peak.

**Levoglucosan and potassium**

Levoglucosan and potassium ion concentrations in PM$_{2.5}$ are typically used as an indicator of biomass burning. The contribution of biomass burning to PM$_{2.5}$ could not be quantified due to the suspected instability of levoglucosan on the BIALAQS filter samples. However, elevated potassium ion concentrations confirmed that biomass burning was indeed present. Potassium ion concentrations were highest during the fall sampling period at S2 MacLean Park, followed by S5 BCIT Marine Campus, and lowest at S3 Pandora Park. It is expected that potassium levels would be even higher during the wintertime when residential wood burning is most prevalent.

**Lead**

Elevated lead concentrations were also found at the T6 Second Narrows and S2 MacLean Park sites indicating the presence of a small local source of lead, possibly road dust. However, lead levels were well below the provincial objective and the EPA’s recently updated National Ambient Air Quality Standard for lead.

**Crustal contribution**

Between 43 and 73% of the PM$_{2.5}$ mass at the CBIA PM speciation sites was composed of organic mass, elemental carbon, fine soil and particle bound water during the three sampling periods. Elemental aluminum, iron, calcium, titanium and zinc data and wind measurements indicated that the impact of road dust appeared to be higher at T6 Second Narrows and S2 MacLean Park compared to other CBIA sites. However, the overall crustal contribution to PM$_{2.5}$ within the CBIA was low.
3.3.2. Mobile Trailer Summary

The BIALAQS mobile trailer was situated close to several emission sources in the CBIA. Although pollutant levels measured at these locations did not necessarily reflect neighbourhood exposure levels, they helped to assess the near-field influence of local emission sources.

Environment Canada’s mobile trailer was outfitted with continuous NOx, SO$_2$, PM$_{2.5}$ and black carbon monitors. Starting in December 2009 the mobile trailer was located at one of four trailer sites (S7 Lynn Pump Station, S8 Lonsdale Seabus, S9 Harbour/Clark and S15 Heliport) for 3-4 week periods. Since the trailer moved between locations during the BIALAQS, the data from each trailer location contain several time gaps. The records for each location do not coincide in time, so it is not appropriate to compare the data from each trailer location to the others. Table A2 in Appendix A presents the basic data statistics for each of the mobile trailer sites.

A summary of the pollutant trends and suspected local emission sources that influenced pollutant levels at the mobile trailer locations is presented in Table 7 below. The figures and discussion in Appendix C describe the variation in pollutant concentrations at each location throughout the day and by season in more detail. Knowledge of local emission sources and their diurnal variation assisted with interpretation of these data.

<table>
<thead>
<tr>
<th>Mobile Trailer Location</th>
<th>Pollutant trend</th>
<th>Suspected local emission source</th>
</tr>
</thead>
<tbody>
<tr>
<td>S7 Lynn Pump Station MT</td>
<td>Somewhat elevated PM$_{2.5}$ and black carbon levels on weekday mornings</td>
<td>Truck traffic along East 3$^{rd}$ Street/Low Level Road and/or locomotives</td>
</tr>
<tr>
<td></td>
<td>Elevated SO$_2$ levels observed during the day in both winter and summer</td>
<td>Ocean-going vessels</td>
</tr>
<tr>
<td></td>
<td>Elevated overnight PM$_{2.5}$ and black carbon levels on winter weekends</td>
<td>Residential wood burning and/or dust from the nearby coal terminal</td>
</tr>
<tr>
<td>S8 Lonsdale Seabus MT</td>
<td>Morning black carbon, SO$<em>2$ and PM$</em>{2.5}$ peak in both summer and winter</td>
<td>Ocean-going vessels</td>
</tr>
<tr>
<td>Mobile Trailer Location</td>
<td>Pollutant trend</td>
<td>Suspected local emission source</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>PM$_{2.5}$ concentrations elevated in evenings</td>
<td>Residential wood burning in winter, secondary particulate formation in summer</td>
</tr>
<tr>
<td></td>
<td>Elevated NO$<em>2$ and PM$</em>{2.5}$ levels during the morning and evening rush hours</td>
<td>Seabus</td>
</tr>
<tr>
<td></td>
<td>Elevated NO$<em>2$, PM$</em>{2.5}$ and BC on summer evenings</td>
<td>Pleasure craft travelling to/from nearby marina</td>
</tr>
<tr>
<td>S9 Harbour/Clark MT</td>
<td>Elevated weekday PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$</td>
<td>Truck traffic on Stewart Street, Vanterm gate truck line-up, locomotives, ocean-going vessels, cargo-handling equipment</td>
</tr>
<tr>
<td></td>
<td>Elevated SO$<em>2$ and PM$</em>{2.5}$ during summer weekends</td>
<td>Ocean-going vessels</td>
</tr>
<tr>
<td>S15 Heliport MT</td>
<td>PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$ elevated on autumn weekday mornings</td>
<td>Truck traffic on Waterfront Road and/or locomotives</td>
</tr>
<tr>
<td></td>
<td>Elevated SO$_2$ during the daytime on summer weekends and weekdays, as well as autumn weekends</td>
<td>Cruise ships</td>
</tr>
</tbody>
</table>

### 3.4. Air Quality Episodes

Pollutant levels within the CBIA exceeded Metro Vancouver’s air quality objectives on a few occasions. Table 8 summarizes the episodes (periods of time when at least one of Metro Vancouver’s short-term air quality objectives was exceeded at one or more CBIA sites) during the BIALAQS. It should be noted that several of the PM$_{2.5}$ exceedances were detected by non-standard monitors (E-Sampler) that have greater measurement uncertainty than the standard instruments (TEOM) used throughout the LFV network. However, standard equipment measured exceedances of the 24-hour PM$_{2.5}$ objective in January and July 2009, and both the 1-hour and 24-hour SO$_2$ objectives in January 2009.
There were no PM$_{2.5}$ or SO$_2$ exceedances at any other LFV network stations during the episodes discussed in this section.

### Table 8: Air Quality Episodes During the BIALAQS.

<table>
<thead>
<tr>
<th>Episode time frame</th>
<th>Contaminant</th>
<th>Short-term Objective (averaging period)</th>
<th>Sites measured</th>
<th>Duration of Exceedance (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 17-18th, 2009</td>
<td>PM$_{2.5}$</td>
<td>25 µg/m$^3$ (24-hour rolling)</td>
<td>S2 MacLean Park, S3 Pandora Park</td>
<td>25*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S4 Lynn Pump Station / S7 Lynn Pump Station MT</td>
<td>26 (35*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T6 Second Narrows</td>
<td>3 (24*)</td>
</tr>
<tr>
<td></td>
<td>SO$_2$</td>
<td>174 ppb (1-hour)</td>
<td>T23 Burnaby – Capitol Hill</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>SO$_2$</td>
<td>48 ppb (24-hour rolling)</td>
<td>T23 Burnaby – Capitol Hill</td>
<td>5</td>
</tr>
<tr>
<td>July 30th, 2009</td>
<td>PM$_{2.5}$</td>
<td>25 µg/m$^3$ (24-hour rolling)</td>
<td>T6 Second Narrows</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T4 Kensington Park</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S8 Lonsdale Seabus MT</td>
<td>14</td>
</tr>
<tr>
<td>August 7-8th, 2009</td>
<td>PM$_{2.5}$</td>
<td>25 µg/m$^3$ (24-hour rolling)</td>
<td>S5 BCIT Marine Campus</td>
<td>24*</td>
</tr>
<tr>
<td>December 26th, 2009</td>
<td>PM$_{2.5}$</td>
<td>25 µg/m$^3$ (24-hour rolling)</td>
<td>S2 MacLean Park, S5 BCIT Marine Campus</td>
<td>2*</td>
</tr>
</tbody>
</table>

* These PM$_{2.5}$ concentrations were monitored using an E-Sampler, as opposed to the network standard (TEOM). Therefore, this value represents the number of hours when PM$_{2.5}$ concentrations may have exceeded Metro Vancouver’s 24-hour averaged air quality objective at these locations. The differences between the co-located TEOM and E-Samplers are discussed in the following subsections.

#### 3.4.1 January 2009 Fog Episode

From January 15th to 22nd, 2009 the CBIA experienced a period of stagnant atmospheric conditions and light winds. Low-lying areas in Metro Vancouver were blanketed by a thick fog during this period (Environment Canada 2009). Outdoor air temperatures at low lying CBIA sites ranged from -3°C overnight to 8°C during the afternoon. However, air temperatures

5 See also [www.youtube.com/watch?v=AeDCHXcDU90](http://www.youtube.com/watch?v=AeDCHXcDU90).
observed at higher elevations outside of the fog bank, such as the T23 Burnaby-Capitol Hill site, were greater with observed temperatures above 3°C.

As illustrated in Figures 17 and 18, PM$_{2.5}$ concentrations were elevated during this period. In fact, PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective for several hours at S2 MacLean Park, S3 Pandora Park, S4 Lynn Pump Station, S7 Lynn Pump Station MT and T6 Second Narrows. As illustrated in Figures 19 and 20, SO$_2$ concentrations were also elevated during this period. At the T23 Burnaby-Capitol Hill site, SO$_2$ levels exceeded Metro Vancouver’s 1-hour SO$_2$ objective for one hour and the 24-hour SO$_2$ objective for 5 consecutive hours. By contrast, pollutant levels at other LFV network stations were relatively low. The unique meteorological conditions within the CBIA during this event likely restricted the dispersion of local emissions. The influence of local sources on pollutant levels at each CBIA site is discussed below.

**S2 MacLean Park**
Elevated PM$_{2.5}$ levels were measured at the S2 MacLean Park site when light winds were blowing from the northeast (17 Jan 2009 at 8:00 am) and east (17 Jan 2009 at 12:00 pm). Port terminals and a residential neighbourhood are situated in these directions. Lack of atmospheric mixing and dispersion during these times suggest that local emission sources contributed to the PM$_{2.5}$ exceedances at this location, but without black carbon or other pollutant concentrations it is difficult to attribute these exceedances to specific sources. As illustrated in Figure 18, PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective for 25 consecutive hours at S2 MacLean Park.

**S3 Pandora Park**
Elevated PM$_{2.5}$ levels were measured at S3 Pandora Park when light winds were blowing from the northwest (17 Jan 2009 at 12:00 pm). A residential neighbourhood and port terminals were situated upwind of S3 Pandora Park at this time. Emissions from the port terminals and residential neighbourhood likely contributed to these elevated PM$_{2.5}$ levels. Figure 18 shows that PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective for 26 consecutive hours at S3 Pandora Park.

As illustrated in Figure 19, SO$_2$ concentrations were also elevated during this time period at S3 Pandora Park, but did not exceed Metro Vancouver’s 1-hour SO$_2$ objective. The main source of SO$_2$ emissions in this area is marine vessels.
T6 Second Narrows
Elevated PM$_{2.5}$ levels were measured 17 Jan 2009 at 6:00 am at the T6 Second Narrows site when the winds were blowing from the north northwest. These elevated concentrations were likely associated with the emissions from local industries and adjacent roadways. As shown in Figure 18, exceedances of Metro Vancouver’s 24-hour PM$_{2.5}$ objective were detected with both the TEOM and E-Sampler. During this time SO$_2$ concentrations were also elevated at the T6 Second Narrows site, but levels did not exceed Metro Vancouver’s 1-hour SO$_2$ objective. The main sources of SO$_2$ emissions in this area are marine vessels and petroleum refining.

T23 Burnaby-Capitol Hill
PM$_{2.5}$ was not monitored at this location. As illustrated in Figure 19, elevated SO$_2$ concentrations were measured at the T23 Burnaby-Capitol Hill station for several hours between January 16$^{th}$ and 21$^{st}$, 2009. An exceedance of Metro Vancouver’s 1-hour SO$_2$ objective was measured at this site on Saturday, January 17$^{th}$ at 11:00 pm when light winds were blowing from the north. The Chevron refinery, to the north of this site, is the closest and most likely source of SO$_2$ emissions influencing this monitoring site. The refinery staff reported their operations were stable and SOx emissions were typical during this period. The fluid catalytic cracker and sulphur recovery units were in compliance with their permitted SOx emission limits. However, the SO$_2$ exceedance on January 17$^{th}$ should have triggered a SOx Curtailment Event as defined in Chevron's permit. During events like this, refinery staff is expected to reduce SO$_2$ emissions by making operational adjustments, which may include increasing its DeSOx additive. Unfortunately, the T23 Burnaby-Capitol Hill station was experiencing data communication issues at this time and the SO$_2$ exceedance was misinterpreted as an instrument calibration, so no action was taken to reduce emissions.

S4 Lynn Pump Station/ S7 Lynn Pump Station MT
As illustrated in Figure 18, exceedances of Metro Vancouver’s 24-hour PM$_{2.5}$ objective were detected by both the E-Sampler (35 hours) and the mobile trailer’s TEOM (26 hours) at this location. As with the E-sampler/TEOM co-location at T6 Second Narrows, the TEOM detected fewer exceedances. Figure 17 shows that the highest PM$_{2.5}$ levels were measured at S4 Lynn Pump Station when the winds were blowing from the east northeast (17 Jan 2009 at 3:00 am) and

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6 The E-Sampler recorded 24 exceedances while the TEOM recorded only 3. The difference in the number of exceedances may be explained by the presence of high humidity. It is suspected that humidity may influence the optical sensor of the E-Sampler resulting in an over-estimation of PM$_{2.5}$ compared with the TEOM. On the other hand, it should be recognized that TEOMs tend to underestimate PM$_{2.5}$ under cold and high humidity conditions because of the heating of the sample stream.
north (17 Jan 2009 at 7:00 am). However, winds were light and somewhat variable throughout the week. Several industrial facilities and a residential neighbourhood are situated to the east northeast and north, respectively, but heavy-duty truck traffic, a rail yard and a coal terminal are also located close by.
Figure 17: Hourly average PM$_{2.5}$ concentrations in the CBIA during the January 2009 fog episode.

*PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).

Note: Metro Vancouver does not have a 1-hour objective for PM$_{2.5}$. 

Light winds = 5 to 1.5 km/hr
Figure 18: 24-hour rolling average PM$_{2.5}$ concentrations in the CBIA during the January 2009 fog episode.

* PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Figure 19: Hourly average SO₂ concentrations in the CBIA during the January 2009 fog episode.
Figure 20: 24-hour rolling average SO$_2$ concentrations in the CBIA during the January 2009 fog episode.
The aethalometer measured black carbon, which is an indicator of diesel fuel combustion and wood smoke. Figure 21 shows that black carbon concentrations were also elevated during the fog episode, particularly on January 17th from the early morning hours to mid-day. It is suspected that wood smoke may have been present during this time. Unfortunately, levoglucosan or potassium analyses, which would have confirmed the presence of wood smoke, were not available during this time period. Figure 21 also shows that SO$_2$ and NO$_x$ levels were elevated from about 9:00 am to noon on January 17th, suggesting that marine vessel emissions may have also contributed to elevated PM$_{2.5}$ levels during that period of time.

**Summary**

During the January 2009 fog episode, atmospheric mixing was limited and stagnant winds prevented local emissions from travelling far from their sources. Under these atmospheric conditions, monitoring CBIA sites were mostly impacted by nearby emission sources. One site (T23 Burnaby-Capitol Hill) was impacted by emissions from a nearby refinery, another (S4 Lynn Pump Station) was likely impacted by marine vessel emissions. This episode illustrates the influence that local emissions can have on CBIA neighbourhoods under the worst case meteorological conditions (e.g., light winds and inversion conditions, very little atmospheric mixing or dispersion).
3.4.2. Late July-Early August 2009 Episode

From July 28th to August 2nd, 2009 air quality in Metro Vancouver and the Fraser Valley Regional District deteriorated due to very hot and sunny conditions which generated high ozone levels in the eastern portion of the LFV. At the same time smoke was also being transported from forest fires to the distant north. In July, the province averaged between 50 and 100 fires daily with July 31 being the most active with a total of more than 175 fires for this one day alone (CIFFC Canada Report 2009). During this episode, the LFV experienced a heat wave with air temperatures observed in the CBIA from 17°C overnight to 36°C during the afternoon. As a result of the degraded air quality, Metro Vancouver issued a regional air quality advisory for the entire LFV during this time.

As illustrated in Figures 22 and 23, PM$_{2.5}$ and SO$_2$ concentrations were elevated during this period. In fact, PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective at T6 Second Narrows (3 hours) and Kensington Park (1 hour). During this period, the mobile trailer was located at the S8 Lonsdale Seabus site where exceedances of the 24-hour objective were also measured (14 hours). Although SO$_2$ concentrations were elevated, they did not exceed Metro Vancouver’s 1-hour average SO$_2$ objective at any location during this episode.

**T6 Second Narrows**

Metro Vancouver’s 24-hour average PM$_{2.5}$ objective was exceeded for 3 hours on 30 July 2009 at T6 Second Narrows. The highest concentrations were observed when winds blew from the southwest and south southwest. This station is located in an industrial area and adjacent to a major roadway. PM$_{2.5}$ and NO$_2$ concentrations showed a distinct diurnal trend with elevated levels during the morning and evening, but lower levels overnight. This trend suggests that local daytime industrial activity, local industrial traffic and vehicle emissions from adjacent roadways contributed to these elevated contaminant levels.

**T4 Kensington Park**

Metro Vancouver’s 24-hour PM$_{2.5}$ objective was exceeded for one hour on 30 July 2009 at T4 Kensington Park. High PM$_{2.5}$ originated from several directions, but the highest concentrations were observed when winds blew from the north. Ozone levels at T4 Kensington Park almost reached Metro Vancouver’s 1-hour ozone objective during this period, suggesting that the region-wide smog also influenced the readings at this location.
S8 Lonsdale Seabus MT
The mobile trailer was moved to the S8 Lonsdale Seabus MT location as part of its regular rotation schedule on July 29th. As noted in Figures 22 and 23, PM$_{2.5}$ and SO$_2$ concentrations were elevated at this location on 30 July 2009 between 04:00 and 10:00 am with light winds blowing from south and southwest. Burrard Inlet is located to the south and southwest of the S8 Lonsdale Seabus MT site. As illustrated in Figure 24, NOx and black carbon levels were also elevated during this time period. The combination of elevated PM$_{2.5}$, SO$_2$, black carbon and NO$_x$ levels and south/southwesterly winds suggests that marine vessel emissions likely influenced the readings at the S8 Lonsdale Seabus MT location between 07:00 and 10:00 am on 30 July 2009. A closer investigation into the 5-minute average data revealed that NOx concentrations spiked regularly over this time period (likely associated with emissions from regular Seabus sailings), but SO$_2$ spiked from 7:46 to 8:02 am. This SO$_2$ spike was likely associated with a plume from an ocean-going vessel. However, since SO$_2$ was not elevated during several other NOx and black carbon spikes, it is suspected that forest fire smoke may have also impacted this site.
Figure 22: Hourly average PM$_{2.5}$ concentrations at CBIA sites during the late July-early August 2009 episode.

* PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Figure 23: Hourly average SO$_2$ concentrations at CBIA sites during late July-early August 2009 episode.
Summary

During the late July-early August 2009 episode, air quality deteriorated in Metro Vancouver and the Fraser Valley Regional District as a result of forest fire smoke from the north and smog formation during very hot and sunny weather conditions. The elevated PM$_{2.5}$ levels observed in the CBIA during this episode were likely the result of a combination of factors including: hot and sunny weather conditions, local and regional emission sources, such as marine vessels, industrial operations and forest fire smoke.

3.4.3. August 7 and 8, 2009 BCIT Marine Campus Episode

On August 7 and 8, 2009 PM$_{2.5}$ concentrations at the S5 BCIT Marine Campus site exceeded Metro Vancouver’s 24-hour rolling PM$_{2.5}$ objective for a total of 24 hours. As described in the previous section, leading up to this episode British Columbia experienced a heat wave resulting in numerous forest fires across the province. August 6, 7 and 8 were overcast with maximum air temperatures approaching 20°C and minimum temperatures of 13°C. Wind was consistently blowing 10 km/h predominantly from the east at night and south around midday. Rainfall on August 9 and 10 corresponded with a decrease in PM$_{2.5}$ concentrations.

Figure 25 shows hourly PM$_{2.5}$ concentrations between August 6 and 10. All CBIA sites followed the same general trend during this period. However, the magnitude of the concentration was
different. The close correlation between PM$_{2.5}$ measurements at all sites suggests that the elevated PM$_{2.5}$ levels resulted from a regional phenomenon. It is likely that smoke from several interior forest fires was transported to the region and entrained down to the surface near Burrard Inlet.

During this episode S3 Pandora Park, S1 Vancouver Yacht Club and S5 BCIT Marine Campus observed higher PM$_{2.5}$ concentrations than other LFV network stations. The S5 BCIT Marine Campus site measured exceedances of the 24-hour objective, while S3 Pandora Park and S1 Vancouver Yacht Club did not. It is unclear why S5 BCIT Marine Campus measured the highest PM$_{2.5}$ during this time. The mobile trailer was located 275 metres away at the S8 Lonsdale Seabus MT site, but it recorded much lower PM$_{2.5}$ concentrations than at the S5 BCIT Marine Campus site. The diurnal trend between the two sites was similar, but PM$_{2.5}$ concentrations were as much as two times greater at the S5 BCIT Marine Campus site. It is suspected that different measurement heights and differences in instrumentation may account for this disparity. The S5 BCIT Marine Campus site employed an E-Sampler situated on the roof of a large three story building, while the Lonsdale Seabus MT site employed a TEOM situated nearer to the ground in a mobile trailer.

Figure 26 shows the black carbon concentration at S6 Norgate with a distinct peak occurring every morning, which was likely caused by the idling of a fire truck in the driveway of the Norgate fire hall. It is interesting to note that same peak was evident in the black carbon to PM$_{2.5}$ ratio (Figure 27) on August 9 and 10 when PM$_{2.5}$ was low, but the peak was not evident on August 6, 7 and 8 when PM$_{2.5}$ was higher. This suggests that there was little black carbon contained within the regional PM$_{2.5}$ that caused elevated values. The lack of black carbon was likely the result of aerosol aging over time suggesting that smoke was transported a day or two from the source and was not local.
Figure 25: Hourly average PM$_{2.5}$ concentrations in the CBIA between August 6 and 10, 2009.

* PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Figure 26: Hourly average black carbon concentrations at S6 Norgate between August 6 and 10, 2009.

Figure 27: Hourly average black carbon to PM$_{2.5}$ ratio at S6 Norgate and S8 Lonsdale Seabus MT between August 6 and 10, 2009.
3.4.4. December 24 to 27, 2009 Episode

Between December 24 and 27, 2009 many CBIA sites experienced elevated PM$_{2.5}$ concentrations. Metro Vancouver’s 24-hour average PM$_{2.5}$ objective was exceeded at S2 MacLean Park for 2 hours and S5 BCIT Marine Campus for 3 hours.

Figure 29 shows hourly PM$_{2.5}$ at the CBIA sites. Fine particulate was elevated during the evenings of December 24, 25 and 26 with the highest peaks occurring on December 25 at S2 MacLean Park and S5 BCIT Marine Campus. It is suspected that PM$_{2.5}$ was elevated as a result of residential wood burning. A 2010 wood smoke survey indicated that two-thirds of residents in the LFV with a wood burning device (e.g., fireplace, fire insert, wood stove, etc.) burn wood on occasion (Ipsos Reid 2010). Most wood burning occurs during the colder evening and morning hours, especially during the holiday period around December 25.

On December 24, 25 and 26 air temperatures observed at Vancouver International Airport operated ranged from -4.3°C to 4.7°C with mean temperatures of 1.0°C, -0.2°C and 2.6°C, respectively. No precipitation fell and no other pollutants were elevated during this period.

Black carbon measurements were available from the S8 Lonsdale Seabus MT and S6 Norgate sites. Figure 30 shows that black carbon was highest in the early morning and late evening hours at both locations, which is consistent with typical residential wood burning practices. Unfortunately, neither levoglucosan nor potassium analysis were not available for this time period.

It should also be noted that a fire broke out during the early hours of December 25, 2009 in an older commercial building in Vancouver at Kingsway and Broadway. This fire destroyed the building complex quickly and took firefighters the majority of the day to extinguish. It is likely that the particulate matter released during the fire influenced local monitoring sites. Winds were predominantly blowing from the south during the morning of December 25. The S2 MacLean Park and S5 BCIT Marine Campus sites were situated north of the commercial building fire and may have been impacted by the associated smoke depending on the height of the mixing layer. Elevated PM$_{2.5}$ concentrations measured at the S2 MacLean Park and S5 BCIT Marine Campus sites during the evening of December 25 were likely the result of residential wood burning in the area, with some influence from the commercial building fire.
Figure 29: Hourly average \(\text{PM}_{2.5}\) concentrations in the CBIA between December 24 and 27, 2009.

* \(\text{PM}_{2.5}\) concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Figure 30: Hourly average black carbon concentrations at S6 Norgate and S8 Lonsdale Seabus MT between December 24 and 27, 2009.
3.4.5. Episodes Summary

Contaminant levels within the CBIA exceeded Metro Vancouver’s short-term air quality objectives during four episodes during the BIALAQS. All four of these episodes occurred in 2009 with two occurring in summer and two in winter. Levels of fine particulate matter exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective during all four episodes at several sites, while the 1-hour SO$_2$ objective was exceeded only on one occasion at one site.

The first episode took place in mid January 2009 when metropolitan Vancouver experienced a period of persistent stagnant atmospheric conditions that blanketed much of the CBIA with a thick cover of low-lying fog for several days. During this period, air dispersion was severely restricted and contaminant concentrations increased at multiple sites. PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour average PM$_{2.5}$ objective at S2 MacLean Park, S3 Pandora Park, S4 Lynn Pump Station and T6 Second Narrows. SO$_2$ levels exceeded Metro Vancouver’s 1-hour average SO$_2$ objective at T23 Burnaby-Capitol Hill.

The second episode occurred in late July to early August of 2009 when air quality in the LFV deteriorated due to smoke from forest fires and elevated ground-level ozone brought on by very hot, sunny, and stable weather conditions. During this time PM$_{2.5}$ levels exceeded Metro Vancouver’s 24-hour PM$_{2.5}$ objective at T6 Second Narrows, T4 Kensington Park and S8 Lonsdale Seabus MT. Ozone levels exceeded Metro Vancouver’s 1-hour objective at several LFV network stations in the eastern portion of Metro Vancouver and the Fraser Valley Regional District.

Shortly after the second episode, another occurred during the second week of August. PM$_{2.5}$ concentrations at S5 BCIT Marine Campus exceeded Metro Vancouver’s 24-hour objective. Leading up to this event was a heat wave that affected all of British Columbia resulting in a record number of forest fires across the province. During this period several CBIA sites experienced elevated PM$_{2.5}$ concentrations compared to other LFV stations, however it was unclear why PM$_{2.5}$ levels were highest at S5 BCIT Marine Campus.

During the last episode many sites experienced elevated PM$_{2.5}$ during the holidays in December 2009. PM$_{2.5}$ concentrations at two sites (S2 MacLean Park and S5 BCIT Marine Campus) exceeded Metro Vancouver’s 24-hour average PM$_{2.5}$ objective during this time. It is likely that PM$_{2.5}$ was elevated overnight on December 24 and 25 as a result of residential wood burning.
Fine particulate was elevated during the evenings of December 24, 25 and 26 with the highest peaks occurring the evening of December 25 at S2 MacLean Park and S5 BCIT Marine Campus. Black carbon concentrations were also elevated overnight at S6 Norgate and S8 Lonsdale Seabus MT during this episode. Additionally, a commercial building fire may have contributed to elevated PM$_{2.5}$ levels measured at some monitoring sites.
4. Conclusions

The Burrard Inlet Area Local Air Quality Study (BIALAQS) was the first in a series of local air quality studies initiated by Metro Vancouver since 2005. The objectives of the monitoring portion of the BIALAQS were to: a) determine how air quality in the CBIA differs from other LFV stations, b) determine the spatial and temporal variability of pollutants within the CBIA, and c) provide information that may be used to determine the major sources contributing to air quality levels. The monitoring phase of the BIALAQS was conducted from July 2008 to June 2010 using twelve fixed monitoring sites and one mobile monitoring trailer which rotated between four locations in the CBIA. This study collected information about air pollutants that have been associated with human health and environmental impacts.

In general the BIALAQS monitoring shows that the CBIA experiences unique air quality compared to other areas in Metro Vancouver and the Fraser Valley Regional District. This conclusion is not surprising given the distinct topography, meteorology and variety of emission sources that are present in the CBIA. However, it should be noted that the CBIA sites tended to capture a large range of localized situations in closer proximity to large emission sources than the other Lower Fraser Valley (LFV) network stations.

*Sulphur Dioxide (SO$_2$) levels were elevated in the CBIA.* Annual concentrations of SO$_2$ measured at CBIA sites were elevated compared to other LFV network stations. The S3 Pandora Park site in East Vancouver experienced the highest annual SO$_2$ concentrations, followed by T1 Downtown Vancouver and T23 Burnaby-Capitol Hill. All three of these sites are located within one kilometre of a marine area and/or a refinery. Although there were no exceedances of Metro Vancouver’s annual SO$_2$ objective at any of the CBIA sites, Metro Vancouver’s 1-hour and 24-hour average SO$_2$ objectives were exceeded briefly at one location near a petroleum refinery during a strong wintertime inversion in January 2009. The World Health Organization’s (WHO) 24-hour SO$_2$ guideline was exceeded several times at all CBIA sites, with the exception of T26 Mahon Park in North Vancouver. The WHO daily SO$_2$ guideline was also exceeded at the T2 Kitsilano and T9 Port Moody stations, which are located close to marine areas, but not other LFV network stations.

*Fine particulate matter (PM$_{2.5}$) levels were periodically elevated in the CBIA.* PM$_{2.5}$ concentrations exceeded Metro Vancouver’s 24-hour objective at two CBIA sites with standard network monitors during a winter inversion episode and a regional summertime air quality
advisory. Several other CBIA sites also recorded exceedances, but these sites employed non-standard monitoring technology with greater uncertainty than the standard network monitors. There were no PM$_{2.5}$ exceedances at any other Lower Fraser Valley (LFV) network stations outside the CBIA during these episodes.

**Black carbon levels at the two CBIA sites were slightly elevated** compared to T34 Abbotsford Airport. Often used as an indicator of diesel fuel combustion or woodsmoke, black carbon concentrations were concurrently monitored at two sites within the CBIA (T6 Second Narrows and S6 Norgate) and one site outside the CBIA during a seven-month period.

**The CBIA experienced elevated vanadium and nickel levels.** Vanadium and nickel levels were significantly higher in the three sets of PM$_{2.5}$ samples collected from CBIA sites than those measured at two LFV network stations outside the CBIA. Although there are no Canadian or Metro Vancouver air quality objectives for nickel and vanadium, the average nickel and vanadium concentrations at the S1 Vancouver Yacht Club (which showed the highest levels) were much lower than the U.S. Agency for Toxic Substances and Disease Registry’s minimal risk levels for chronic inhalation exposure. Nickel and vanadium are found in residual/heavy fuel oil burned in ocean-going vessels and are emitted as particles during combustion.

**Nitrogen dioxide (NO$_2$) levels were similar to the rest of the network, with the exception of the T1 Downtown Vancouver station.** NO$_2$ levels did not exceed Metro Vancouver’s 1-hour average objective during the study at any location, however the T1 Downtown Vancouver site slightly exceeded the annual NO$_2$ objective. The T1 Downtown Vancouver station experienced the highest NO$_2$ concentrations in the region, which is anticipated given its close proximity to traffic along Robson and Hornby Streets. NO$_2$ concentrations at other CBIA sites were similar to those at other LFV network stations. A traffic-dominated diurnal trend was evident at several sites including S3 Pandora Park, S6 Norgate, T4 Kensington Park and T26 Mahon Park, although not as prominent as the downtown site.

**Unique poor air quality episodes occurred within the CBIA.** There were four distinct episodes during the study when contaminant levels within the CBIA exceeded or may have exceeded Metro Vancouver’s short-term air quality objectives. All of these episodes occurred in 2009, two during summer and two during winter. The 24-hour average PM$_{2.5}$ objective was exceeded during all four episodes at multiple sites, while the 1-hour average SO$_2$ objective was exceeded only on one occasion at one site. The summer 2009 episodes occurred during regional air quality advisory conditions with significant photochemical activity and forest fire smoke from the
interior of British Columbia. Local sources, such as marine vessels and other fossil fuel combustion, also contributed. In winter, the data suggest that residential wood smoke and/or diesel fuel combustion likely contributed to exceedances of Metro Vancouver’s 24-hour PM$_{2.5}$ objective, and refinery emissions resulted in exceedances of Metro Vancouver’s 1 and 24-hour SO$_2$ objectives in the nearby community. There were no exceedances of Metro Vancouver’s PM$_{2.5}$ or SO$_2$ objectives at any LFV network stations outside of the CBIA during these episodes.

Based on the monitoring results it is clear that the CBIA experiences unique air quality. Differences in emissions, topography and meteorology result in different air quality patterns in the CBIA compared with other areas. Pollutant levels across the CBIA vary considerably, and this local scale variability is not necessarily captured by the current air quality monitoring network.
5. Recommendations

Based on the above conclusions, several actions to improve and better track air quality within the CBIA are recommended.

Review of SO₂ Objectives

During the BIALAQS study, the World Health Organization (WHO) daily SO₂ guidelines were exceeded several times at most monitoring sites within the CBIA. The WHO updated its SO₂ guidelines in 2005. These guidelines are significantly more stringent than the current SO₂ objectives for Metro Vancouver. It is important to note that WHO air quality guidelines are purely science-based and not legally binding. They are intended to support air quality improvement and the protection of public health, but WHO also recognizes that governments should consider their own local circumstances carefully before adopting these guidelines as air quality objectives. In addition, Health Canada is currently updating its Science Assessment for SO₂. It is recommended that Metro Vancouver reviews its SO₂ objectives using the results of Health Canada’s assessment (when complete), the WHO guidelines and input from public and industry stakeholders. More stringent SO₂ objectives may be difficult to meet in the CBIA without the implementation of significant mitigative measures.

Mitigation of SO₂ Emissions

SO₂ concentrations were higher at CBIA sites than other LFV network stations. During one wintertime inversion episode, SO₂ levels exceeded Metro Vancouver’s 1-hour average SO₂ objective for one hour and the 24-hour average objective for 5 hours at the T23 Burnaby-Capitol Hill station, close to the Chevron Refinery. In addition, the WHO’s daily SO₂ guideline was exceeded several times at all CBIA sites, except T26 Mahon Park. To reduce impacts on people who live, work and play within the CBIA, measures should be taken to reduce SO₂ emissions from marine vessel activities and petroleum refining.

Marine Vessels: Marine vessels are a significant source of SO₂ emissions in the CBIA due to the high level of marine activity and the high sulphur content of marine fuel. To reduce impacts on people who live, work and play within the CBIA, it is recommended that Metro Vancouver continues to work with Port Metro Vancouver to investigate and implement measures that will reduce SO₂ emissions from marine vessel activities. It should be recognized that several steps have already been taken to reduce SO₂ emissions from marine vessels since this study was initiated. Port Metro Vancouver has established shore power at Canada Place which enables properly-outfitted cruise ships to shut down their engines while docked and connect to the
electrical grid. In addition, starting in mid-2012 the International Maritime Organization’s Annex VI protocol will come into force. This protocol contains air emission regulations, including more stringent Emission Control Area fuel and emission standards for marine vessels in Canadian waters which are expected to significantly reduce emissions of sulphur oxides and nitrogen oxides from marine vessels.

**Petroleum Refining:** Another large source of SO$_2$ emissions in the CBIA is the Chevron refinery. The SO$_2$ exceedance on January 17$^{th}$, 2009 at the T23 Burnaby-Capitol Hill station should have triggered a SOx Curtailment Event as defined in Chevron’s permit. During a SOx Curtailment Event, refinery staff is expected to reduce SO$_2$ emissions by making operational adjustments, which may include increasing its DeSOx additive. Unfortunately, the T23 Burnaby-Capitol Hill station was experiencing data communication issues at this time and the high SO$_2$ readings were misinterpreted as an instrument calibration, so no action was taken to reduce emissions. To mitigate events like this in the future, *Metro Vancouver should continue to work with the Chevron Refinery to ensure reliable ambient air quality data communications and to routinely review SO$_2$ excursion mitigation procedures.*

In addition, Environment Canada is leading a federal, provincial and territorial process to develop industrial emissions requirements for equipment groups and industrial sectors, called the Base Level Industrial Emissions Requirements (BLIERS). This process will establish industrial emission requirements for the petroleum refining sector and may require further reductions of a number of priority pollutants, including SO$_2$.

**Additional Monitoring and Analyses**

To better characterize the SO$_2$ levels within communities in the CBIA, *enhanced monitoring of SO$_2$ in adjacent populated communities on the CBIA’s south shore is recommended.*

Additional SO$_2$ monitoring within the CBIA will also help track the effectiveness of petroleum refining and marine vessel emission management efforts - in particular, the implementation of the marine Emission Control Area.

PM$_{2.5}$ concentrations were periodically elevated in the CBIA, particularly under specific meteorological conditions. However, the use of non-standard PM$_{2.5}$ monitoring instruments made comparisons to other LFV network stations challenging. In addition, the composition of PM$_{2.5}$ was not analysed in the winter and summer seasons. To confirm that PM$_{2.5}$ concentrations are periodically elevated in the CBIA and obtain more information about source apportionment, *additional monitoring and speciation of PM$_{2.5}$ within a few CBIA communities using standard*
**instrumentation is recommended.** Since only 7 months of concurrent black carbon data was collected from three sites in the entire LFV, **additional black carbon monitoring is recommended in the CBIA** to confirm the conclusion that black carbon levels are elevated in the CBIA compared to other LFV network stations.

During the study period Metro Vancouver received numerous complaints about air quality within the CBIA. However, the majority of the complaints were associated with odours. The highest percentage of all odour complaints was attributed to a rendering plant located at the north end of Commercial Drive in east Vancouver. Meteorological observations, including wind speed and direction, are very important to assist with the determination of the odour source and inform the development of mitigation measures. **It is recommended that Metro Vancouver collects representative meteorological measurements (including wind speed and direction, air temperature and humidity) within the community where most of the complaints originate.** The location considered should facilitate representative meteorological measurements.

Pollutant levels at T6 Second Narrows air quality monitoring network station are highly influenced by local industrial emission sources. The T6 Second Narrows station is located within an industrialized area and does not represent community exposure levels. However, given the pollutant levels observed during the BIALAQS at both T6 Second Narrows and the nearby S4 Lynn Pump Station, monitoring within a nearby community would better represent community exposure. **It is recommended that Metro Vancouver evaluates the value of the T6 Second Narrows station within the LFV network.**

During the BIALAQS, several volatile organic compound grab samples were collected and chemically analyzed at Environment Canada’s laboratory in Ottawa. However, the results have not yet been summarized. As these data may provide additional information for source apportionment, **analysis of the speciated VOC data is recommended.** Once completed, the VOC results will be appended to this report.

Metro Vancouver initiated a dispersion modelling study which considered the impact of several emission sources in the CBIA on outdoor air quality levels. However, this work was not completed because spatially allocated emission estimates were not available for some sources until recently. **It is recommended that Metro Vancouver collaborates with Port Metro Vancouver to conduct additional dispersion modelling.** Dispersion modelling will help to further assess the contribution of emission sources and test the effectiveness of emission reduction strategies.
6. References

www.arb.ca.gov/ch/communities/ra/westoakland/documents/westoaklandreport.pdf

www.arb.ca.gov/ch/communities/ra/westoakland/documents/factsheet0308.pdf


www.metrovancouver.org/about/publications/Publications/Air_Toxics_Emission.pdf


www.portmetrovancouver.com/Libraries/ENVIRONMENT/2010_LEI_0_-_Executive_Summary.sflb.ashx

## Appendix A BIALAQS Fixed and Mobile Site Data Statistics

### Table A1. BIALAQS Fixed Site Data Statistics

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<th>Short-term objectives</th>
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<th>Maximum (μg/m³)</th>
<th>Date of maximum (hour beginning)</th>
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<td>O$_1$</td>
<td>91</td>
<td>1-hour</td>
<td>82 ppb</td>
<td>12.0</td>
<td>56.6</td>
<td>29/07/2009 16:00</td>
</tr>
</tbody>
</table>

December 2012 91
### Site Name: S1 Vancouver Yacht Club
- **Duration**: 03-Apr-09 to 30-Jun-10
- **Parameters**: PM$_{2.5}$
- **Data Completeness**: 62%
- **Averaging period**: 24-hour rolling
- **Short-term objectives**: 25 µg/m$^3$
- **Mean**: 4.7
- **Maximum**: 24.6
- **Date of maximum (hour beginning)**: 08/08/2009 19:00

### Site Name: S2 MacLean Park
- **Duration**: 29-Jul-08 to 30-Jun-10
- **Parameters**: PM$_{2.5}$
- **Data Completeness**: 84%
- **Averaging period**: 24-hour rolling
- **Short-term objectives**: 25 µg/m$^3$
- **Mean**: 5.3
- **Maximum**: **40.2**
- **Date of maximum (hour beginning)**: 17/01/2009 16:00

### Site Name: S4 Lynn Pump Station
- **Duration**: 17-Jul-08 to 30-Jun-10
- **Parameters**: PM$_{2.5}$
- **Data Completeness**: 76%
- **Averaging period**: 24-hour rolling
- **Short-term objectives**: 25 µg/m$^3$
- **Mean**: 4.9
- **Maximum**: **93.5**
- **Date of maximum (hour beginning)**: 17/01/2009 19:00

### Site Name: S5 BCIT Marine Campus
- **Duration**: 03-Jul-08 to 30-Jun-10
- **Parameters**: PM$_{2.5}$
- **Data Completeness**: 94%
- **Averaging period**: 24-hour rolling
- **Short-term objectives**: 25 µg/m$^3$
- **Mean**: 4.9
- **Maximum**: **29.7**
- **Date of maximum (hour beginning)**: 08/08/2009 19:00

### Other LFV Network Sites

#### T1 Downtown Vancouver
- **Duration**: 03-Jul-08 to 17-May-10
- **Parameters**:
  - **NO$_2$**: 92, 1-hour, 107 ppb, 21.5, 60, 29/07/2009 19:00
  - **CO**: 89, 1-hour, 26.5 ppm, 0.26, 1.79, 19/01/2009 10:00
  - **SO$_2$**: 95, 24-hour rolling, 48 ppb, 3.4, 14, 29/07/2009 19:00
  - **O$_3$**: 94, 1-hour, 174 ppb, 3.4, 97, 28/05/2009 06:00
  - **O$_3$**: 92, 1-hour, 82 ppb, 8.7, 46, 02/07/2008 15:00
  - **SO$_2$**: 97, 1-hour, 174 ppb, 2.2, **212**, 17/01/2009 23:00
  - **SO$_2$**: 99, 24-hour rolling, 48 ppb, 2.2, **54.4**, 18/01/2009 01:00
  - **TRS**: 98, 1-hour, 5 ppb, 0.1, 4.1, 29/07/2009 07:00

#### T23 Burnaby - Capitol Hill
- **Duration**: 03-Jul-08 to 30-Jun-10
- **Parameters**:
  - **SO$_2$**: 98, 1-hour, 174 ppb, 3.1, 65, 28/08/2009 05:00
  - **SO$_2$**: 100, 24-hour rolling, 48 ppb, 3.1, 20.7, 06/10/2009 06:00
  - **TRS**: 98, 1-hour, 5 ppb, 0.1, 1.9, 13/07/2008 05:00
  - **THC**: 83, 1-hour, N/A, 2.39, 22.3, 29/07/2009 23:00

#### T24 Burnaby North
- **Duration**: 03-Jul-08 to 30-Jun-10
- **Parameters**:
  - **SO$_2$**: 97, 1-hour, 24-hour rolling, 174 ppb, 3.1, 65, 28/08/2009 05:00
  - **PM$_{10}$**: 97, 1-hour, 174 ppb, 3.1, 20.7, 06/10/2009 06:00
  - **TRS**: 98, 1-hour, 5 ppb, 0.1, 1.9, 13/07/2008 05:00
  - **THC**: 83, 1-hour, N/A, 2.39, 22.3, 29/07/2009 23:00

#### T26 Mahon Park
- **Duration**: 03-Jul-08 to 30-Jun-10
- **Parameters**:
  - **SO$_2$**: 97, 1-hour, 24-hour rolling, 174 ppb, 3.1, 65, 28/08/2009 05:00
  - **PM$_{10}$**: 97, 1-hour, 24-hour rolling, 50 µg/m$^3$, 11.2, 34.3, 02/10/2008 06:00

---

*Duration is for the first monitor listed.

b Percentage of hourly readings collected from 04-Jul-08 to 30-Jun-10.

c See “Averaging period” column for the averaging period used and the "Short-term objective" column for units. Maximum values have been appropriately averaged for comparison to the short-term objectives. RED text indicates that this concentration exceeds Metro Vancouver’s short-term (1-hour or 24-hour rolling) air quality objectives.

*PM$_{2.5}$ concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
### Table A2. BIALAQS Mobile Site Data Statistics

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Duration</th>
<th>Parameters</th>
<th>Averaging period</th>
<th>Short-term objective</th>
<th>Mean</th>
<th>Maximum</th>
<th>Date of maximum (hour beginning)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S7 Lynn Pump Station Mobile Trailer</strong></td>
<td>31/12/2008 08:00 to 20/01/2009 09:00</td>
<td><strong>PM$_{2.5}$</strong></td>
<td>24-hour rolling</td>
<td>25 μg/m$^3$</td>
<td>4.9</td>
<td><strong>37.3</strong></td>
<td>18/01/2009 00:00</td>
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<tr>
<td></td>
<td></td>
<td><strong>NO$_2$</strong></td>
<td>1-hour</td>
<td>107 ppb</td>
<td>15.8</td>
<td>51.5</td>
<td>19/01/2009 10:00</td>
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<td></td>
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<td>174 ppb</td>
<td>2</td>
<td>41.3</td>
<td>18/01/2009 09:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>24-hour rolling</td>
<td>48 ppb</td>
<td>1.9</td>
<td>13.5</td>
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<td></td>
<td></td>
<td>Black carbon</td>
<td>1-hour</td>
<td>N/A</td>
<td>1</td>
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<td>17/01/2009 03:00</td>
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<tr>
<td><strong>S8 Lonsdale Seabus Mobile Trailer</strong></td>
<td>22/01/2009 14:00 to 19/02/2009 09:00</td>
<td><strong>PM$_{2.5}$</strong></td>
<td>24-hour rolling</td>
<td>25 μg/m$^3$</td>
<td>6.4</td>
<td><strong>26.2</strong></td>
<td>30/07/2009 19:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NO$_2$</strong></td>
<td>1-hour</td>
<td>107 ppb</td>
<td>18.6</td>
<td>71.6</td>
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<td>3.1</td>
<td>90.6</td>
<td>30/07/2009 07:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>24-hour rolling</td>
<td>48 ppb</td>
<td>3</td>
<td>14.6</td>
<td>24/04/2009 12:00</td>
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<td></td>
<td>Black carbon</td>
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<td>N/A</td>
<td>1.2</td>
<td>18.2</td>
<td>18/05/2010 08:00</td>
</tr>
<tr>
<td><strong>S9 Harbour/Clark Mobile Trailer</strong></td>
<td>25/03/2009 10:00 to 23/04/2009 07:00</td>
<td><strong>PM$_{2.5}$</strong></td>
<td>24-hour rolling</td>
<td>25 μg/m$^3$</td>
<td>6.1</td>
<td>13.7</td>
<td>05/07/2009 22:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NO$_2$</strong></td>
<td>1-hour</td>
<td>107 ppb</td>
<td>22.1</td>
<td>68.9</td>
<td>06/04/2009 07:00</td>
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<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>1-hour</td>
<td>174 ppb</td>
<td>4.3</td>
<td>49.7</td>
<td>16/07/2009 07:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>24-hour rolling</td>
<td>48 ppb</td>
<td>4.3</td>
<td>20.1</td>
<td>05/07/2009 13:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black carbon</td>
<td>1-hour</td>
<td>N/A</td>
<td>1.6</td>
<td>11.7</td>
<td>04/11/2009 08:00</td>
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<tr>
<td><strong>S15 Heliport Mobile Trailer</strong></td>
<td>21/07/2009 11:00 to 28/07/2009 10:00</td>
<td><strong>PM$_{2.5}$</strong></td>
<td>24-hour rolling</td>
<td>25 μg/m$^3$</td>
<td>5.7</td>
<td>17.4</td>
<td>27/07/2009 20:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>NO$_2$</strong></td>
<td>1-hour</td>
<td>107 ppb</td>
<td>18.2</td>
<td>53.3</td>
<td>23/09/2009 14:00</td>
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<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>1-hour</td>
<td>174 ppb</td>
<td>5.4</td>
<td>77.1</td>
<td>27/07/2009 09:00</td>
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<tr>
<td></td>
<td></td>
<td><strong>SO$_2$</strong></td>
<td>24-hour rolling</td>
<td>48 ppb</td>
<td>5.4</td>
<td>19.7</td>
<td>18/06/2010 07:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black carbon</td>
<td>1-hour</td>
<td>N/A</td>
<td>1.4</td>
<td>14.5</td>
<td>26/01/2010 07:00</td>
</tr>
</tbody>
</table>

*RED text* indicates that this concentration exceeds Metro Vancouver’s short-term (1-hour or 24-hour rolling) air quality objectives.

*a* Duration is for the first monitor listed.

*b* Percentage of hourly readings collected from 04-Jul-08 to 30-Jun-10.

*c* See “Averaging period” column for the averaging period used and the “Short-term objective” column for units. Maximum values have been appropriately averaged for comparison to the short-term objectives. *RED text* indicates that this concentration exceeds Metro Vancouver’s short-term (1-hour or 24-hour rolling) air quality objectives.

*PM$_{2.5}$* concentrations were monitored using an E-sampler at these sites, as opposed to the network standard (TEOM).
Appendix B  BIALAQS PM$_{2.5}$ Speciation Data Analysis Report - Prepared by Environment Canada
Burrard Inlet Area Local Air Quality Study
PM$_{2.5}$ Speciation Data Analysis

Final Report

Prepared by:

Environment Canada
Science Division
Meteorological Service of Canada
Pacific & Yukon Region

September 2012
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Summary

As part of Metro Vancouver’s Burrard Inlet Area Local Air Quality Study (BIALAQS) effort to gain a better understanding of the air quality in the Central Burrard Inlet Area (CBIA), fine particulate matter (PM$_{2.5}$) was collected on filters at several sites for speciation analysis. The CBIA consists of a mix of densely populated neighbourhoods and port operations, including ocean-going vessels, cruise ships, cargo handling equipment, heavy-duty trucks, bulk shipping terminals, rail lines and a refinery. No previous particle speciation sampling has taken place in this area, and it is expected that the local emission sources may reveal different PM$_{2.5}$ chemical compositions at CBIA sites compared to other locations in the Lower Fraser Valley (LFV). A comparison between the BIALAQS samples and the region’s long term National Air Pollution Surveillance (NAPS) PM$_{2.5}$ speciation sites in the LFV was made to assess this, in addition to an assessment of the inter-site comparability within the CBIA.

PM$_{2.5}$ speciation data from seven CBIA sites (Vancouver Yacht Club Coal Harbour, MacLean Park, Pandora Park, Lynn Pump Station, BCIT Marine Campus, Norgate Firehall and Second Narrows) and two NAPS sites (Burnaby South and Abbotsford Airport) were used in this analysis. PM$_{2.5}$ samples were collected using an E-Sampler (Met One Instruments Inc.), which in addition to providing continuous nephelometric particulate measurements, allowed for the concurrent collection of an integrated PM$_{2.5}$ sample on a filter. The data presented here consists of three sampling events, classified as fall, early spring and late spring. As only a single filter could be collected with the E-Sampler for each sampling period, analysis was limited to water extractable ions, metals and sugar compounds. The resulting speciation data was used to perform a partial PM$_{2.5}$ mass reconstruction at the CBIA sites.

Overall the average PM$_{2.5}$ concentration measured over the three sampling periods at the CBIA sites during this study was 4.0 µg/m$^3$, which is likely an underestimate due to suspected volatization of PM$_{2.5}$ off the E-Sampler filter. Specifically, ammonium nitrate (ANO3) data were deemed to be biased low due to suspected volatilization from the single filter set up, as concentrations were significantly lower at the CBIA sites compared to the two NAPS sites. Ammonium sulphate (ASO4) measured at CBIA sites averaged 1.3 µg/m$^3$, which was significantly higher than concentrations at the two NAPS sites. On a percentage basis, the ASO4 contribution to PM$_{2.5}$ mass averaged 29% at the CBIA sites, compared to 17% and 12% at Burnaby South and Abbotsford, respectively. The contribution of sea salt to SO$_4^{2-}$ at the CBIA sites was estimated to be approximately 2%. An upper limit of the late spring period dimethyl sulphide (DMS) (biogenic) contribution to non-sea salt SO$_4^{2-}$, using methane sulphonic acid (MSA) data, was calculated to be approximately 14%, compared to 19% at Burnaby South. These data indicate the greater importance of anthropogenic sulphur dioxide emissions to aerosol...
formation in the CBIA compared to Burnaby South and Abbotsford. The highest concentrations of ASO4 were at the three sites on the south shore of Burrard Inlet, which were impacted by winds predominantly from or along the inlet or from the east during the sampling periods. ASO4 was highest in late spring at all but one site, which coincides with the seasonality of ocean going vessel activity at the port and biogenic emissions of sulphur. Sodium chloride accounted for a small fraction of the PM$_{2.5}$ mass, averaging 0.1 µg/m$^3$ at the CBIA sites, which was about half of that measured at the NAPS sites.

The Unknown fraction, which made up between 43 and 73% of the PM$_{2.5}$ mass at the CBIA sites, would be made up of the missing components organic mass, elemental carbon, fine soil and particle bound water. Concentrations of the crustal elements Al, Ca, Fe and Ti were significantly lower at the CBIA sites compared to Burnaby and Abbotsford, indicating that the fine soil contribution to PM$_{2.5}$ in the CBIA is likely lower than at the NAPS sites. Black carbon (BC) concentrations, measured with an Aethalometer at two CBIA sites were similar to elemental carbon (EC) concentrations at Burnaby and Abbotsford, however, on a percentage basis the BC contribution to PM$_{2.5}$ mass averaged 17% at the CBIA sites compared to an average EC contribution of 12% at both Burnaby South and Abbotsford, which is likely indicative of a higher relative contribution of BC sources to PM$_{2.5}$ in the CBIA.

Using vanadium as a tracer and assuming its content in heavy fuel oil burned in ships frequenting the CBIA is within a range of 65 – 150 ppm, the average ocean going vessel (OGV) contribution to primary PM$_{2.5}$ at the CBIA sites was estimated to range from 6-37%, which is significantly higher than that at Burnaby South (2-6%) and Abbotsford (0.3-0.8%). Overall the OGV contribution was highest in the late spring sampling period and at the Yacht Club and two other south shore sites, which follows the spatial and temporal pattern of ASO4 concentrations and indicates the importance of OGV contribution to sulphate concentrations in the CBIA. The contribution of biomass burning to PM$_{2.5}$ using levoglucosan as a tracer could not be quantified due to its suspected instability on BIALAQS filter samples, as concentrations were significantly lower at the CBIA sites compared to the two NAPS sites, however, potassium ion data indicated that a biomass burning contribution was present, particularly during the fall sampling period.

Elemental Al, Fe, Ca, Ti and Zn data and wind measurements indicated that the impact of road dust appeared to be higher at Second Narrows and MacLean Park compared to other CBIA sites, however, the overall crustal contribution to PM$_{2.5}$ was low within the CBIA. Elevated lead concentrations were also found at the Second Narrows and MacLean Park sites, which indicates a small local source of lead, possibly road dust. Although concentrations of the toxic metals Ni, V and Pb were elevated in CBIA, compared to Burnaby and Abbotsford, levels measured were well below established guidelines, even when the potential low bias caused by the extraction methodology employed in this study was taken into account.
Results from this study confirm one of the major findings of the criteria air contaminants analysis that the CBIA experiences unique air quality compared to other areas of the LFV, also extends to the composition of PM$_{2.5}$. Efforts to reduce PM$_{2.5}$ in the CBIA should consider reduction of sulphur dioxide as one of the key strategies. Steps currently being taken to reduce sulphur dioxide emissions in the CBIA, including the implementation of the Emission Control Area for marine vessels and the use of shore power for cruise ships, should have a positive impact on PM$_{2.5}$ levels. It is recommended that future studies to assess the effectiveness of such reduction strategies should include full speciation monitoring techniques and monitoring over a longer time period.
1. Introduction

The Burrard Inlet Area Local Air Quality Study (BIALAQS) was undertaken by Metro Vancouver from 2008-2010 in order to gain a better understanding of the air quality in the Central Burrard Inlet Area (CBIA) and provide information that can be used to determine outdoor exposures and associated human health risks (Metro Vancouver, 2012). To achieve this, a comprehensive suite of air pollutants were measured at multiple sites around the CBIA over a two year period, including fine particulate matter (PM$_{2.5}$), black carbon, NO$_2$, SO$_2$, CO, O$_3$, and VOCs, as well as meteorological parameters. In addition, a number of PM$_{2.5}$ samples were collected on filters at several sites for speciation analysis.

PM$_{2.5}$ speciation sampling is an important step towards informing air quality management actions to reduce ambient PM$_{2.5}$ levels, as it allows for the identification and quantification of the individual species contributing to bulk PM$_{2.5}$ mass. Knowledge of the constituents of PM$_{2.5}$ can, in some cases, be combined with knowledge of the emission profiles of common sources of PM$_{2.5}$ to apportion the measured PM$_{2.5}$ to individual source categories. In addition to source contribution information, knowledge of the presence of toxic species in ambient PM$_{2.5}$ can provide information on potential human health impacts.

The CBIA consists of a mix of densely populated neighbourhoods and port operations, including ocean-going vessels, cruise ships, cargo handling equipment, heavy-duty trucks, bulk shipping terminals, rail lines and a refinery. No previous particle speciation sampling has taken place in this area, and it is expected that the local emission sources may reveal different PM$_{2.5}$ chemical compositions at CBIA sites compared to other locations in the Lower Fraser Valley (LFV). To assess this, PM$_{2.5}$ filter samples collected by Metro Vancouver were analysed by Environment Canada. A comparison between the CBIA samples and the two long term National Air Pollution Surveillance (NAPS) PM$_{2.5}$ speciation sites in the LFV were made, in addition to an assessment of the inter-site comparability within the CBIA. As only a limited number of samples were collected, a comprehensive, quantitative source apportionment was not possible, however, ambient concentrations, useful source information and temporal and spatial trends were derived from the data and are presented in this report.

2. Methodology

2.1 Sampling Sites

PM$_{2.5}$ speciation data was available at seven CBIA sites as depicted in Figure 1: Vancouver Yacht Club (Coal Harbour) (S1), MacLean Park (S2), Pandora Park (S3), Lynn Pump Station (S4), BCIT Marine
BIALAQS PM$_{2.5}$ Speciation Data Analysis (Environment Canada)

Campus (S5), Norgate (Firehall) (S6) and Second Narrows (T6). In addition, data from the region’s two National Air Pollution Surveillance Particle Speciation sites, Burnaby South (T18) and Abbotsford Airport (T34), were used as part of the analysis. T18 is located in a school in a residential area of Burnaby, while T34 is in a rural agricultural area of Abbotsford and is surrounded by dense poultry farming operations and berry crop production. Information on the sites located within the CBIA and potential impact of nearby sources is detailed in the BIALAQS report (Metro Vancouver, 2012).

![Figure 1: Map of Lower Fraser Valley, the Central Burrard Inlet Area (CBIA) and CBIA sites (inset)](image)

### 2.2 Sampling Methodology

PM$_{2.5}$ samples were collected using an E-Sampler (Met One Instruments Inc.), which in addition to providing continuous nephelometric particulate measurements, allowed for the concurrent collection of an integrated PM$_{2.5}$ sample on a filter. The E-Sampler was equipped with a sharp-cut cyclone, which
excluded particles greater than 2.5 μm. Pre- and post-sampling filter weights were measured by Metro Vancouver allowing for the calculation of bulk PM$_{2.5}$ concentration over the measuring period by dividing the difference of the pre-sampling and the post-sampling filter weights by the total volume of air collected. The period of study consisted of three sampling events, classified in this report as fall (October 8 – November 10, 2009), early spring (March 24 – April 14, 2010), and late spring (May 20 – June 18, 2010). Due to power failures, some sampling time was lost at Lynn Pump station and Pandora Park during the fall period and at MacLean Park during the late spring sampling period. A list of all the sampling times and details are displayed in Table 1.

Table 2: Total sampling time and sampling volumes during three sampling periods at the seven CBIA sites

<table>
<thead>
<tr>
<th>Station</th>
<th>Sample ID</th>
<th>Start Date</th>
<th>End Date</th>
<th>Total Sampling Time [hr]</th>
<th>Sampling Vol. [m$^3$]</th>
<th>PM$_{2.5}$ [µg/m$^3$]</th>
</tr>
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<tr>
<td>Second Narrows</td>
<td>8A</td>
<td>10/8/2009</td>
<td>11/10/2009</td>
<td>792:00</td>
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<td>58.6</td>
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<td>696:00</td>
<td>80.6</td>
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<td>11/10/2009</td>
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<td>85.5</td>
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<td>4/14/2010</td>
<td>504:00</td>
<td>58.3</td>
<td>3.5</td>
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<td>5/20/2010</td>
<td>6/18/2010</td>
<td>696:00</td>
<td>80.5</td>
<td>3.4</td>
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<td>BCIT Marine Campus</td>
<td>8C</td>
<td>10/8/2009</td>
<td>11/10/2009</td>
<td>792:00</td>
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<td>4/14/2010</td>
<td>504:00</td>
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<td>4.8</td>
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<td>91.4</td>
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<td>696:00</td>
<td>80.6</td>
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Power Failures:
$^1$ Oct 20 – Oct 22 (51 hr 59 min), $^2$ Oct 31 – Nov 3 (77hr 59 min), $^3$ June 1 – June 2 (22 hr 59 min)

For the NAPS speciation sites at Burnaby South and Abbotsford Airport, 1 in 3 day speciation data available during each of the three sampling periods were averaged to allow for a comparison to the BIALAQS data. The comparisons, therefore, are not direct temporal comparisons due to the different sampling periods (whole period integrated vs. average of 1 in 3 day samples) but nevertheless give an indication of spatial variability of PM$_{2.5}$ composition in the LFV. At T18 there were 12, 8 and 11 samples
BIALAQS PM$_{2.5}$ Speciation Data Analysis (Environment Canada)

for the fall, early spring and late spring periods, respectively. The T34 station was shut down in April 2010, therefore late spring period data were not available at this site and only 5 samples were available for the early spring period; 12 samples were used for the fall period. NAPS speciation sampling and analysis methodology is explained in detailed in Dabek-Zlotorzynska et al., 2011. Reconstructed mass [RCM] was performed for the T18 and T34 sites following standard NAPS procedures as follows:

$$[\text{RCM}] = [\text{ANO}_3] + [\text{ASO}_4] + [\text{OM}] + [\text{EC}] + [\text{SOIL}] + [\text{TEO}] + [\text{NaCl}] + [\text{PBW}] \quad \text{Eq. 1}$$

where,

Ammonium nitrate $[\text{ANO}_3] = 1.29[\text{NO}_3^-]$  
Ammonium sulphate $[\text{ASO}_4] = [\text{SO}_4^{2-}] + [\text{NH}_4^+] - 0.29[\text{NO}_3^-]$  
Organic mass $[\text{OM}] = k^*[\text{OC}]$  
Elemental carbon $[\text{EC}] = [\text{EC}]$  
Fine soil $[\text{SOIL}] = 3.48[\text{Si}] + 1.63[\text{Ca}] + 1.5[\text{Fe}] + 1.41[\text{K}] + 1.94[\text{Ti}]$  
Other elements $[\text{TEO}] = 1.47[\text{V}] + 1.29[\text{Mn}] + 1.27[\text{Ni}] + 1.25[\text{Cu}] + 1.24[\text{Zn}] + 1.32[\text{As}] + 1.08[\text{Pb}] + 1.2[\text{Se}] + 1.37[\text{Sr}] + 3.07[\text{P}] + 1.31[\text{Cr}]$  
Sodium chloride $[\text{NaCl}] = [\text{Na}] + [\text{Cl}]$  
Particle bound water $[\text{PBW}] = 0.32([\text{SO}_4^{2-}] + [\text{NH}_4^+]$)

Since phosphorous was not measured, the $[\text{TEO}]$ calculation was modified to omit that term.

As with the NAPS speciation samples, BIALAQS filters were sent to Environment Canada’s Environmental Science and Technology Centre (ESTC) in Ottawa in August 2010 and were analysed following the standard NAPS techniques. As only a single filter could be collected with the E-Sampler for each sampling period, analysis was limited to water extractable ions, metals, and sugar compounds. The resulting speciation data was used to perform a partial PM$_{2.5}$ mass reconstruction at the CBIA sites. Due to the unavailability of data, the $[\text{OM}]$, $[\text{EC}]$, $[\text{SOIL}]$ and $[\text{PBW}]$ terms in Equation 1 could not be determined. Aethalometer black carbon (BC) data, however, was available at the Norgate and Second Narrows sites. Co-located EC and BC measurements at Burnaby South from Sep. 2010 to Sep. 2011 showed a near to one to one relationship (slope = 1.06, $r^2$ = 0.84), whereas EC measurements were slightly higher than BC measurements at Abbotsford, based on co-located data from May 2009 to Apr. 2010 (slope = 1.2, $r^2$ = 0.88). Given these strong correlations, aethalometer BC data was used as a surrogate for [EC] in the mass reconstruction at Second Narrows and Norgate, though it should be noted that data are not necessarily representative of EC concentrations at these sites. The following equation, therefore, was used to determine RCM at the CBIA sites:

$$[\text{RCM}] = [\text{ANO}_3] + [\text{ASO}_4] + [\text{TEO}] + [\text{NaCl}] + [\text{BC} \text{ (where available)}] + [\text{Unknown}] \quad \text{Eq. 2}$$
where,

\[ \text{Unknown} = [\text{PM2.5}] – [\text{ANO3}] – [\text{ASO4}] – [\text{TEO}] – [\text{NaCl}] – [\text{BC}] \] (where available)

One notable limitation of the use of E-Samplers was that neither an upstream denuder nor backup filter could be employed. The use of a denuder and backup filter are important when sampling for particulate nitrate, and to a lesser extent sulphate, as their use can reduce sampling artefacts. The denuder captures and removes SO$_2$, which can be converted to SO$_4^{2-}$ on the filter leading to a positive artefact. Similarly the denuder captures and removes HNO$_3$ which could lead to a positive NO$_3^-$ artefact. Use of a back-up nylon filter, which has a high affinity for gaseous nitrate, captures nitrate that is prone to volatilization off the front Teflon filter, thereby allowing for correction of negative sampling artefacts.

3. Results and Discussion

3.1 PM$_{2.5}$ Mass Reconstruction

PM$_{2.5}$ mass reconstructions for the three periods at all monitoring sites are shown in Figure 2. Also shown on the graph are the period average E-Sampler nephelometric PM$_{2.5}$ readings. Overall the average PM$_{2.5}$ concentration measured using the E-Sampler’s filter at the CBIA sites was 4.0 µg/m$^3$ compared to an average of 5.2 µg/m$^3$ for Burnaby and Abbotsford over the same periods. This is in contrast to full BIALAQS results, which concluded that PM$_{2.5}$ concentrations are periodically elevated in the CBIA compared to other sites in the LFV. This discrepancy could be due to the limited sampling period of the filter based sampling, the different sites in the LFV used for comparison and also the different monitoring technology, which could have lead to gain or loss of semi-volatiles off the E-Sampler filter over the course of the sampling period. The majority of measurements agree within 25% and ± 1 µg/m$^3$ but slightly larger biases for the filter based measurements were found at MacLean Park (negative, late spring), Pandora Park (negative, early and late spring and at the Yacht Club (positive, late spring).
Figure 2: PM$_{2.5}$ mass reconstruction at the seven CBIA sites and Burnaby South and Abbotsford. The three sampling periods for each site are shown from left to right: Fall, Early Spring, Late Spring. The black diamonds show the period average E-Sampler nephelometric PM$_{2.5}$ readings.

* PM$_{2.5}$ speciation were monitored using standard NAPS sampling instrumentation at these sites, as opposed to the E-sampler methodology used at all CBIA sites.

** Second Narrows and Norgate sites are black carbon (BC), while Burnaby South and Abbotsford sites are elemental carbon (EC)

Observed ANO$_3$ concentrations ranged 0.04 to 0.15 µg/m$^3$ and averaged 0.08 µg/m$^3$ at the CBIA sites with the concentrations, on average, being highest in the fall sampling period. In comparison, concentrations at the two NAPS sites ranged from 0.58 to 0.92 µg/m$^3$ and averaged 0.66 and 0.92 µg/m$^3$, at Burnaby and Abbotsford, respectively. On a percentage basis the ANO$_3$ contribution to PM$_{2.5}$ mass averaged 2.1% at the CBIA sites, compared to 14% and 17% at Burnaby South and Abbotsford, respectively. This large discrepancy is almost certainly caused in part by the different monitoring technology employed at the CBIA sites as the lower contributions of ANO$_3$ indicates a negative sampling artefact. The percentage of total nitrate that was measured on the back-up nylon filter (indicating a negative artefact) for samples used in this study at T18 was 47% (SD=20%), with higher than average artefacts in the late spring and lower than average artefact in the early fall due to increased volatilization at warmer temperatures. To complicate matters, however, sampling of nitric acid may cause a positive ANO$_3$ artefact due to the deposition of gas phase nitric acid directly to the filter in the absence of a denuder. Given that significantly lower nitrate concentrations were found at the CBIA sites compared to the NAPS sites it is likely that the negative artefact is dominant, however, the magnitude of the error cannot be accurately assessed, therefore BIALAQS ANO$_3$ data is best used only to provide an estimate of spatial variability between the sites. Overall, the degree of variability between sites was small but MacLean Park and Second Narrows showed the highest ANO$_3$ contribution and Pandora Park and Yacht Club the lowest.
The ASO4 measured at all the CBIA sites ranged from 0.9 to 1.8 μg/m³ and averaged 1.3 μg/m³, compared to a range of 0.60 to 0.91 μg/m³ and average of 0.80 μg/m³ and 0.62 μg/m³ at Burnaby and Abbotsford, respectively. The ratio of non-sea salt SO₄²⁻ (nssSO₄²⁻) to SO₄²⁻, calculated using measured Na⁺ and a SO₄²⁻:Na⁺ mass ratio of 0.252 for sea salt (Sharma et al, 2003), averaged 0.98 at the CBIA sites and 0.96 and 0.97 at Burnaby South and Abbotsford, respectively. A caveat to the BIALAQS findings is that positive artefacts for SO₄²⁻ are possible due to conversion of SO₂ on the filter, which was not preceded by a denuder as used in the NAPS sampling methodology. Previous studies in the US have found slopes ranging from 0.81 – 1.22 when comparing sulphate measured via filter-based samplers with and without upstream denuders (Benner et al, 1991; Drenwick et al, 2003; Ames and Malm, 2001). Assuming a high end positive artefact of 20%, average ASO4 concentrations still appear to be higher at the CBIA sites compared to T18 and T34. On a percentage basis the ASO4 contribution to PM₂.₅ mass averaged 29% at the CBIA sites, compared to 17% and 12% at Burnaby South and Abbotsford, respectively. In order to account for potential errors due to the influence of artefacts on the total PM₂.₅ mass, a recalculation was performed using the average E-Sampler nephelometer PM₂.₅ in place of the filter-based PM₂.₅ and the average percentage contribution of ASO4 at the CBIA sites remained at 29%. This indicates the greater importance of sulphur emissions to aerosol formation in the CBIA compared Burnaby South and Abbotsford. Sources of sulphur emissions in the CBIA include marine shipping, diesel combustion, petroleum refining and the oxidation of marine dimethyl sulphide (DMS) biogenic emissions. The highest concentrations of sulphate were at the Yacht Club, followed by Pandora Park and MacLean Park, while Norgate had the lowest. Figure 3 shows PM₂.₅ pollution roses averaged over the 3 sampling periods for the CBIA sites. During the period of study, sites on the south shore of Burrard Inlet – the three sites having the highest concentration and contribution of sulphate, had winds predominantly from or along Burrard Inlet or from the east. With the exception of MacLean Park, which had slightly higher levels in the fall, the concentration of ASO4 was highest in late spring at all other sites, which coincides with increased ocean going vessel activity and the oxidation of DMS from marine algae, which is known to peak in the spring and summer periods in the Strait of Georgia (Sharma et. al., 2003; Norman et al., 2003).
Black carbon, which was measured using an aethalometer at Second Narrows and Norgate, had concentrations ranging from 0.42 to 1.2 µg/m³ and averaged 0.72 µg/m³ over the three sampling periods compared to EC values ranging from 0.38 to 1.0 µg/m³ and averages of 0.61 µg/m³ and 0.72 µg/m³ at Burnaby and Abbotsford, respectively. On a percentage basis the BC contribution to PM$_{2.5}$ mass averaged 17% at the CBIA sites (using the average E-Sampler nephelometer value for total PM$_{2.5}$), compared to an average EC contribution of 12% at both Burnaby South and Abbotsford. Assuming that EC is biased high compared to BC at Burnaby and Abbotsford (by 6 and 20%, respectively, as discussed above) this appears to be indicative of a higher relative contribution of BC sources to PM$_{2.5}$ in the CBIA; these include ocean going vessels, diesel combustion (heavy duty trucks and rail) and possibly wood smoke. At both CBIA sites BC concentrations were highest during the fall period sampling period, followed by the late spring and early spring sampling periods. Increased impact by wood smoke during the fall season could possibly be contributing to the seasonality observed here – analysis of BC seasonality is discussed in more detail in the full BIALAQS report.

On average, the concentration of NaCl ranged from 0.08 to 0.19 µg/m³ and averaged 0.12 µg/m³ at the CBIA sites compared to a range of 0.18 to 0.36 µg/m³ and averages of 0.25 µg/m³ and 0.23 µg/m³ at Burnaby and Abbotsford, respectively. It is possible that the NAPS sites are more impacted by salt particles from Georgia Strait, which has more breaking waves compared to the calmer waters of Burrard Inlet. At all CBIA sites the highest concentrations of NaCl were either in the fall or early spring sampling
periods. The highest average NaCl concentrations were found at MacLean Park and Yacht Club, while the lowest were found at Lynn Pump Station and Norgate. TEO concentrations averaged 0.029 μg/m³ at the CBIA sites, compared to 0.024 μg/m³ at Burnaby South and Abbotsford. Trace metal results are discussed in further detail below.

The Unknown fraction, which made up between 43 and 73% of the PM₃.₅ mass at the CBIA sites, would be made up of the missing components OM, EC (at sites where it was not measured), crustal matter SOIL and PBW. At Second Narrows and Norgate the Unknown fraction, which would be made up of mostly OM, averaged 48% of the measured mass and varied slightly between the seasons, ranging from approximately 43 – 52%. In comparison, OM made up an average of 38% and 44% of the PM₂.₅ mass at Burnaby and Abbotsford, respectively, but showed a larger seasonal variation.

### 3.2 Trace Metals Results

The distribution of concentrations of trace metals for the three sampling periods at all CBIA sites are displayed along with the distribution of concentrations for individual samples from Burnaby and Abbotsford in Figure 4a and b. Silver, beryllium and uranium were largely below detection limits and therefore are not discussed further. It can be seen in Figure 4 that concentrations of As, Ba, Cu, Cd, Co, Cr, Mn, Mo, Sb, Se and Sr did not vary greatly between the CBIA sites and Burnaby/Abbotsford, as they had overlapping interquartile ranges, whereas Al, Fe, Ni, Pb, Ti, V and Zn, showed greater variability – these results are discussed in further detail below.

![Figure 4: Average trace metals concentrations using water extraction at seven CBIA sites (combined) and Burnaby South and Abbotsford (individual samples). The solid square represents the median, the box the 25th to 75th percentiles and the whiskers the minimum and maximum. Maximum values for Al at T18 and Sr at the CBIA sites were 60 and 6.3 ng/m³, respectively.](image-url)
BIALAQS PM$_{2.5}$ Speciation Data Analysis (Environment Canada)

It should be noted that due to only one filter being available for analysis for the BIALAQS samples, trace metals were extracted in water, resulting in less than full recovery for some elements due to lower solubility. Figure 5 shows a comparison of 2009-2010 trace metal data at Burnaby South using water extraction (WICPMS) versus acid extraction (ICPMS), which allows for near complete extraction of metals from the PM$_{2.5}$. It can be seen from the regression slopes in Figure 5 that results for WICPMS are generally lower, therefore trace metal data reported here are likely to be biased low, with the exception of possibly cadmium, cobalt, strontium, vanadium and zinc. To facilitate comparison with the CBIA sites, Burnaby South and Abbotsford trace metals data in Figure 4 are also WICPMS.

![Figure 5: Scatter plots of water-extracted metals (WICPMS) versus acid-extracted metals (ICPMS). The black line is the regression line and the red is the 1:1 line.](image)

Aluminum, iron and titanium are typically associated with particulate of crustal origin. The combined concentrations of Al, Fe and Ti at the CBIA sites ranged from 4.0 to 13 ng/m$^3$ compared to a range of 10 to 19 ng/m$^3$ at Burnaby and Abbotsford (Figure 6). On average, these three crustal elements constituted 0.15% of the PM$_{2.5}$ mass at the CBIA sites and 0.35 and 0.19% of the mass at Burnaby and Abbotsford, respectively. These results indicate a slightly lower impact of crustal matter on PM$_{2.5}$ at the CBIA sites compared to the NAPS sites, particularly Burnaby. Overall the highest average concentrations were found at Seconds Narrows followed by MacLean Park, indicating a local source of fugitive dust impacting these sites. Given the proximity to and impact of wind directions from high volume traffic corridors at these sites, road dust is a possible source. A concrete batch plant within 200m of the Second Narrows site is another possible source of elevated crustal elements. The lowest concentrations were
found at BCIT Marine Campus, Yacht Club and Norgate. Overall there was no clear seasonal trend to the crustal element data, with different sites displaying maxima during each of the sampling periods.

Figure 6: Concentrations of aluminum, iron and titanium at the CBIA sites and at Burnaby South and Abbotsford. The three sampling periods for each site are shown from left to right: Fall, Early Spring, Late Spring.

Nickel and vanadium are found in residual/heavy fuel oil (HFO) burned in ocean going vessels (OGV) and are emitted as particles during combustion. Concentrations of Ni and V were found to be higher at all seven CBIA sites compared to Burnaby and Abbotsford (Figure 7). Nickel concentrations ranged from 0.9 to 4.3 ng/m³ at the CBIA sites and 0.2 to 1 ng/m³ at Burnaby South and Abbotsford, while vanadium concentrations ranged from 3 to 16 ng/m³ at the CBIA sites and 0.3 to 2.9 ng/m³ at Burnaby South and Abbotsford. The V/Ni ratio was consistent across the CBIA averaging 3.6 ± 0.18, which is higher than the ratio found previously at sites impacted by ship emissions in Victoria (2.2) (Poplowski et al, 2008), Seattle (2.1) (Kim and Hopke, 2008), Los Angeles (2.7) (Agrawal et al, 2009) and Gibraltar (2.5) (Pandolfi et al, 2009). This higher ratio is likely caused due to the water extraction methodology, which is favourable to vanadium compared to nickel (Figure 5). Similarly, the concentrations ranges observed in this study are slightly lower overall than levels found in the above referenced studies, which is also likely due in part to the water extraction methodology employed here. Using the regression equations in Figure 5 to correct the Ni and V concentrations for low recovery, the average V/Ni ratio becomes 2.1 at the CBIA sites and 2.0 and 1.7 at Burnaby and Abbotsford, respectively. The lower nickel and vanadium concentrations found at Burnaby and Abbotsford, lower percentage contribution to PM$_{2.5}$ and lower V/Ni ratios are indicative of these two sites’ greater distance from marine sources (Agrawal et al, 2009).

Overall the Yacht Club site had the highest combined average concentrations of Ni and V followed by Pandora Park, while the Norgate site had the lowest concentrations. These results make sense when the direction of the wind impacting the sampling sites is considered (Figure 3). The Ni and V concentrations follow the spatial pattern of ASO4 concentrations and further illustrate the impact of OGV emissions at
these sites. With the exception of Lynn Pump Station, where early spring concentrations were only slightly higher, nickel and vanadium concentrations were highest in late spring across all sites. The number of ships calling at all terminals in Burrard Inlet were 6.4, 7.8 and 8.4 per day in the fall, early spring and late spring periods, respectively (G. Olszewski, pers. comm.), which explains the seasonal pattern of Ni and V concentrations observed here.

![Figure 7: Concentrations of nickel and vanadium at the CBIA sites and at Burnaby South and Abbotsford. The three sampling periods for each site are shown from left to right: Fall, Early Spring, Late Spring.](image)

Following the methodology of Agrawal et al, 2009, the OGV contribution to primary PM$_{2.5}$ was estimated according to the following equation:

$$PM_{(OGV)} = (r)V_a \times F_V$$

where,
- $PM_{(OGV)} = ocean$ going vessel primary PM$_{2.5}$ concentration estimate ($\mu g/m^3$)
- $V_a = ambient$ vanadium concentration ($\mu g/m^3$)
- $F_V = average$ is the V content of the heavy fuel oil from all vessels (ppm)
- $r = average$ ratio of PM$_{2.5}$ to normalized V emitted (= 8205)

Vanadium was chosen as a more accurate tracer compound due to its higher average recovery by the water extraction method used here (Figure 5). As no fuel sample testing was undertaken for this study, an estimation of V content of fuels used in OGVs frequenting the CBIA was required. According to a recent national marine emission inventory, the sulphur content in fuel of OGVs on the west coast burning heavy
fuel oils ranges from 1% to 3.5% (SNC Lavalin Environment, 2012), which corresponds to the residual marine fuel (HFO) grades RMA or RMB, which have maximum V content of 150 ppm (ISO, 2005). Additionally the V content of locally supplied intermediate fuel oil (IFO) used in cruise ships docking in the CBIA is 65 ppm (Gary Olszewski, pers. comm.). These values of 150 ppm and 65 ppm (which match quite closely to the F_V range of 100 ± 47 determined in the referenced study from six different ships in the port of Los Angeles), therefore, are used as upper and lower limits for the F_V value in calculating the OGV contribution to primary PM_{2.5} (Eq. 3), the results of which are displayed in Figure 8. The upper limit displayed assumes that all V measured at the receptor sites is derived from combustion of fuel oil having a V content of 65 ppm, whereas the lower limit assumes a V content of 150 ppm. In reality the V content of OGV emissions impacting the site varies, and thus the average OGV contribution to primary PM_{2.5} is somewhere within the range shown. Another assumption of this analysis is that no other major sources of V are impacting the monitoring site. The other major emission source of V in ambient air is power generation from residual fuel oil or coal combustion. A check of the inventory for the Canadian portion of Lower Fraser and Whatcom County confirmed that there are no large permitted sources residual fuel oil combustion (D. Jennejohn, pers. comm.; C. Christoforou, pers. comm). Two permitted sources of coal burning (cement plants) exist in the region, both of which are approximately 15km to the south-southeast of the CBIA, (L. Bates-Frymel, pers. comm.), however, neither facility reported emissions of vanadium in the years 2009 and 2010 (Environment Canada, 2012).

Averaged over the three sampling periods, the Yacht Club site had the highest contribution of OGV to primary PM_{2.5}, estimated to be in the range of 16-37%, followed by Pandora Park (11-26%) and MacLean Park (10-22%), while Norgate had the lowest (6-15%). These results indicate that the south shore of Burrard Inlet is more impacted by primary PM_{2.5} from OGVs than the north shore, which in turn is significantly more impacted than Burnaby South (2-6%) and Abbotsford (0.3-0.8%), further up the valley. With the exception of Lynn Pump Station where early spring contributions were only slightly higher, the OGV contribution was estimated to be highest in late spring across all sites. For comparison, also shown on the graph, are a calculation of OGV contribution to PM_{2.5} using the V tracer method for the years 2003-2008 and the results of a source apportionment analysis using positive matrix factorization (PMF) for the same years at Burnaby South and Abbotsford (So et al, 2012). The 5 year average of the OGV contribution via the V tracer method was found be 1.0 and 0.9% at Burnaby and Abbotsford, respectively. which, when the error limits are considered, is in relatively close agreement with the BIALAQS data set. The fuel oil combustion contribution to PM_{2.5} via PMF analysis was found to be 6% and 9% at Burnaby and Abbotsford, respectively, indicating some discrepancy between the two methods, however, when the error limits of the PMF analysis are taken into account, the numbers do agree reasonably well.
Figure 8: Contribution of OGV to primary PM$_{2.5}$ at CBIA sites, Burnaby and Abbotsford (V tracer method); and contribution of fuel oil combustion to PM$_{2.5}$ (PMF) at Burnaby and Abbotsford.

There are no Canadian guidelines for Ni and V in ambient air, however, the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRL) for chronic-duration inhalation exposure (≥1 year) are 100 ng/m$^3$ and 90 ng/m$^3$, respectively. Average Ni and V concentrations at the Yacht Club site, which showed the highest levels, were 12 and 3.2 ng/m$^3$, respectively, and were much lower than the chronic MRLs established by ATSDR. Recent health studies have shown that increases in the inter-quartile range of the proportion of Ni and V in PM$_{2.5}$ were associated with increased respiratory and cardiovascular hospital admissions (Bell et al, 2009), cardiovascular hospital emissions (Zanobetti et al, 2009) and daily deaths (Ni only) (Franklin et al., 2008), while increases in the inter-quartile range of ambient Ni and V concentrations were associated with wheezing in children (Patel et al., 2009).

Lead concentrations ranged from 0.7 to 21.2 ng/m$^3$ at the CBIA sites and 0.9 to 1.4 ng/m$^3$ at Burnaby South and Abbotsford. This observed spatial variation is primarily due to lead concentrations at the Second Narrows and MacLean Park sites which are significantly higher than all the other sites (Figure 9). Percentages of lead in PM$_{2.5}$ at Second Narrows and MacLean Park, ranged from 0.38 to 0.55% and 0.17 to 0.27%, respectively, and were approximately 20x and 10x higher than those found at Norgate, Burnaby South and Abbotsford. This is indicative of a local source of lead impacting the Second Narrows and MacLean Park sites. Point sources of lead reporting to the National Pollutant Release Inventory for 2009 and 2010 in the CBIA include a laboratory located ~1.5km northwest of Second Narrows and the Vancouver Wharves Terminal located ~7.5km to the west. Possible area sources of lead in the CBIA are aviation fuel combustion (float planes and helicopters) and road dust. The PM$_{2.5}$ pollution roses for the
periods of sampling show primary impacts from the west and north to east sectors for Second Narrows and from the E and ENE at MacLean Park (Figure 3), which doesn’t match particularly well with the point sources identified above. This lack of evidence, combined the significantly lower concentrations at other sites, including those that are upwind, indicates small localized sources of Pb in proximity to the Second Narrows and MacLean Park sites, possibly road dust. Another possibility in the case of MacLean Park are the heliport or float plane terminals located 1.5 km and 2.5 km northwest of the site, respectively. While concentrations of Pb are elevated at some sites in the CBIA, they are well below the provincial objective of 2 µg/m$^3$ (annual average) and the EPA’s recently updated NAAQS level of 0.15 µg /m$^3$ (3 month average), even when the probable low bias of Pb is taken into account. There is no national air quality standard for Pb in Canada.

![Figure 9: Concentrations of lead at the CBIA sites and at Burnaby South and Abbotsford](image)

Zinc is emitted from industrial metal refining and processing, waste incineration and traffic (tire wear) sources. Average Zn concentrations at all seven CBIA sites were found to be slightly lower those of at Burnaby and Abbotsford. Zn concentrations ranged from 3.0 to 23 ng/m$^3$ at the CBIA sites, and 6.0 to 17 ng/m$^3$ at Burnaby South and Abbotsford (Figure 10). The higher maximum at the CBIA sites is due to a high early spring sample at the Yacht Club, the cause of which is uncertain. With the exception of this one high reading, the highest average concentrations were found at MacLean Park followed by Seconds Narrows, which were also the two highest sites for Al, Fe, and Ti, further indicating that road dust, including tire wear, may be have a higher impact at these sites.
3.3 Trace Ions Results

Concentration of trace ions at all CBIA sites combined are shown side by side with Burnaby and Abbotsford data in Figure 11. Bromide lithium, nitrite, phosphate and propionate levels were largely below the detection limits and therefore are not discussed further.

Concentrations of acetate and formate are much lower at the CBIA sites compared to Burnaby South and Abbotsford, whereas the oxalate concentrations are more similar. This is likely due to loss of the more volatile formate and acetate off the E-Sampler filter. Similar concentrations of oxalate give some
indication of the relative contribution of organic aerosol to PM$_{2.5}$ in the CBIA compared to sites further up the valley, however, measurement of total OC at the BIA sites would be necessary to fully assess this. Calcium, which is typically associated with particulate of crustal origin, is significantly lower at the CBIA sites compared to Burnaby South and Abbotsford. These results are in agreement with those of aluminum, iron and titanium, discussed above, which indicated a lower impact of crustal material at the CBIA sites compared to the NAPS sites. Within the CBIA, the highest concentrations of calcium were measured at Second Narrows and MacLean Park, as was seen for Al, Fe, Ti and Pb.

Levoglucosan concentrations at the CBIA sites ranged from 0.8 to 3.6 ng/m$^3$ – much lower than the range of 38 to 168 ng/m$^3$ measured at Burnaby South and Abbotsford (Figure 12). At Burnaby South and Abbotsford, the percentage of levoglucosan in PM$_{2.5}$ ranged from 0.96% to 2.24%, while percentages at the CBIA sites ranged from 0.02 to 0.09%. While the lower levels found in the CBIA could be indicative of a lower impact of wood smoke, the very large discrepancy is likely influenced by sampling methodology. Levoglucosan has been used as a quantitative tracer for biomass burning emissions for several years, however, recent studies have shown that it may not be as stable in the atmosphere as previously assumed due to degradation in the presence of OH radicals (Hennigan et al, 2010; Hoffman et al 2010). It is possible that significant degradation of levoglucosan occurred over the course of the long sampling periods employed for the CBIA samplers or possibly during storage of the filters at room temperature prior to shipping to the lab. In addition, levoglucosan recoveries in NAPS samples using an upstream denuder have been found to be approximately 50% higher compared to undenuded filter samples (Dabek-Zlotorzynska, pers. comm.). A combination of these factors could be causing the lower concentrations found at the CBIA sites but the magnitude of these errors can not be assessed. Although it is also present to some extent in sea salt and crustal matter, the potassium ion is another commonly used marker for biomass burning. Using a Na$^+$/K$^+$ ratio typical of seawater, the fall season contribution of seawater to K$^+$ was calculated to be approximately 5%, indicating that the majority of K$^+$ measured was likely due to burning. Given that K$^+$ is present at levels similar to those at Burnaby and Abbotsford and was significantly higher in the fall season (Figure 13) does indicate that a wood smoke impact is present. Also, data from the Aethalometer at the Second Narrows and Norgate sites showed evidence of wood smoke (Metro Vancouver, 2012). Additionally a wood smoke sampling campaign in the winter of 2004-2005 found levoglucosan concentrations to be within a factor of 2 of between the Burnaby South site and a downtown site (Larson et al, 2007), compared to factor of 30 found here during the fall period. These other measurements, along with the uniformly low concentrations found in this study, provide further evidence that levogluocosan may not have been stable on CBIA filter samples, therefore, results from this study cannot be used to estimate wood smoke contribution to PM$_{2.5}$ in the CBIA. The K$^+$ results, however, do allow a spatial comparison of the relative impact of biomass burning, which appears to be highest at MacLean Park, followed by BCIT Marine campus, and lowest at Pandora Park.
Methane sulphonic acid (MSA) concentrations at CBIA sites ranged from 0 to 40 ng/m$^3$ with the highest concentrations occurring in the late spring (Figure 14). The high late spring concentrations, caused by the oxidation of dimethyl sulphide (DMS) from marine algae, were very consistent across the CBIA sites and Burnaby South, ranging from 36 to 40 ng/m$^3$, indicating that it is well-mixed in this season. No MSA was detected at Burnaby South during fall and early spring periods, at MacLean Park and Norgate during the early spring period, or at Abbotsford during the fall period, and no sample was taken at Abbotsford in the late spring. The spring period ratio of MSA to nssSO$_4^{2-}$ averaged 0.034 at the CBIA sites and 0.041 at Burnaby South. This ratio is significantly lower than the average ratio of 0.23 found in the open north Pacific Ocean (Phinney et al, 2006), as expected due to the influence of near- and onshore anthropogenic sources of SO$_4^{2-}$ impacting the sites in this study. In the absence of anthropogenic sources of SO$_4^{2-}$, the MSA:nssSO$_4^{2-}$ ratio is indicative of the relative contribution of the temperature dependant formation of MSA vs. SO$_2$ in one of the DMS oxidation pathways (Seinfeld and Pandis, 2006). Using a ratio of 20% for the MSA pathway and 80% for the SO$_2$ pathway measured in the north Pacific (ambient temperature of 9.8 – 15°C) (Phinney et al, 2006), the late spring period DMS contribution to nssSO$_4^{2-}$ could be up to 14% on average at the CBIA sites and 19% at Burnaby South. This approximation represents an upper limit as it is assumed here that 100% of the SO$_2$ converts to SO$_4^{2-}$. Despite the assumptions inherent in this calculation it is in good agreement with the previous estimates of the average DMS contribution to
nssSO$_4^{2-}$ in the LFV of 14% (fall, spring, summer) (Sharma et al, 2003) and 13% (summer only) (Norman et al, 2004).

Figure 14: Concentrations of MSA at the CBIA sites and at Burnaby South and Abbotsford

4. Conclusions

The use of the E-Sampler filter during the BIALAQS allowed for a partial mass reconstruction of PM$_{2.5}$ and provided useful source attribution information based on three ~3-5 week sampling periods. The methodology was subject to limitations, including the potential for positive and negative sampling artefacts, however, the majority of filter based PM$_{2.5}$ measurements agreed with the concurrent E-Sampler nephelometer measurements within 25% and ± 1 μg/m$^3$.

Overall the average PM$_{2.5}$ concentration measured over the three sampling periods at the CBIA sites during this study was 4.0 μg/m$^3$, which is likely an underestimate due to suspected volatization of PM$_{2.5}$ off the E-Sampler filter. Specifically, ANO3 data were deemed to be biased low due to suspected volatilization from the single filter set up, as concentrations were significantly lower at the CBIA sites compared to the two NAPS sites. ASO4 measured at CBIA sites averaged 1.3 μg/m$^3$, which was significantly higher than concentrations at the two NAPS sites. On a percentage basis, the ASO4 contribution to PM$_{2.5}$ mass averaged 29% at the CBIA sites, compared to 17% and 12% at Burnaby South and Abbotsford, respectively. The contribution of sea salt to SO$_4^{2-}$ at the CBIA sites was estimated to be approximately 2%, while an upper limit of the late spring period DMS (biogenic) contribution to non-sea salt SO$_4^{2-}$, using MSA data, was calculated to be approximately 14%, compared to 19% at Burnaby South. These data indicate the greater importance of anthropogenic sulphur dioxide emissions to aerosol formation in the CBIA compared Burnaby South and Abbotsford. The highest concentrations of ASO4 were at the three sites on the south shore of Burrard Inlet, which were impacted by winds predominantly from or along the inlet or from the east during the sampling periods. ASO4 was highest in late spring at all but one site, which coincides with the seasonality of ocean going vessel activity at the port and...
biogenic emissions of sulphur. NaCl accounted for a small fraction of the PM$_{2.5}$ mass, averaging 0.1 µg/m$^3$ at the CBIA sites, which was about half of that measured at the NAPS sites.

The Unknown fraction, which made up between 43 and 73% of the PM$_{2.5}$ mass at the CBIA sites, would be made up of the missing components OM, EC, SOIL and PBW. Concentrations of the crustal elements Al, Ca, Fe and Ti were significantly lower at the CBIA sites compared to Burnaby and Abbotsford, indicating that the SOIL contribution to PM$_{2.5}$ in the CBIA is likely lower than at the NAPS sites. BC concentrations, measured with an Aethalometer at two CBIA sites were similar to EC concentrations at Burnaby and Abbotsford, however, on a percentage basis the BC contribution to PM$_{2.5}$ mass averaged 17% at the CBIA sites compared to an average EC contribution of 12% at both Burnaby South and Abbotsford, which is likely indicative of a higher relative contribution of BC sources to PM$_{2.5}$ in the CBIA.

Using vanadium as a tracer and assuming its content in marine fuel is within a range of 65 – 150 ppm, the average OGV contribution to primary PM$_{2.5}$ at the CBIA sites was estimated to range from 6-37%, which is significantly higher than that at Burnaby South (2-6%) and Abbotsford (0.3-0.8%). Overall the OGV contribution was highest in the late spring sampling period and at the Yacht Club and two other south shore sites, which follows the spatial and temporal pattern of ASO$_4$ concentrations and indicates the importance of OGV contribution to sulphate concentrations in the CBIA. The contribution of biomass burning to PM$_{2.5}$ using levoglucosan as a tracer could not be quantified due to its suspected instability on CBIA filter samples, as concentrations were significantly lower at the CBIA sites compared to the two NAPS sites, however, K$^+$ data indicated that a biomass burning contribution was present, particularly during the fall sampling period. Al, Fe, Ca, Ti and Zn data and wind measurements indicated that the impact of road dust appeared to be higher at Second Narrows and MacLean Park compared to other CBIA sites, however, the overall crustal contribution to PM$_{2.5}$ was low within the CBIA. Elevated Pb concentrations were also found at the Second Narrows and MacLean Park sites, which indicates a small local source of Pb, possibly road dust. Although concentrations of the toxic metals Ni, V and Pb were elevated in CBIA, compared to Burnaby and Abbotsford, levels measured were well below established guidelines, even when the potential low bias caused by the extraction methodology employed in this study was taken into account.

Results from this study confirm one of the major findings of the criteria air contaminants analysis that the CBIA experiences unique air quality compared to other areas of the LFV, also extends to the composition of PM$_{2.5}$. Efforts to reduce PM$_{2.5}$ in the CBIA should consider reduction of sulphur dioxide as one of the key strategies. Steps currently being taken to reduce sulphur dioxide emissions in the CBIA, including the implementation of the Emission Control Area for marine vessels and the use of shore power for cruise ships, should have a positive impact on PM$_{2.5}$ levels. It is recommended that future studies to assess the effectiveness of such reduction strategies should include full speciation monitoring techniques and monitoring over a longer time period.
5. References


BIALAQS PM$_{2.5}$ Speciation Data Analysis (Environment Canada)


September 2012 22
BIALAQS PM$_{2.5}$ Speciation Data Analysis (Environment Canada)


Appendix C Mobile Trailer Data

The BIALAQS mobile trailer sites were established to provide additional pollutant data at locations closer to suspected emission sources. It is important to note that pollutant levels at these locations do not necessarily reflect neighbourhood exposure levels. Table B1 provides information about the emission sources that are adjacent to the BIALAQS Mobile trailer locations.

Table B1: Significant Emission Sources within One Kilometre of the BIALAQS Mobile Trailer Locations

<table>
<thead>
<tr>
<th>Monitoring Location</th>
<th>Significant Emission Sources</th>
<th>Distance from Site (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 50</td>
</tr>
<tr>
<td>S7</td>
<td>Lynn Pump Station Mobile Trailer&lt;br&gt;Neptune Terminals (Coal, Potash, Agri-bulk, vegetable oils)&lt;br&gt;Port terminal (Wood Products, Smelter Products)&lt;br&gt;Saskatchewan Wheat Pool (Grain)&lt;br&gt;Rail yard&lt;br&gt;Truck route (East 3rd Street and Low Level Road)&lt;br&gt;Ocean-going vessels&lt;br&gt;Residential heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>S8</td>
<td>Lonsdale Seabus Mobile Trailer&lt;br&gt;Marina (pleasure crafts)&lt;br&gt;Seabus terminal (passenger ships)&lt;br&gt;Ocean-going vessels&lt;br&gt;Vancouver Drydock&lt;br&gt;Railway&lt;br&gt;Residential and commercial heating (natural gas and possibly wood)</td>
<td>x</td>
</tr>
<tr>
<td>S9</td>
<td>Harbour/Clark Mobile Trailer&lt;br&gt;Major roadway and truck route (Clark Drive)&lt;br&gt;Rail yard&lt;br&gt;Rogers Sugar (Sugar)&lt;br&gt;Agricore United UGG (Grain)&lt;br&gt;Vanterm Port Gates&lt;br&gt;Centerm Port (Containers)&lt;br&gt;Ocean-going vessels&lt;br&gt;Cruise ship terminal (Ballantyne)</td>
<td>x</td>
</tr>
<tr>
<td>S15</td>
<td>Heliport Mobile Trailer&lt;br&gt;Rail yard&lt;br&gt;Cruise ship terminal (Canada Place)&lt;br&gt;Centerm Port (Containers)&lt;br&gt;Seabus terminal (passenger ships)&lt;br&gt;Heliport (Helicopters)&lt;br&gt;Ocean-going vessels</td>
<td>x</td>
</tr>
</tbody>
</table>
The trailer was outfitted with continuous NOx, SO$_2$, PM$_{2.5}$ and black carbon monitors, and starting in December 2009 it was situated at one of four trailer locations for 3-4 weeks and then moved to the next site. Since the trailer moved between locations during the CBIA study, the data from each trailer location contain several time gaps. The records for each location do not coincide in time, so it is not appropriate to compare the data from the trailers to each other.

Data were not collected for entire seasons at the mobile sites. Nonetheless, they have been organized by the season in following figures to aid with interpretation of seasonal trends.

**S7 Lynn Pump Station Mobile Trailer**
The mobile trailer was situated at the S7 Lynn Pump Station MT site on the North Shore for five 3-4 week periods starting in December 2008. Figure B1 summarizes the hourly-averaged concentrations observed during the short monitoring periods at this location. It should be noted that it may not be appropriate to compare the seasons at this location due to the difference in the number of monitoring days per season. Nonetheless, these diurnal trends provide some useful information to assist with source identification.

As depicted in Figure B1, PM$_{2.5}$ concentrations were lowest overnight during both the winter and summertime weekdays at S7 Lynn Pump Station. Levels were higher during the summer at this location, with highest concentrations observed midday weekdays. Oddly, PM$_{2.5}$ concentrations were generally higher during the weekend morning hours than weekdays. Nearby sources of PM$_{2.5}$ include traffic along East 3rd Street/Low Level Road and a coal terminal.

Black carbon was lowest during summer weekends. On summer weekdays, black carbon increased between 4:00 and 9:00 am and then gradually decreased throughout the day. On winter weekdays, black carbon peaked between 8:00 and 9:00 am, but a second peak was observed during the evening hours. On winter weekends, black carbon concentrations were variable throughout the day. The S7 Lynn Pump Station MT site is close to East 3rd Street and Low Level Road so the elevated morning weekday levels may reflect high levels of diesel traffic, whereas the elevated evening and overnight levels may reflect residential wood burning from residences to the north or dust from the nearby coal terminal.

NO$_2$ concentrations were generally lower during the weekends than weekdays. Low concentrations were observed overnight. Since traffic is one of the largest sources of NO$_2$, it is understandable that higher NO$_2$ concentrations would be observed during weekdays when traffic volumes are higher.

SO$_2$ concentrations were consistently low overnight, but slightly elevated during the day. Morning and afternoon/evening peaks were observed during the summer months, while levels
were elevated midday during the winter. The mid-afternoon summer SO\textsubscript{2} dip may be a result of conversion to secondary sulphate during the warmer, more intense sunshine-hours of the day. The largest known source of SO\textsubscript{2} emissions near S7 Lynn Pump Station MT is ocean-going marine vessels.

Figure B1: Diurnal trends in hourly-averaged PM\textsubscript{2.5}, black carbon, NO\textsubscript{2} and SO\textsubscript{2} at Lynn Pump Station Mobile Trailer site.

Legend notations in brackets indicate the average number of sampling days for each season

**S8 Lonsdale Seabus Mobile Trailer**

The mobile trailer was situated at the S8 Lonsdale Seabus MT site on the North Shore for five 3-4 week periods starting in January 2009. Figure B2 summarizes the hourly-averaged concentrations observed during the short monitoring periods at this location.

As illustrated in Figure B2, PM\textsubscript{2.5} concentrations were elevated during the summer at this location, with highest concentrations observed between 7:00 and 11:00 am. In winter, PM\textsubscript{2.5} concentrations were lower, but they followed a similar pattern with a delayed peak between 10-11:00 am. PM\textsubscript{2.5} levels decreased in the afternoon, but rose again during the evenings. As noted in Section 3.3.1, the potassium levels were elevated in the fall PM\textsubscript{2.5} speciation samples collected at the nearby S5 BCIT Marine Campus site in fall of 2009, which identifies a potential local contribution from wintertime residential wood smoke. However, it is unclear why PM\textsubscript{2.5} levels were also elevated during summer evenings.
In general, black carbon, SO$_2$ and PM$_{2.5}$ at the S8 Lonsdale Seabus MT site peaked during mid-morning hours in summertime, but concentrations peak later in the morning during the winter. Marine vessels are significant local sources of all three pollutants.

NO$_2$ concentrations were generally lower during the summer than winter at this location. Winter weekends and weekdays show a bi-modal trend with elevated levels during the morning and evening rush hours. During the summer NO$_2$ concentrations were higher during the late evening hours. Combined with elevated PM$_{2.5}$ and BC, it is suspected that summer evening marine pleasure craft sailings from the nearby marina may have influenced the air quality at this location.

Figure B2: Diurnal trends in hourly-averaged PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$ at the Lonsdale Seabus Mobile Trailer site.

Legend notations in brackets indicate the average number of sampling days for each season

**S9 Harbour/Clark Mobile Trailer**

The mobile trailer was situated at the S9 Harbour/Clark MT site for five 3-4 week periods starting in March 2009. This site is adjacent to the truck entrance at Port Metro Vancouver’s Vanterm Terminal. Figure B3 summarizes the hourly-averaged concentrations observed during the short monitoring periods at this location. Data were not collected during the winter at the S9 Harbour/Clark MT site, so Figure B3 presents the spring values instead. It should be noted that it may not be appropriate to compare the seasons at this location due to the difference in the
number of monitoring days per season. Nonetheless, these diurnal trends provide useful information to assist with source identification.

PM$_{2.5}$ concentrations increased in the morning hours on both summer and spring weekdays and gradually decreased during the day, with the exception of a secondary spike in the summer from 12:00 noon to 1:00 pm. Black carbon and NO$_2$ showed a very similar weekday trend. Both black carbon and NO$_2$ levels were significantly lower during the weekends. Given the S9 Harbour/Clark MT site’s proximity to the truck entrance for Vanterm Terminal, the elevated weekday trend in PM$_{2.5}$, black carbon, and NO$_2$ is not surprising. Port-related truck traffic was much less on weekends during this time period (personal communication with Gary Olszewski – Port Metro Vancouver, 2012). Trucks tend to arrive in the morning for cargo pick-up and drop-off causing a spike in pollutant concentrations in the morning and a smaller spike just after noon. Diesel-powered cargo handling equipment is also operated in this area.

SO$_2$ levels were also elevated during the mornings, although the summer maximum occurred three hours early in the summer than spring. It suspected that locomotives and marine vessels in the area contributed to these elevated weekday SO$_2$ levels.

Elevated PM$_{2.5}$ and SO$_2$ levels occurred during the two summer weekends at this site. Light winds were generally from the north, the direction of Vanterm. Levels were particularly elevated the weekend of July 4-5, 2009. Several marine vessels were at berth, but the number of vessels was not unusual during this weekend (personal communication with Gary Olszewski – Port Metro Vancouver, 2012).
Figure B3: Diurnal trends in hourly-averaged PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$ at the S9 Harbour/Clark Mobile Trailer site.

Legend notations in brackets indicate the average number of sampling days for each season.

S15 Heliport Mobile Trailer

The mobile trailer was situated at the S15 Heliport MT site for five 3-4 week periods starting in July 2009. Figure B4 summarizes the hourly-averaged concentrations observed during the short monitoring periods at the Heliport site. Very little data was collected during the winter at the Heliport site, so Figure B4 presents the autumn values instead.

PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$ concentrations increased in the weekday morning hours during the autumn, but similar peaks were not observed during the summertime. PM$_{2.5}$ and NO$_2$ levels also rose during autumn evening hours, suggesting the possible influence of local traffic.

SO$_2$ concentrations were typically elevated from about 8:00 am to 3:00 pm during the summer (both weekdays and weekends) and early autumn weekends. The closest source of SO$_2$ emissions is the cruise ship terminal at Canada Place, where cruise ships dock during the summer and early autumn.
Figure B4: Diurnal trends in hourly-averaged PM$_{2.5}$, black carbon, NO$_2$ and SO$_2$ at the S15 Heliport Mobile Trailer site.

*Legend notations in brackets indicate the average number of sampling days for each season*
Glossary

BIALAQS = Burrard Inlet Area Local Air Quality Study
CBIA = Central Burrard Inlet Area
CO = carbon monoxide
DPM = diesel particulate matter (particulate matter emitted from diesel engines)
NO = nitric oxide
NO$_2$ = nitrogen dioxide
NOx = oxides of nitrogen (NO + NO$_2$)
PM$_{2.5}$ = fine particulate matter (particles less than 2.5 microns in diameter)
SO$_2$ = sulphur dioxide
LFV = Lower Fraser Valley (Metro Vancouver and the Fraser Valley Regional District)

Nomenclature for CBIA Sites and LFV Network Stations
S1 = Vancouver Yacht Club
S2 = MacLean Park
S3 = Pandora Park
S4 = Lynn Pump Station
S5 = BCIT Marine Campus
S6 = Norgate
S7 = Lynn Pump Station Mobile Trailer
S8 = Lonsdale Seabus Mobile Trailer
S9 = Harbour/Clark Mobile Trailer
S15 = Heliport Mobile Trailer
T1 = Downtown Vancouver
T2 = Kitsilano, Vancouver
T4 = Kensington Park, North Burnaby
T6 = Second Narrows, North Vancouver
T9 = Rocky Point Park, Port Moody
T12 = Chillwack
T13 = North Delta
T14 = Burnaby Mountain
T15 = Surrey East

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7 see Section 1.2 for a more detailed description of these pollutants
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T17 = Richmond
T18 = South Burnaby
T20 = Pitt Meadows
T27 = Langley Township
T29 = Hope
T30 = Maple Ridge
T31 = Vancouver Airport
T32 = Coquitlam
T33 = Abbotsford
T34 = Abbotsford Airport